BENTHIC MACROINVERTEBRATES AS WATER QUALITY INDICATORS IN ITALIAN LAKES

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With 3 figures and 2 tables

ABSTRACT. Benthic macroinvertebrates and environmental measures were collected in 29 Italian lakes since the '50s. Artificial Neural Networks were used to cluster the sampling sites according to species assemblages. Species ordination matched with oxygen percent saturation, transparency, water conductivity and water depth more than with trophic variables (total phosphorus, nitrates).

RESUMO: Desde os anos 50 têm sido recolhidas amostras de macroinvertebrados bentónicos e medidas diversas variáveis ambientais em 29 lagos Italianos. Recorreu-se a Redes Neuronais Artificiais para agrupar os locais de amostragem de acordo com a estrutura das comunidades. Verificou-se que a ordenação das espécies se relaciona mais com a condutividade e concentração de oxigénio do que com a profundidade e variáveis tróficas (fósforo total e nitratos).

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INTRODUCTION

Benthic macroinvertebrates in lentic habitats are considered indicators of oxygen levels and trophic conditions and were used to develop classifications for Northern European and American lakes, based in particular on chironomid and oligochaete species (WIEDERHOLM, 1980). Nevertheless many of those indicator taxa were never recorded in Southern European lakes, so those indexes cannot be applied to these waters. For what concerns Italy, at present there is little information on the macrobenthic lacustrine fauna and the ecological status is assessed on the basis of physico-chemical variables (D.L. 152/99 modif. 246/00). Nevertheless the Water Framework Directive (WFD, 2000/60/CE) requires urgent development of a biotic index for lake assessment and monitoring. Surveys were realized in Italy from the 1950s up to date, but many focused on a single taxocenosis and environmental data matching with biotic samples are often lacking. Recently the existing data were analyzed to develop a Benthic Quality Index (BQIL) for Italian Lakes (ROSSARO *et al.*, 2006; ROSSARO *et al.*, 2007). An indicator score was assigned to each species on the basis of its optimum value for dissolved oxygen, Secchi transparency and total phosphorus and an index was developed following the Benthic Quality Index by WIEDERHOLM (1980). The BQIL could be useful in fulfilling the WFD requests, but at present the development of this index is still tentative and new samplings are necessary to test and validate it. The main problem concerns the definition of the optimum values for each taxon in different lake types (MARZIALI *et al.*, 2006). The aim of this paper is to clarify the distribution of species in the sampling sites in relation to the environmental variables and to separate the lakes in groups according to the fauna present using Artificial Neural Networks (KOHONEN, 2001).

MATERIAL AND METHODS

Data about benthic macroinvertebrate fauna and environmental variables of 29 Italian lakes were analyzed in the present work (Table 1). These data were collected within different surveys (ROSSARO *et al*., 2006 and 2007), from the ‘50s to 2005. Fauna was collected during the spring full circulation and the late summer stratification in the soft bottom with an Ekman, Petersen or Ponar grab or a sledge net (NOCENTINI, 1979; NOCENTINI, 1989; CORBELLA *et al.,* 1956). Samples were sieved (250 µm mesh size) and fixed in 10% neutralized formaldehyde.

Physical (sampling depth, water temperature, Secchi transparency) and chemical (percent of oxygen saturation, conductivity, pH, total phosphorus, N-nitrates and N-ammonia) variables were measured near the bottom in the same sampling site, year and month where benthic macroinvertebrates were sampled. Macroinvertebrates were counted and identified to genus or species. Data were filed in a relational Microsoft Access® database. Only samples collected with a grab and only taxa present in at least

10 samples were included in data analysis. In all 29 lakes with 1267 sampling sites, 60 macroinvertebrate taxa (49 of which at species level) and 9 environmental variables were selected. A Kohonen Self-Organizing Mapping (SOM) analysis (KOHONEN, 2001) was carried out using Matlab R2007b®; this is an unsupervised competitive learning neural network methodology, which allows to map the sites in a n-dimensional space on the basis of their biological closeness and to group them into separate clusters (LEK & GUÉGAN, 2000). Environmental variables values are included in the map in a second step of analysis, but do not influence ordination and clustering. Correlation coefficient between environmental variables and the first three PCA projections from SOM (KOHONEN, 2001) were also calculated.

RESULTS

A total of 570 macroinvertebrate taxa were identified, among which chironomids (373 species) and oligochaetes (85 taxa) prevailed, followed by 67 taxa of other aquatic insects, 37 of mollusks and 8 of crustaceans. Among chironomids, 158 Chironominae, 151 Orthocladiinae, 43 Tanypodinae, 18 Diamesinae and 3 Prodiamesinae species were recorded. Taxa richness was higher in the lakes with the highest volume and depth, as in Lake Garda (279), Lake Maggiore (131) and in Lake Como (114) (Table 1). A SOM map 11x17 ordered the sampling sites on the basis of biological data, the sites were then classified into 9 clusters (Fig. 1). Each taxon was mapped in the SOM map (Fig. 2), then environmental variables values were included (Fig. 3). Dissolved oxygen, transparency, conductivity, depth and water temperature were the environmental variables more correlated with PCA projections (Table 2).

TABLE 1. List of the sampled lakes with geographical and morphometric information, sampling methods used, number of samples and taxa richness.

Lake	**Longitude E**	**Latitude N**	**Volume 10^6 m^3**	**Maximum depth (m)**	**Sampling Method**	**Nº samples**	**Taxa richness**
Alserio	9° 12’	45° 7’	16.6	8	Ekman grab, sludge net	18	44
Annone Est	9° 21’	45° 48’	24	11	Ekman grab, Ponar grab	80	27
Annone Ovest	9° 20’	45° 49’	6.8	10	Ekman grab, sludge net	25	10
Bolsena	11° 55’	42° 35’	9200	151	Petersen grab	40	74
Bracciano	12° 14’	42° 7’	5053	165	Petersen grab	34	60
Caldonazzo	11° 14’	46° 0’	148.9	49	Ekman grab	46	40
Canzolino	11° 13’	46° 1’	0.15	15	Ekman grab	40	27
Comabbio	8° 41’	45° 46’	16.5	14	Ponar grab	38	42

TAB. 1. (Cont.)

Lake	Longitude E	Latitude N	Volume 10^6 m^3	Maximum depth (m)	Sampling Method	Nº samples	Taxa richness
Como	9° 16’	45° 50’	22500	410	Ponar grab, sludge net	153	114
Endine	9° 56’	45° 46’	11.9	9	Ekman grab, sludge net	20	29
Garda	10° 31’	45° 26’	49031	350	Petersen grab, sludge net	195	279
Garlate	9° 16’	45° 50’	70	34	Petersen grab	17	48
Ghirla	8° 44’	45° 0’	3	14	Ekman grab, sludge net	9	59
Idro	10° 26’	45° 44’	684	122	Ponar grab	8	13
Iseo	10° 20’	45° 39’	7600	251	Petersen grab	20	25
Lamar	11° 0’	46° 1’	0.3	9.6	Ekman grab	40	26
Lases	11° 13’	46° 1’	1.8	26	Ekman grab	40	44
Levico	11° 16’	46° 0’	12.9	38	Ekman grab	40	53
Maggiore	8° 33’	45° 57’	37500	370	Ekman, Petersen grab, sludge net	169	131
Mergozzo	8° 27’	45° 57’	82.9	73	Petersen grab	40	104
Monate	8° 39’	45° 47’	45	34	Ponar grab	38	36
Montorfano	9° 8’	45° 46’	1.9	7	Ekman grab, sludge net	27	30
Pertusillo	15° 56’	40° 16’	155	91	Petersen grab	62	15
Pusiano	9° 16’	45° 48’	69.2	24	Ekman grab, sludge net	27	55
Sartirana	9° 16’	45° 50’	1.2	3	Ekman grab, sludge net	1	13
Segrino	9° 16’	45° 49’	1.2	9	Ekman grab, sludge net	27	24
Tenno	10° 48’	45°56’	3.9	47.7	Ekman grab	40	51
Varese	8° 42’	45° 50’	160	26	Ponar grab	214	72
Vico	12° 10’	42° 18’	260	48.5	Petersen grab	48	19

TABLE 2. Correlation coefficients and probability values in brackets (** means highly significant correlations) between the first three PCA projections calculated with SOM analysis and environmental variables.

Environmental variables	Unit of measure	I	II	III
Depth	m	0.238 (**)	-0.307 (**)	-0.367 (**)
O_2 % sat	%	-0.289 (**)	0.443 (**)	0.192 (**)
Water temperature	°C	-0.206 (**)	0.268 (**)	0.306 (**)
Water conductivity	µS cm^{-1}	0.113 (**)	0.118 (**)	0.443 (**)
pH		0.002 (0.965)	0.060 (0.139)	0.331 (**)
Secchi Transparency	cm	-0.178 (**)	0.360 (**)	0.010 (0.818)
Total phosphorus	µg L^{-1}	0.117 (**)	-0.151 (**)	-0.059 (0.166)
NO_3	µg L^{-1}	0.147 (**)	-0.290 (**)	-0.220 (**)
NH_4	µg L^{-1}	-0.050 (0.220)	-0.138 (**)	0.125 (**)

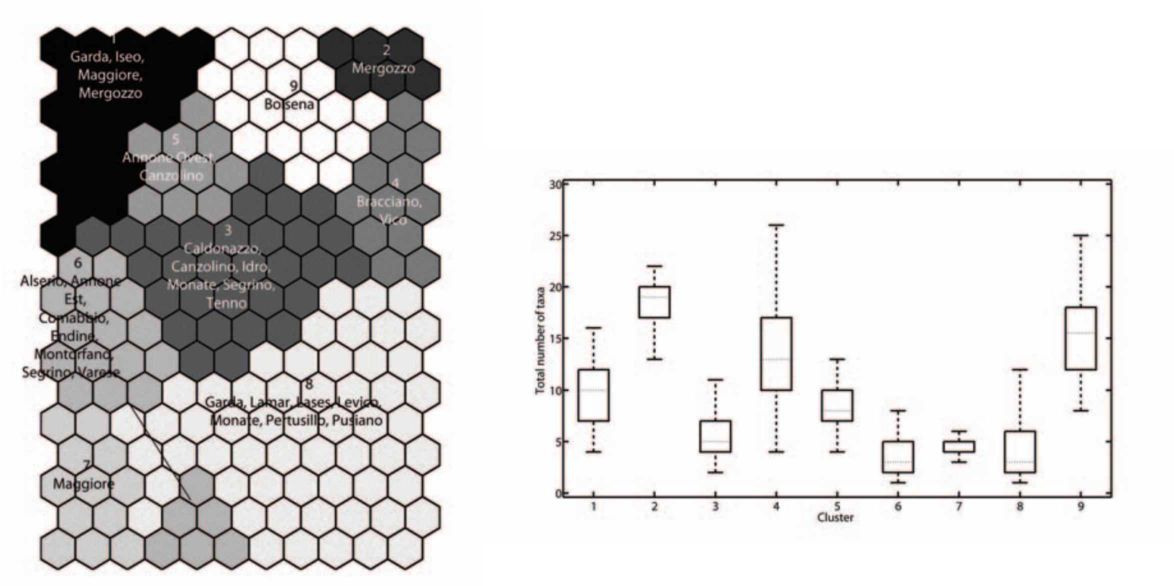

Figure 1. Left: SOM map (11x17) of the sampling sites grouped into 9 clusters according to the biological data. Right: total number of taxa found per site for each cluster; dotted lines = median value, boxes= lower and upper quartiles, dashed lines = the most extreme values within 1.5 x interquartile range from the ends of the box.

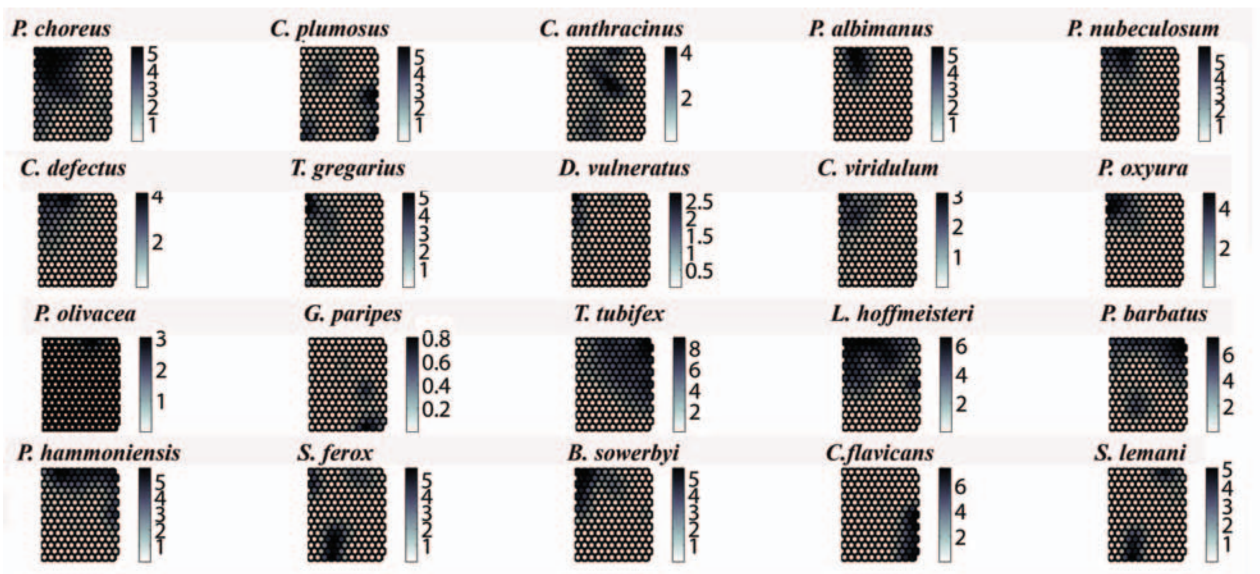

Figure 2. SOM maps of the most abundant taxa. Bars represent the codebook values of each taxon.

Cluster 2 comprised sites of Lake Mergozzo, the most oligotrophic lake, with the highest values of dissolved oxygen and transparency and the lowest conductivity (Figs. 1 and 3). It was characterized by the highest taxa richness (a mean of 19 taxa per sample) and by high abundance of intolerant taxa as the Orthocladiinae *Psectrocladius oxyura* Langton, 1985, *Orthocladius oblidens* (Walker, 1856), *Orthocladius frigidus* (Zetterstedt, 1838) and *Parakiefferiella bathophila* (Kieffer, 1912), the Tanytarsini *Stempellina bausei* (Kieffer, 1911) and *Tanytarsus gregarius* Kieffer, 1909, the Chironomini *Dicrotendipes nervosus* (Stæger 1839) and *Demicryptochironomus vulneratus* (Zetterstedt, 1838) (Fig. 2) (BRUNDIN, 1974). Clusters 4 and 9 comprised volcanic lakes of Central Italy (Bolsena, Bracciano and Vico), which were characterized by the highest values of conductivity and pH (Figs. 1 and 3). These lakes were colonized mainly by *Polypedilum nubeculosum* (Meigen, 1804), *Cryptochironomus defectus* (Kieffer, 1913), *Cladopelma viridulum* (Linnaeus, 1767), *Paratendipes albimanus* (Meigen, 1818), *Cladotanytarsus mancus* (Walker, 1856), *Endochironomus tendens* (Fabricius, 1775), *Parachironomus arcuatus* (Goetghebuer, 1919), *Cricotopus fuscus* (Kieffer, 1909), *Valvata piscinalis* (Müller, 1774), *Echinogammarus* sp., *Dero digitata* (Müller, 1774) and *Dugesia tigrina* (Girare, 1850); the mean taxa richness was high (13-16 taxa per sample) (Fig. 1). Cluster 1 was composed of wide profundal lakes as Garda, Iseo and Maggiore (Northern basin), characterized by oligo-mesotrophic conditions (Figs. 1 and 3). *Chironomus anthracinus* Zetterstedt, 1860, *Prodiamesa olivacea* (Meigen, 1818), *Tubifex* spp., *Bichaeta sanguinea* Bretscher, 1900, *Uncinais uncinata* (Oersted, 1842) and *Alboglossiphonia heteroclita* (Linnaeus, 1761) were the most abundant taxa (Fig. 2). Clusters 5, 3 and 7 comprised small mesotrophic lakes as Annone Ovest, Monate, Segrino, Caldonazzo and the Southern basin of Lake Maggiore: these sites were characterized by low taxa richness (5-8 taxa per sample by mean) and by high values of conductivity and nitrates (Figs. 1 and 3). They were colonized mainly by *C. anthracinus*, *Tanypus punctipennis* Meigen 1818, *Phaenopsectra flavipes* (Meigen, 1818), *Micropsectra atrofasciata* (Kieffer, 1911) and *Asellus aquaticus* (Linnaeus, 1758). Clusters 8 and 6 were composed of the most eutrophic sites, with the highest values of total phosphorus and ammonia and the lowest values of dissolved oxygen and transparency (Figs. 1 and 3). They consisted of small meso and eutrophic lakes (e.g. Alserio, Endine, Comabbio, Montorfano, and Pusiano etc.), artificial lakes (Pertusillo) and the most organic-polluted sites of Lake Garda. The mean taxa richness per sample was the lowest (3) and the most abundant species were *Glyptotendipes paripes* (Edwards, 1929), *Cladotanytarsus atridorsum* Kieffer, 1924 and *Chaoborus flavicans* (Meigen, 1830).

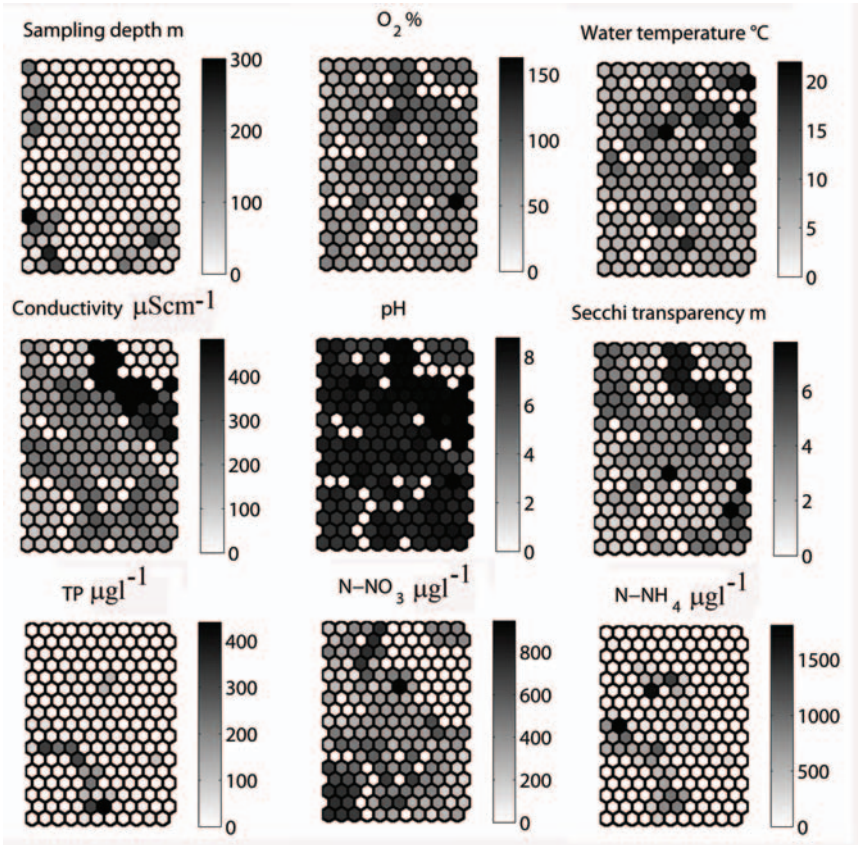

Figure 3. SOM map of the 9 environmental variables. Bars represent the measured values of the variables.

DISCUSSION

Sites were ordered according to benthic macroinvertebrates along a trophic gradient, from the upper right part of the map (oligotrophic conditions) to the lowest left part (eutrophic conditions) (Fig. 1). Orthocladiinae, Tanytarsini and mollusks prevailed in the most oligotrophic sites, Chironomini and oligochaetes in the most eutrophic ones. Lakes were grouped into clusters according to both natural and anthropogenic factors. For examples volcanic lakes were separated because of their high values of conductivity, deep large lakes were separated from small lakes according to morphometric variables (Fig. 3). Small lakes were grouped on the basis of the trophic condition (total phosphorus, ammonia). This was in accordance with results by ROSSARO *et al.* (2006, 2007) who analyzed forty-two lakes (twenty nine of which were included in the present paper) with canonical correlation analysis: relations between fauna and conductivity, trophic and morphometric factors were emphasized.

The different sampling effort in the different lakes (Table 1) makes a comparison of species richness difficult. For example sludge net samples in the littoral zone determined the high species number observed in some lakes.

Benthic macroinvertebrates were shown to be potentially good quality indicators in Italian lakes and the high number of taxa collected could be an interesting source of information. Nevertheless, the development of a valid index for Southern European lakes is still hindered by the lack of homogeneous biological and environmental data on the study lakes and the lack of information on many areas. Different taxa assemblages were separated according to different lake types; therefore the collection of new data is needed to examine the response of community in each lake type.

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