Macrobenthic community and chemical characteristics of four alpine lakes in canton Ticino

Autor(en): **Boggero, Angela / Nobili, Marcella**

Objekttyp: **Article**

Zeitschrift: **Bollettino della Società ticinese di scienze naturali**

Band (Jahr): **86 (1998)**

Heft 1

PDF erstellt am: **31.05.2024**

Persistenter Link: https://doi.org/10.5169/seals-1003269

Macrobenthic community and chemical characteristics of four Alpine lakes in Canton Ticino

Angela Boggero and Marcella Nobili
C.N.R. Istituto Italiano di Idrobiologia, 28922 Verbania Pallanza (Italy)

Riassunto: Il presente lavoro considera le caratteristiche chimiche e la composizione della fauna macrobentonica di quattro laghi alpini situati sul versante meridionale delle Alpi Centrali e compresi nel bacino imbrifero del Lago Maggiore (Canton Ticino). Campioni di tipo qualitativo sono stati prelevati contemporaneamente a campioni di acqua per le analisi chimiche, durante il periodo libero da ghiaccio, negli anni compresi fra il 1991 ed il 1993. I risultati ottenuti mostrano che la composizione della fauna macrobentonica è quella tipica di ambienti di alta quota, dove le estreme condizioni ambientali permettono la sopravvivenza di poche specie di invertebrati. Inoltre bassi valori di pH e alcalinità sembrano influire sulla struttura di comunità determinando un'abbondanza prevalente delle famiglie e delle entità tassonomiche più tolleranti.

Abstract: Four Alpine lakes located on the southern slope of the Central Alps in the watershed of Lake Maggiore (Canton Ticino) were studied with regard to their chemical and macroinvertebrate faunal composition. Qualitative samples, together with those for water chemistry analyses, were taken from 1991 to 1993 during the ice-free period. The results obtained show a faunal composition typical of mountain sites, where few invertebrate species can survive the severe environmental conditions. The probable impact of low pH and in particular low alkalinity on the structure of the community is reflected in the prevailing presence of the more tolerant families and systematic entities.

INTRODUCTION

Atmospheric acid deposition has resulted in the acidification of thousands of lakes and rivers in Europe and North America (WRIGHT 1983; DAVIS *et al.* 1990). Habitats undergoing acidification can often suffer rapid pH depression during rainstorms and/or snowmelt events or be exposed to long-term acidification. In the affected sites, there have been profound changes in the ecosystem structure due to the toxic effects of the altered water chemistry. However, all aquatic environments do not show the same sensitivity to the acidification phenomenon. In fact, a large number of physical, chemical and biological characteristics influence the sensitivity of surface waters to acidification and may cause alteration or disappearance of biological components of the environment (such as fishes, crustaceans, molluscs and insect larvae). The biotic effects of acid deposition depend to a great extent on the environmental characteristics of the ecosystems, as some of these are able to buffer atmospheric acidity. The morphological, geo-lithological and meteorological characteristics of high altitude lakes make them highly sensitive, because of their poor ability to neutralize atmospheric acidity. Many studies have been carried out on high altitude lakes over the last ten years with regard to the problem of acidification and the implications of the long-range transport of pollutants. A study aiming specifically at high altitude, remote lakes in the Alps shows that they can be affected by acidification (MOSELLO 1981, 1984; SCHNOOR & STUMM 1986; BARBIERI & RIGHETTI 1987; ZOBRIST *et al.* 1987; PSENNER 1989; TAIT & THALER 1988; MOSELLO *et al.* 1992a, 1992b, 1993).

The present paper reports part of the research conducted by the Istituto Italiano di Idrobiologia in co-operation with the University of Bergen, on the effects of acid deposition on surface water in the Alpine environment. Littoral macro-invertebrates occupy a key position in the food web, and an analysis of the composition and structure of this community can furnish good information on water quality because of its use as a biological indicator. In particular, macroinvertebrates are extremely sensitive to acidification (RADDUM *et al.* 1988) as their community structure changes much more rapidly due to pH variations than does that of fish (WATHNE *et al.* 1995).

The main aim of this project was to study four mountain lakes in the Alps whose geographic, morphometric, paleoecological and chemical characteristics are well known (see BOGGERO *et al.* 1996 for a review), to obtain information on the present structure of the macrobenthic community and to provide a basis for identifying alterations to the ecosystem which may have been caused by atmospheric pollution.

MATERIALS AND METHODS

Study area

Canton Ticino is situated on the southern slope of the Central Alps (Lepontine Alps) forming a part of the hydrographic watershed of Lake Maggiore (Fig. 1). The sam-

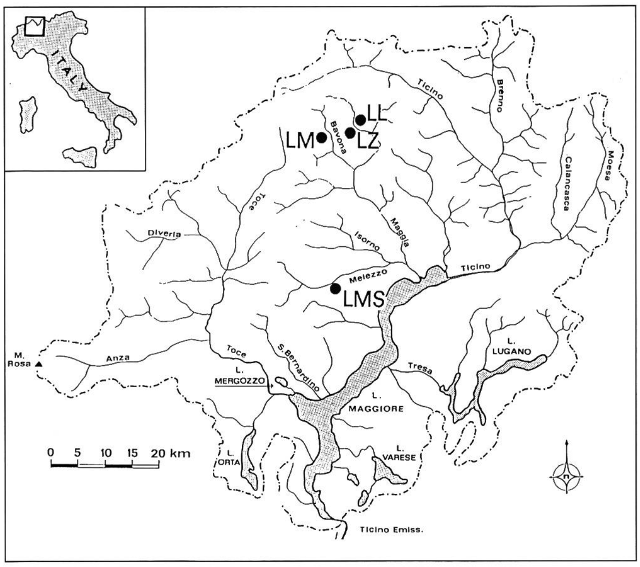

Fig. 1. Location of the studied lakes in the watershed of Lake Maggiore.

pled lakes are located in the Maggia Valley, in particular in the Lavizzara (lakes Laiozza and Zota), Bavona (L. Matörgn) and Onsernone (Lake Muino Superiore) subvalleys. They are mainly located above the timberline (Tab. 1), at altitudes ranging between 1900 and 2500 m a.s.l., have small surface and watershed areas, and are subjected to an amount of precipitation of over 1800 mm.

The bedrock of Canton Ticino mainly consists of gneiss (ortogneiss, paragneiss and rare amphibolites) and calcareous schists, with the presence of small amounts of calcareous belts, gypsum and serpentinites. An area of particular interest in Canton Ticino is the Maggia Valley, the bedrock of which consists mainly of crystalline rock of the «Maggia tectonic unit» (GIOVANOLI *et al.* 1988). Predominating rocks are granite and metamorphic gneiss of pre-Carboniferous age. Schistose rocks of Jurassic-Cretaceous age and units of dolomite and calcite containing sandstone are present in small parts of the area.

The lithology and land cover of the watersheds are summarized in table 1 and described in detail elsewhere (BOGGERO *et al.* 1996). The complex geology of the Alpine region and the resolution scale of the geological studies do not exclude the possibility of the presence of minor amounts of carbonate rocks, even in watersheds identified as mainly composed of silicic, low-weathering rocks.

Large parts of the watersheds (Tab. 1) are formed of landslide detritus and bare rocks and present steep slopes, with a small percentage covered by alpine meadows, except for the watershed of L. Muino Superiore where these are the main feature. Shrubs and glaciers are rare, with the former found only around Lake Muino Superiore and the latter in the watershed of L. Zota.

Water chemistry

The sampling strategy adopted in Canton Ticino focused on sensitive watersheds. Lake water was collected at the outflow or from the surface, well away from any interference from inflows, in 1 liter polyethylene bottles. Sampling was performed mainly in 1991÷1993 at different periods throughout the ice-free season (June-October). The samples were stored at 4°C in the dark and the chemical analyses performed up to a maximum of five days after sampling. The analytical methods used by the laboratory of the C.N.R.-Istituto Italiano di Idrobiologia are listed in table 2.

Macroinvertebrates

a) Sampling method

Qualitative samples were taken, at the same time as those for water chemistry analyses, using the Kick method (FROST *et al.* 1971; STOREY *et al.* 1991). Sampling stations were selected taking the substratum into account: the outlet river, when present, was treated as a separate station. A net with a 225 µm mesh aperture was used, attached to a 20*25 cm metal frame, with a 1.5 m long handle.

The samples were fixed in 80% ethanol and taken to the laboratory, where they were washed over a 225 µm sieve. The organisms were then sorted from the sediment in white trays under a stereo microscope.

	Laiozza	Zota	Matörgn	Muino Sup.
Valley	Lavizzara	Lavizzara	Bavona	Onsernone
Latitude North	46°27'26"	46°27'31"	46°26'23"	46°11'56"
Longitude East	08°33'23"	08°34'27"	08°28'58"	08°29'23"
Altitude	2365	2229	2450	1970
Lake area	0.013	0.012	0.022	0.002
Watershed area	1.40	0.31	0.91	0.05
Precipitation amount	1950	1950	1900	1850
Bare rocks	89%	95%	97%	20%
Alpine meadows	4%	2%	1%	73%
Shrubs	–	–	–	4%
Glaciers	5%	–	–	–
Lithology	1-(2)-(3)	1-(3)	1	1

Tab. 1 - Main geographic, morphometric, land cover and lithologic features of the lakes considered. Altitude: m a.s.l.; lake and watershed area: km^2; precipitation amount: mm. Lithology: 1-acidic; 2-calcareous; 3-mafic rocks. The groups in brakets are only present in small lenses in the watersheds.

Parameters	Methods
pH	glass electrode potentiometric determination
Conductivity	conductivity cell, Wheatstone bridge
Ca, Mg, Na, K	atomic absorption spectrophotometry (flame)
Ammonium	molecular spectroscopy (indophenol blue)
Sulphate	ion chromatography
Nitrate	ion chromatography
Chloride	ion chromatography
Alkalinity	acidimetric titration (end point 4.5-4.2; RODIER 1978)
Reactive silica	ammonium molibdate + $SnCl_2$ (GOLTERMAN *et al.* 1978)

Tab. 2 - Analytical methods used.

b) Sampling site description

Lake Laiozza (LL): One of the sampling stations is located at the outflow (St. 1) and presents stony substrate, while the others are littoral and composed of landslip material (St. 2) and fine sediment of glacial origin, with sparse terrestrial plant remains (St. 3).

Lake Zota (LZ): the first sampling site has stony substrate consisting of landslip material (St. 2); the second is composed of fine sediment of glacial origin, with sparse terrestrial plant remains (St. 3). The lake has no outflow.

Lake Matörgn (LM): the first station, at the outflow, presents stony sediment with some coarse sand; the second site is composed of gravel and sand with a small amount of organic matter; and the last (St. 3) has rocky sediment partly covered by sand.

Lake Muino Superiore (LMS): gravel and sand with sparse terrestrial plant remains comprise the substrate of the first site (St. 2); gravel and glacial silt make up the substrate of the second (St. 3).

The acidification index

The acidification index has been developed to assess damage to invertebrates in freshwater, based on critical limits for different species, determined from laboratory experiments with low ionic and humic content, and from observations in the field (RADDUM & FJELLHEIM 1984, 1987; RADDUM *et al.* 1988; FJELLHEIM & RADDUM 1990). The model focuses on the acid-sensitivity of invertebrate species, subdivided in four groups with scores from 0 (tolerant) to 1 (highly sensitive). Each site is given a score, between 0 and 1, depending on the score of the most sensitive organism found. The mean acidification score gives information on the degree of acidification in a lake. Level 1 indicates an unacidified area, while, at the other extreme, level 0 refers to sites containing only very highly tolerant species and which are regarded as being severely damaged by acidification. Unfortunately, information on the sensitivity of chironomids to acidity is scarce and only a preliminary list categorizing acid sensitive, indifferent and acidophilous species is presented in WATHNE *et al.* (1995).

In recent years knowledge of the composition of macroinvertebrate communities with the same acidification score has improved and additional factors (physico chemical factors, eutrophic level, geographic location, biological interactions) to that of the impact of acidification have been considered. As a matter of fact, several invertebrates, especially snails, mussels, leeches and mayflies, are limited by calcium concentrations below 50 µeq l^{-1}, even when the pH is 5.5-6.0, while, with increasing pH, a few of these species can tolerate a lower calcium content (ØKLAND & ØKLAND 1986; LIEN *et al.* 1992).

	Laiozza	Zota	Matörgn	Muino Sup.
Date	19/09/91	19/09/91	29/08/93	18/06/92
Temperature	12.5	12.5	9	3
Conductivity	7.8	7.5	10.1	9.5
pH	6.07	5.75	6.64	5.48
Hydrogen ion	1	2	0	3
Calcium	38	32	72	44
Magnesium	7	7	12	12
Sodium	10	10	10	11
Potassium	7	7	5	5
Ammonium	1	1	1	2
S cations	65	60	100	77
Alkalinity	11	7	39	5
Sulphate	45	34	48	37
Nitrate	10	20	14	29
Chloride	3	3	2	4
S anions	69	65	103	75
RP	0	0	2	0
TP	4	2	3	2
TIN	0.21	0.43	0.34	–
Reac. Si	0.54	0.45	0.54	0.98

Tab. 3 - Chemical characteristics of the examined lakes. Temperature: °C; conductivity: µS cm^{-1} 18°C; ions: µeq l^{-1}; RP and TP: µg P l^{-1}; TIN: mg N l^{-1}; Reac. Si: mg Si l^{-1}.

RESULTS

Water chemistry

The lakes (Tab. 3) do not differ greatly in their chemical characteristics and have a low ionic content: the highest concentrations are found in LM with 203 µeq l^{-1}, corresponding to a conductivity of 10 µS cm^{-1} at 18°C. They do not show cases of strong acidification (HENRISKEN 1980), as none has pH below 5.0, but in three of them total alkalinity is below 20 µeq l^{-1}, the threshold at which the first signs of damage to biota may be observed (RADDUM & FJELLHEIM 1984; SCHINDLER *et al.* 1985; PSENNER 1989; PSENNER & ZAPF 1990). Calcium is the main cation, followed by magnesium and sodium, while potassium is of minor importance. Ammonium is negligible, with values which are always below 4 µeq l^{-1}. In these lakes, lying in watersheds composed mainly of acidic rocks and with a strong atmospheric contribution, the main anions are sulphate and nitrate, with the exception of LM in which bicarbonates are the second most important anion. Chloride concentrations are below 5 µeq l^{-1}; finally, all the lakes present total inorganic nitrogen and reactive phosphorus concentrations respectively below 0.5 mg N l^{-1} and 4 µg P l^{-1}.

Macroinvertebrates

Although all the lakes show little variability as regards the number of taxonomic entities (Fig. 3), with a minimum of 21 in LZ, the number of individuals varies greatly, ranging between 3740 and 333 animals.

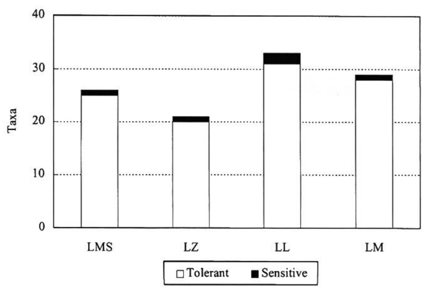

Fig. 3. Proportion of acid-sensitive to total number of systematic entities. Abbreviation as in figure 2.

		Laiozza			Zota		Matörgn			Muino Sup.	
		St. 1	St. 2	St. 3	St. 2	St. 3	St. 1	St. 2	St. 3	St. 2	St. 3
Diptera	Chironomidae										
	Apsectrotanypus trifascipennis (Zetterstedt)		12		1				2		
	Macropelopia		11	4							
	Procladius (Holotanypus)		56	4							
	Zavrelimyia	25	396	80	17			33	48	9	3
	Cardiocladius						2				
	Corynoneura cf. *scutellata*	110	848	480	124	23	2	92	210	7	87
	Cricotopus (Isocladius) sylvestris group	2	2	5							
	Eukiefferiella claripennis (Lundbeck)					1					
	Heterotrissocladius marcidus group	111	382	737	178	923	8	61	153		
	Heterotrissocladius marcidus		78	21	22	3		16	25	3	34
	Limnophyes						3		2	32	
	Paratrichocladius						3				
	Smittia					2					
	Tvetenia calvescens group						1				
	Orthocladiinae indet.	19									
	Paracladopelma camptolabis group										13
***	*Micropsectra* cf. *radialis*	1	15	1	59	32		5	27	6	2
	Micropsectra							13			
	Paratanytarsus austriacus (Kieffer)		7	17		1					9
	Paratanytarsus sp. B	2		46							
	Tanytarsus		4					5			2
***	*Tanytarsus lugens* group	3	8	85							
	Prodiamesa olivacea (Meigen)		2	3							
	Protanypus			1	1						
	Pseudodiamesa branickii (Nowicki)						4				
	Pseudodiamesa nivosa (Goetghebuer)							2			
	Pseudokiefferiella parva (Edwards)						1				
	Diamesinae indet.						14				

Tab. 4 - List of the systematic entities of Diptera Chironimidae found in the studied lakes. ***: acid sensitive taxa.

In the four lakes considered, the macrobenthos (Tabs 4, 5 and 6 and Fig. 2A) is prevalently composed of Insecta, particularly Diptera Chironomidae, which represent more than 95% of the community in LZ and LL, and more then 50% in LMS and LM. Second in importance in the last two lakes are Oligochaeta, which represent 16% and 37% of the community, respectively. Plecoptera (Nemouridae), Trichoptera (Limnephilidae) and Coleoptera (Dytiscidae) are quite well represented in LMS (Tab. 5), while Hydracarina and Turbellaria are less frequent, with the latter present in LM only. Other groups like Corixidae, Tipulidae, Ceratopogonidae, Culicide and Simulidae are negligible and have been grouped together in the discussion.

The most abundant chironomids (Tab. 4 and Fig. 2B) are the Orthocladiinae with *Corynoneura* cf. *scutellata* and *Heterotrissocladius marcidus* group, common in all the stations. Tanypodinae and Tanytarsinae are present in all the lakes, the former mainly composed of the genus *Zavrelimyia*, the latter of *Micropsectra* cf. *radialis*, which is quite well distributed in the 4 lakes. There is a noteworthy presence, especially in Station 3, of *Paratanytarsus* sp. and *Tanytarsus lugens* group in LL and *Paracladopelma camptolabis* in LMS. Diamesinae are scarce and present, in a small percentage, only in LM.

Oligochaetes (Tab. 6 and Fig. 2C) are dominated by Enchytraeidae and Lumbriculidae which represent more than 70% of the population in 3 lakes (LMS, LZ and LL) but only 45% in LM, where Naididae, with *Nais elinguis*, are particularly numerous in Station 1. Tubificidae and especially Haplotaxidae (Others) are of minor importance, the latter present with two individuals in LM.

Figure 2 shows the same distribution of groups expressed in percentages for Lake Matörgn considering (LM1) and not considering (LM2) the contribution of the outlet. The outlet is absent in two (LMS and LZ) of the 4 lakes and its contribution is negligible as regards LL, and was not reported in the figure. As regards LM, there is a large contribution of Oligochaetes (LM1 respect to LM2), especially Enchytraeidae and Naididae, while the contribution of Chironomidae Diamesinae is relatively low.

Finally, following the Raddum index attribution of the score, we did not find any sensitive taxa. However, 2 acid-

		Laiozza			Zota		Matörgn			Muino Sup.	
		St. 1	St. 2	St. 3	St. 2	St. 3	St. 1	St. 2	St. 3	St. 2	St. 3
Plecoptera	Nemouridae										
	Nemurella pictetii	8	1								3
	Nemoura										10
	indet.	12									
Trichoptera	Limnephilidae										
	Limnephilus									6	7
	Stenophylax	1			1						
	Potamophylax		1	3	4	3		7	10	2	
	indet.						1	4	2	3	
Coleoptera	Dytiscidae										
	Agabus bipustulatus		1	2		1				1	
	Agabus congener		5								
	Stictotarsus (Potamonectes) griseostriatus										9
	indet.	1	5	1	2	1					1
	Hydroporus foveolatus									6	2
	Hydroporine indet.	2	24	4	4	1					1
	Helophoridae										
	Helophorus cf. *glacialis*										1
Emiptera	Corixidae										
	Arctocorisa carinata	2	1	2	1						12
Diptera	Tipulidae										
	Dicranota			1	1	12	8	17	3		
	Ceratopogonidae									9	1
	Culicidae										1
	Simulidae						1				

Tab. 5 - List of the systematic entities of other Insecta found in the studied lakes.

sensitive taxa (proposed index between 0.5 and 1) were identified among the Chironominae tribus Tanytarsini. One of these, the *Tanytarsus lugens* group, was found only in LL, while *Micropsectra* cf. *radialis* was quite common. As a consequence, three lakes have a score of between 0.5 and 1, while that of LM is 0.33. Figure 3 shows the ratio of sensitive species to the total number of taxonomic entities found in the lakes.

DISCUSSION AND CONCLUSIONS

The invertebrate fauna recorded in these high altitude lakes consists mainly of species that are geographically widespread and typical of mountain sites, where few invertebrate species are able to tolerate the severe environmental conditions. The environmental pressure on the fauna seems to be generally high, and the altitude of the site has a major impact on the faunal composition above 2000 m in the Alps (WATHNE *et al.* 1995). High altitude lakes therefore present a qualitatively and quantitatively poorer faunal composition than do lowland lakes. Some of the impoverishment in LMS is due to the fact that the sampling was performed during the ice-melt, when the lake surface was still partially covered by ice and the first pupae were just emerging, while in the others the samples were taken in summer, when there is a constant contribution of young larvae of the new generations. The presence of a littoral macrobenthos characterized by a comparatively low number of systematic entities (below 35), especially in LZ, undoubtedly reflects the severe climatic conditions (low temperature and long ice-cover period, from October till June) and the low trophic levels. This agrees with the finding of taxa characteristic of cold (*Heterotrissocladius marcidus* group and *Corynoneura* cf. *scutellata*) and high altitude water; typical

		Laiozza			Zota		Matörgn			Muino Sup.	
		St. 1	St. 2	St. 3	St. 2	St. 3	St. 1	St. 2	St. 3	St. 2	St. 3
Oligochaeta	Enchytraeidae	7	1	30		15	187	4	6	16	10
	Naididae										
	Nais elinguis						236		3		
	Lumbriculidae		5	3	2			7	7	12	5
	Stylodrylus							9			9
	Tubificidae	1	14	2					33		
	Haplotaxidae										
	Haplotaxis gordioides							2			
Turbellaria	Tricladida	4					6	10	13		
Acari	Hydracarina										
	Lebertia	1	8	3				5	19		
	Gnaphiscus		1								
	Feltria	1			1		1	2	1		

Tab. 6 - List of the systematic entities of Oligochaeta, Turbellaria and Hydracarina found in the studied lakes.

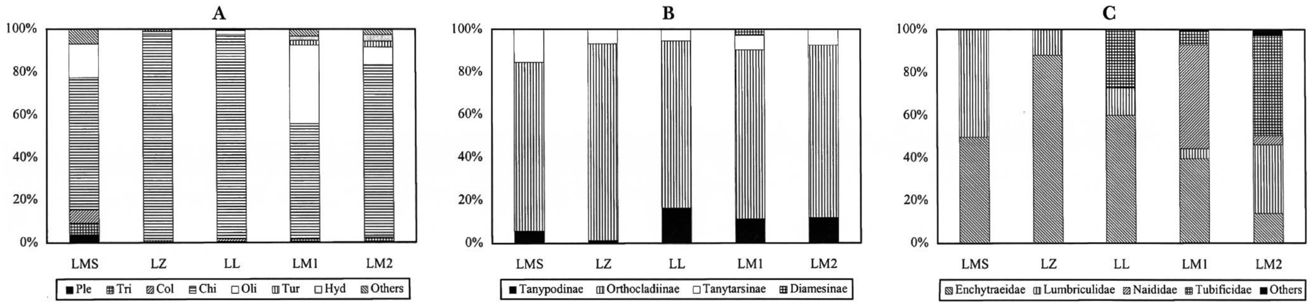

Fig. 2. Percentages of the main groups of macroinvertebrates (A) and of the chironomid (B) and oligochaet (C) communities of the lakes considered. Ple: Plecoptera; Tri: Trichoptera; Col: Coleoptera; Chi Chironomidae; Oli: Oligochaeta; Tur: Turbellaria; Hyd: Hydracarina; Others: rare groups. LMS: L. Muino Superiore; LZ: L. Zota; LL: L. Laiozza; LM: L. Matörgn (see text for explanation of LM1 and LM2).

in this case was the presence of *Pseudodiamesa* in LM, the highest in altitude of the considered lakes.

Regarding the low trophic level, the presence of the *Tanytarsus lugens* group and *Micropsectra* cf. *radialis*, indicators of moderately and ultra-oligotrophic waters (SÆTHER 1979), respectively, is in accordance with the total phosphorus and inorganic nitrogen concentrations of these lakes of below 4 µg P l^{-1} and 0.5 mg N l^{-1}, respectively.

In addition, low pH and in particular low alkalinity (LZ and LMS) affect the structure of the benthic community, as is confirmed by the tolerance limit proposed for Central Europe by SKJELKVÅLE *et al.* (1994; pH = 6 and Alk = 50 µeq l^{-1}). In fact, when there is a high atmospheric input of acidity, the lakes showing lower values are sensitive to a drop in pH and alkalinity. Particularly noticeable is the absence of molluscs, which are very sensitive to acid conditions, especially when low pH and alkalinity values are associated with low calcium concentrations (ØKLAND & ØKLAND 1986). In contrast, molluscs were found in Lake Paione Inferiore (WATHNE *et al.* 1995), the alkalinity and pH of which do not fall drastically at the snow-melt and where the calcium content is always above 50 µeq l^{-1}.

The composition of the insect community is also significant, formed as it is of a small number of systematic entities and dominated by those more tolerant to variations in pH values. They are the Diptera Chironomidae, in particular the genus *Heterotrissocladius marcidus* group, the families Nemouridae, Limnephilidae and Dityscidae among the Plecoptera, Trichoptera and Coleoptera, respectively (WATHNE *et al.* 1995). The more tolerant Oligochaet families (Enchytraeidae and Lumbriculidae) also prevail, while Naididae, which are particularly sensitive to low alkalinity and pH, are absent in the lakes with alkalinity < 20 µeq l^{-1} and predominant in LM, which presents higher figures, probably due to the presence of small lenses of carbonate rocks which do not show up at the resolution scale of the map used.

The low record of sensitive species in each lake is a further indication of a possible change due to acidification. From the acidification index it looks as if LM, with a score of 0.33, should be considered the most damaged of the studied lakes, because its river outlet presents only highly tolerant species, but this is not in agreement with its chemical features. However, it must be noted that the Raddum acidification index and its extension to the chironomids is based on the fauna in sub-alpine and lowland watersheds and includes many taxa not found in Alpine regions. As a consequence, mountain lakes may be misclassified on the basis of their fauna, since important indicator species may be absent due to altitudinal factors rather than to acidity.

This paper underlines the need for extending research to watersheds and lakes on calcareous bedrock at the same altitude and latitude, and for a seasonal sampling to highlight discrepancies due to bio-geography and different pH and alkalinity levels, and to obtain a representative list of taxa for the lake.

Acknowledgements
This research was financially supported by a grant from NATO - CNR (Announcement n. 217.27 - Senior fellowship programme 1994). Thanks are due to Dr. G.G. Raddum and Dr. A. Fjellheim of the University of Bergen (Norway) for stimulating discussions and to Dr. Ø. A. Schnell and A. Fieldså, of the same University, for their help in the identification of the Diptera Chironomidae and Coleoptera, to Dr. R. Mosello and to Dr. A.M. Nocentini of the C.N.R.-Istituto Italiano di Idrobiologia, the former for providing the chemical data and the latter for her contribution to the discussion.

REFERENCES

BARBIERI A., RIGHETTI G., 1987. Chimica delle deposizioni atmosferiche nel Canton Ticino ed effetti sulle acque dei laghi alpini d'alta quota. In: Mosello R. & B. De Margaritis (Eds), Atti Simp. Deposizioni acide: un problema per acque e foreste. Verbania Pallanza, 9-10 Aprile 1987. Documenta Ist. ital. Idrobiol., 14: 19-34.

BOGGERO A., MARCHETTO A., BARBIERI A., SASSI A., CONEDERA M., TARTARI G.A., MOSELLO R., 1996. Idrochimica dei laghi alpini del Canton Ticino (Alpi Centrali) in relazione con la chimica delle precipitazioni. Documenta Ist. ital. Idrobiol., 57: 273 pp.

DAVIS R.B., ANDERSON D.S., WHITING M.C., SMOL J.P., DIXIT S.S., 1990. Alkalinity and pH of three lakes in northern New England, U.S.A. Phil. Trans. R. Soc. Lond. B, 327: 413-421.

FJELLHEIM A., RADDUM G.G., 1990. Acid precipitation: biological monitoring of streams and lakes. The Science of the Total Environment, 96: 57-66.

FROST S., HUNI A., KERSHAW W.E., 1971. Evaluation of a kicking technique for sampling stream bottom fauna. Can. J. Zool., 49: 167-183.

GIOVANOLI R., SCHNOOR J.L., SIGG L., STUMM W., ZOBRIST J., 1988. Chemical weathering of crystalline rocks in the catchment area of acidic Ticino lakes, Switzerland. Clays Clay Miner., 36: 521-529.

GOLTERMAN H.L., CLYMO R.S., OHNSTAND M.A.M., 1978. Methods for physical and chemical analysis of fresh waters. I.B.P. Handbook, 8, Blackwell, Oxford: 213 pp.

LIEN L., RADDUM G.G., FJELLHEIM A., 1992. Critical loads of acidity to freshwater, fish and invertebrates. NIVA, Norwegian Institute for Water Research, O 89185, Oslo, 36 pp.

MOSELLO R., 1981. Chemical characteristics of fifty Italian Alpine lakes (Pennine-Lepontine Alps), with emphasis on the acidification problem. Mem. Ist. ital. Idrobiol., 39: 99-118.

MOSELLO R., 1984. Hydrochemistry of high altitude alpine lakes. Schweiz. Z. Hydrol., 46: 86-99.

MOSELLO R., BARBIERI A., MARCHETTO A., PSENNER R., TAIT D., 1992a. Research on the susceptibility of Alpine lakes to acidification. In: Mosello R., B.M. Wathne & G. Giussani (Eds), Limnology on groups of remote lakes: ongoing and planned activities. Documenta Ist. ital. Idrobiol., 32: 23-30.

MOSELLO R., BARBIERI A., BENDETTA G., BOGGERO A., MARCHETTO A., PSENNER R., TAIT D., TARTARI G.A., 1993. Quantification of the susceptibility of alpine lakes to acidification. In: de Bernardi R., R. Pagnotta & A. Pugnetti (Eds), Strategies for lake ecosystems beyond 2000. Mem. Ist. ital. Idrobiol., 52: 355-386.

MOSELLO R., MARCHETTO A., BOGGERO A., TARTARI G.A., BOVIO M., CASTELLO P., THALER B., TAIT D., BENDETTA G., BARBIERI A., RIGHETTI G., POLLI B., CONEDERA M., VALLEGGIA C., PSENNER R., 1992b. Final report. Quantification of the susceptibility of Alpine lakes to acidification. Contract CEE/CNR EV4V-0114 (1988-1991), 75 pp.

ØKLAND J., ØKLAND K.A., 1986. The effects of acid deposition on benthic animals in lakes and streams. Experientia, 42: 471-486.

PSENNER R., 1989. Chemistry of high mountain lakes in siliceous catchments of the Central Eastern Alps. Aquat. Sci., 51: 108-128.

PSENNER R., ZAPF F., 1990. High mountain lakes in the Alps: peculiarity and biology. In: Johannessen M., R. Mosello & H. Barth (Eds), Acidification processes in remote mountain lakes. Air Pollution Research Report 20, Guyot, Brussels, pp. 22-38.

RADDUM G.G., FJELLHEIM A., 1984. Acidification and early warning organisms in freshwater in western Norway. Verh. int. Ver. Limnol., 22: 1973-1980.

RADDUM G.G., FJELLHEIM A., 1987. Effects of pH and aluminium on mortality, drift and moulting of the mayfly (*Baetis rhodani*). Annls. Soc. r. zool. Belg., 117, Suppl. 1: 77-87.

RADDUM G.G., FJELLHEIM A., HESTHAGEN T., 1988. Monitoring of acidification by the use of aquatic organisms. Verh. int. Ver. Limnol., 23: 2291-2297.

RODIER J., 1978. L'analyse de l'eau. Dunod, Orleans, 1136 pp.

SÆTHER O.A., 1979. Chironomid communities as water quality indicators. Holarctic Ecology, 2: 65-74.

SCHINDLER D.W., MILLS K.H., MALLEY D.F., FINDLAY D.L., SHEARER J.A., DAVIES I.J., TURNER M.A., LINSEY G.A., CRUIKSHANK D.R., 1985. Long-term ecosystem stress. The effect of eight years of acidification in a small lake. Science, 228: 1395-1401.

SCHNOOR J.L., STUMM W., 1986. The role of chemical weathering in the neutralization of acidic deposition. Schweiz. Z. Hydrol., 48: 171-195.

SKJELKVÅLE B.L., NEWELL A.D., RADDUM G., JOHANNESSEN M., HOVIND H., TJOMSLAND T., WATHNE B.M., 1994. The six year report: acidification of surface water in Europe and North America. Dose/response relationships and long-term trends. NIVA - Report, 3041: 135 pp.

STOREY A.W., EDWARD D.H.D., GAZEY P., 1991. Surber and kick sampling: a comparison for the assessment of macroinvertebrate community structure in streams of south- western Australia. Hydrobiologia, 211: 111-121.

TAIT D., THALER B., 1988. Controllo del processo di acidificazione nei laghi d'alta quota in provincia di Bolzano. Provincia Autonoma, Bolzano, Italia.

WATHNE B.M., PATRICK S.T., MONTEITH D., BARTH H. (Eds), 1995. AL:PE 1 Report for the period April 1991-April 1993. European Commission, Ecosystem Research Report, 9: 292 pp.

WRIGTH R.F., 1983. Predicting acidification of North American lakes. Acid Rain Res. Rep. 4/83: 165 pp.

ZOBRIST J., SIGG L., SCHNOOR J.L., STUMM W., 1987. Buffering mechanism in acidified Alpine lakes. In: Barth H. (Ed.), Reversibility of acidification. Elsevier, London, pp. 117-125.