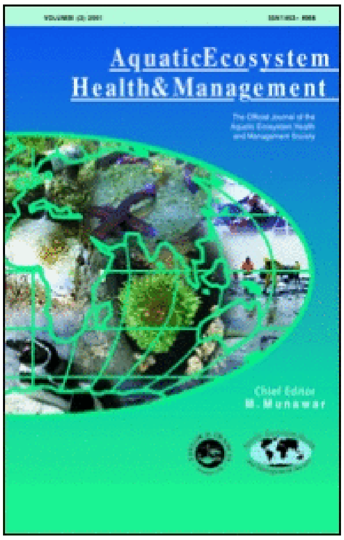

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Recovery assessment in Lake Nemi (Italy) after a twenty year period (1981–2001) using plant-associated invertebrates

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Lake Nemi was subjected to organic pollution in the 1970s due to domestic wastes, which led to a severe eutrophication process. Local authorities consequently planned a gradual waste diversion programme completed in 1990. Comparison between data on plant-associated invertebrates in the period of maximum eutrophication (1981/82) and twenty years after the total waste diversion (2001/02) was carried out with the aim of demonstrating the performance of this littoral community for the purpose of lake recovery assessment. Following the water clarity improvement characterizing the 2001/02 period, the macrophyte community displayed an amelioration in plant diversification, an enlargement of the colonized area, and an appearance of Charales, important bioindicators of oligotrophic conditions. In complete agreement with this new situation, the invertebrate fauna extended its colonization, and the species composition and quantitative structure changed completely. A considerable increase in species richness and diversity, and significant modifications of percentages and densities of bioindicator taxa (cladocerans, gastropods and acari) showed a very appreciable recovery, which can be defined as a phase of "oligotrophication". This trophic state is closely related to nutrient reduction in the water and enhanced by a drift of organic materials from littoral to profundal bottoms. This was due to the remarkable water level reduction of about five meters which occurred in the lake in recent times.

Keywords: littoral benthos, temporal changes, ecological quality

Introduction

The small volcanic Lake Nemi was studied during the last century on several occasions because it was affected by two extensive phases of physico-chemical and biological deterioration of water quality: the first one occurred after the years 1928–1932, when the lake was almost completely emptied to recover an ancient roman ship (D'Ancona, 1933; D'Ancona and Volterra D'Ancona, 1935); the second one after the years 1970–1975 due to severe organic pollution by domestic wastes from the surrounding Genzano and Nemi villages, and from the nursing home "Villa delle Querce" (Ferrara and Margaritora, 1982; Bazzanti, 1983; Bazzanti and Seminara, 1985; Mastrantuono, 1983, 1986a, 1986b). As a consequence of this eutrophication process, associated also with dramatic decreases of fish populations, progressive remediation measures were adopted and the wastes were channelled elsewhere in accordance with a gradual action plan completed within 1990.

In this study we report a comparison between data on the zoobenthos associated with aquatic vegetation, referring to two periods (1981/82 and 2001/02) for the purpose of demonstrating the performance of

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this littoral community in the assessment of the lake recovery process. As is well known, aquatic vegetation plays a key role for the lake food chain; the close synergy between plants and zoobenthos is able to maintain high quality in a freshwater ecosystem through a complex series of feedback mechanisms acting on the top-down and bottom-up control of trophic resources. Aquatic plants take up nutrients from the water and sediments, prevent erosion from the shores and resuspension of fine materials, and provide shelter and food to invertebrates, increasing their species richness and abundance (Dieter, 1990; Jeppesen et al., 1997; Horppila and Nurminen, 2001; Blindow et al., 2002; James et al., 2000).

The interest in re-studying plant-associated invertebrates in Lake Nemi was augmented further by the considerable water level reduction of about five meters which occurred in the lake in recent years. This phenomenon was due to both unfavourable climatic conditions, and increasing human withdrawal of surface and subterranean waters from the catchment basin. For the same reasons, in many parts of the world water level reduction and/or fluctuations represent a new problem in natural lakes today, especially in littoral zones that can be rapidly and heavily affected by this phenomenon. It reduces species richness and abundance in the plant community, causing a cascade effect on the invertebrates associated with this substrate.

In this light, this survey does not represent a simple description of the invertebrate composition, but provides a definition of the lake ecological conditions by means of bioindices and bioindicators that can be used in biomonitoring practices, in compliance with the recent inclusion of some littoral invertebrates in the "Water Framework Directive" (CEC, 2000). Moreover the comparison between previous and recent results plays an essential role in identifying the trend of faunal modifications over time and constitutes a valuable data-set for future controls and/or any lake management proposals. Indeed, in order to be considered effective, any remediation experience carried out in a lake must be aimed at re-establishing a trophic chain with the objective of reaching the "maximum biodiversity" linked with a sustainable use of the water resource for human purposes, such as drinking, agricultural and recreational activities. Any action plan aimed at achieving this purpose will benefit from detailed knowledge of the biological composition and its changes over time in order to ensure complete success.

Study area and methods

Lake Nemi is located about 30 km south of Rome, at a level of 316 m a.s.l. It has a perimeter of 5.4 km, an area of 1.8 km^2 and a maximum depth of 32.4 m. Renewal time was estimated as 15 years (Gaggino et al., 1985). Only sporadic bathing and recreational activities affect the lake, but the private use of surrounding lands has caused evident morphological modifications of some lakeshore sites, especially banks and elimination of aquatic and semi-aquatic plants.

During both investigations (1981/82 and 2001/02), the samples were collected at the same sites every two months for one year (Fig. 1). Station N was not investigated in 1981/82 because it was completely lacking in vegetation due to the high degree of pollution. For collecting samples, a sledge dredge (frame opening: 35x20 cm; mesh size: 180μm) was towed for about 50 m, parallel to the shore, following a sinusoidal path at each selected depth range (0–4 m and 4–8 m). The ranges were established according with the maximum depth of plant colonization. The material was preserved in formalin (5% final formaldehyde concentration) in the field. Plant abundance at the depth ranges was estimated approximately from

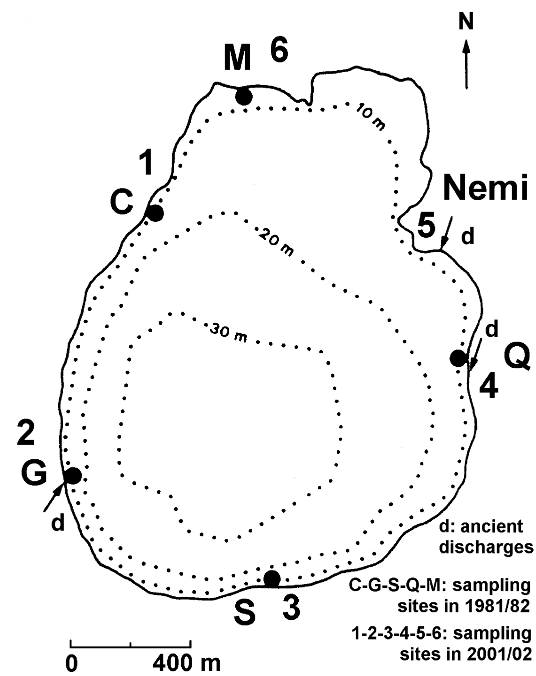

Figure 1. Map of Lake Nemi and location of the sampling stations.

the relative occurrence in the collected samples and assigned to one of these four categories: <10%; 10–30%; 30–60%; >60%. Additional information was obtained in the field by visually assessing plant abundance and distribution. The macroinvertebrates were separated completely from the entire sample and the meiobenthic ones from suitable subsamples under a stereomicroscope at low magnification. Shannon diversity (Margalef, 1957) and quantitative similarity (PSc, Renkonen, 1938) were applied to annual mean densities of all taxa.

Monthly measures of water clarity of the two periods of investigation were kindly provided by Prof. F.G. Margaritora (Dept. Anim. and Hum. Biol., Univ. "La Sapienza" of Rome). Total phosphorus measures, referring to the year 2000, were kindly supplied by Dr. Tartari (IRSA, Brugherio, Italy).

Results

The examination of important physico-chemical data showed that water clarity considerably increased in all seasons in 2001/02, with a maximum value of 9.6 m in summer (July 2002, Table 1), which is also the period of maximum vegetation growth. The transparency improvement was enhanced by complete disappearance of fine suspended organic matter, which in 1981/82 represented one of the primary causes of the turbid water state. The comparison of total phosphorus content in summer periods (the only available data refers to 2000, Table 2) has clearly shown the significant reduction of the values in comparison with the past. Both transparency and total phosphorus measured in 2000/2002 can be considered indicative of a great reduction of trophic status, according to the O.E.C.D. classification (1982) founded on these paramenters.

The comparative analysis of plant composition and distribution in 1981/82 and 2001/02 (Table 3) showed that the submerged vegetation increased in species richness (from 5 to 9 taxa) and extended the colonization from a maximum depth of 4 m to 8 m, following the water clarity improvement observed in 2001/02. The increase in number of taxa was especially due to *Potamogeton* species, as well as a first record of Charales algae. In terms of density, *Myriophyllum spicatum* and *Ceratophyllum demersum* still represented the dominant taxa.

The analysis of the invertebrate assemblage displayed very noticeable changes in species richness, percentages and numerical structure. Species richness increased by 10 units in 2001/02 and showed a very high species replacement, given that only 27 of the 61 taxa present in 1981/82 were found again in 2001/02 (Table 4). Faunal groups displaying the greatest increase in number of taxa were nematodes, mites and cladocerans (Table 4), while insects as a whole showed a moderate reduction (from 25 in 1981/82 to 19 taxa in 2001/02). The increase in species richness occurred to varying degrees at all sampling stations, just as diversity values which increased everywhere, with the sole exception of station 3S (Table 5). The diversity measured on total fauna changed indeed in a noticeable way, increasing from a value of 2.2 in 1981/82 to 3.4 in 2001/02. The fauna quantitative structure displayed a complete change: in spite of a more extensive colonization in deep water by invertebrates, the densities of total fauna revealed a remarkable decline in numbers in 2001/02 (semiquantitative data: from 176001 to 60662 counted individuals), with very significant reductions at all sampling stations and depths, with respect to both total colonized range (0-8 m) and two different sampled ranges (Table 6).

Cladocerans actually declined significantly in both percentages (Fig. 2) and numerical values in 2001/02 (from 116991 in 1981/82 to 6977 in 2001/02), almost completely due to the diminution in density of *Chydorus sphaericus* (Table 4). Secondarily, oligochaetes were subjected to a considerable reduction both in percentages and relative abundance, while copepods and chironomids increased in percentage in 2001/02, with considerable numerical increase for copepods and similar numerical values for chironomids (Table 4). Other less abundant groups, considered together as "Alia", showed slightly higher percentages in 2001/02, although their numbers decreased notably (from 13327 in 1981/82 to 6018 counted individuals in 2001/02),

Table 1. Water clarity (Secchi depth) in Lake Nemi in both periods of study.

Transparency (m)	IX	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	mean
1981/82	0.8	0.8	1.8	6.3	1.6	2.1	1.8	1.4	1.1	0.6	0.9	2.2	1.8
2001/02	8.0	6.9	4.2	3.0	2.7	2.7	3.0	1.8	8.3	8.8	9.6	6.3	5.4

Table 2. Total phosphorus in Lake Nemi in 1982 (means of monthly measures) and comparison between summer values in 1982 and 2000 (data of 2000 kindky supplied by Dr. Tartari, IRSA, Brugherio, Italy).

TP-P (μgl^{-1})	1m	5m	10m	20m	25m	mean
1982	96	172	172	234	279	190.6
IX/1982	106	160	389	582	610	369.4
IX/2000	6.5	9.1	16.5	51.5	54	27.5

especially for the reduction of hydroids and ostracods. The highly different quantitative structure is clearly demonstrated by the very low value of the quantitative similarity PSc between 1981–2001, which reached only 16.7 percent.

Discussion and conclusions

Increased water clarity and reduction of phosphorus content in Lake Nemi (Tables 1 and 2) certainly have represented the basis for the process of its biological recovery. A summary of the most significant biological metrics adopted for describing the lake recovery process are presented in Table 7. They constitute a set of both bioindices and bioindicators progressively selected and validated during a long series of previous investigations on plant-associated invertebrates in lakes of Central Italy (Mastrantuono, 1986b, 1990, 1991, 1993; Mastrantuono and Mancinelli, 1999, 2003, 2005). The descriptors proved to be valid especially when all parameters together were taken into consideration. It was actually found to be advantageous to use several combined descriptors to make a diagnosis of ecological status, because the high complexity of this

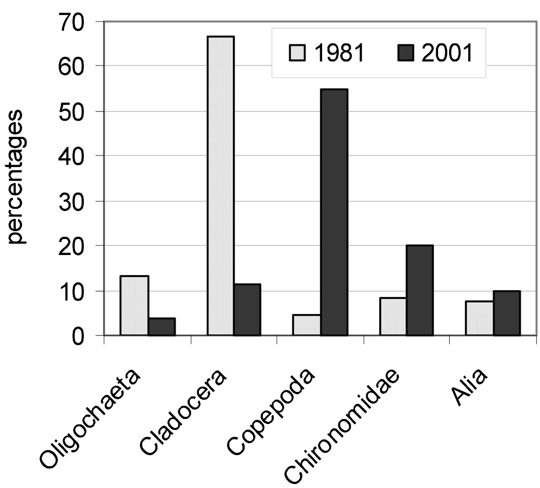

Figure 2. Percentage fauna composition in littoral vegetation of Lake Nemi in the two years.

littoral community, its high homeostatic character and the large number of interactions between biological and abiological components make it difficult to fully accept the validity to any single parameter alone. Moreover it was clearly demonstrated to be very difficult to reach a reliable diagnosis by means of simplified measures, whereas the importance of a detailed investigation of the invertebrate assemblages carried out at least over a one year period gradually became decisive. Also other authors (Burton et al., 1999; García-Criado et al., 2004) widely stated that a finer taxonomic resolution at the genus and species level is necessary to obtain a representative result when using bioindices, a view accepted also in the European Water Framework Directive.

The brief analysis of the plant substratum in Lake Nemi in the two periods showed three positive features (Table 3): increase in species richness, substantial enlargement of the bottom colonized area, appearance of Charales. The reduction of the eutrophication, which improved water clarity and reduced the surplus of organic matter in the sediments, is

Table 3. List of identified aquatic plants and distribution in Lake Nemi in the two periods. •: rare; ••: scarce; •••: abundant; ••••: very abundant.

	1981/82	2001/02	
Lake Nemi	0–4 m	0–4 m	4–8 m
Charales		•	
Myriophyllum spicatum	••••	••••	••
Ceratophyllum demersum	•••	••	••••
Potamogeton crispus			
Potamogeton perfoliatus	•	••	•
Potamogeton pectinatus		•••	
Potamogeton pusillus	••		
Potamogeton natans		••	
Potamogeton lucens (?)		••	
Potamogeton sp.			•
Najas marina	•	•	•
10	5	8	5

Table 4. List of taxa associated with aquatic vegetation in Lake Nemi: number of taxa, percentage presence and annual mean number of counted individuals.

Lake NEMI	Number of taxa 1981/82	Number of taxa 2001/02	Percentages 1981/82	Percentages 2001/02	Annual means 1981/82	Annual means 2001/02
HYDROIDA	1	1	4.6	4.7	8160	2833
Hydra sp.			4.6	4.7	8160	2833
TURBELLARIA	1	2	0.05	1.6	83	995
Dugesia tigrina (Girard)			0.05	1.6	83	985
Typhloplana sp.				0.02		10
NEMATODA	2	7	0.01	0.1	21	50
Aphanolaimus aquaticus (Daday)				0.001		1
Ethmolaimus pratensis De Man				0.04		23
Tripyla glomerans (Bastian)				0.001		1
Tobrilus gracilis (Bastian)			0.01	0.007	19	4
Mononchus truncatus Bastian				0.005		3
Chronogaster sp.				0.003		2
Dorylaimina indet.				0.03		16
Mermithidae			0.001		2	
OLIGOCHAETA	14	13	13.1	3.7	23026	2251
Aeolosoma hemprichi (Ehremberg)				0.06		36
Chaetogaster diaphanus (Gruithuisen)			0.05	0.003	97	2
Chaetogaster diastrophus (Gruithuisen)			1.2	0.2	2170	141
Chaetogaster langi (?) Bretscher			0.08		149	
Pristina menoni (Aiyer)			0.001		2	
Pristina aequiseta Bourne			0.01	0.005	23	3
Pristina foreli Piguet			0.001	0.001	2	1
Pristinella sp.				0.003		2
Stylaria lacustris (L.)				2.9		1769
Nais barbata (Müller)			0.8	0.08	1494	47
Nais simplex Piguet			0.5		849	
Nais pardalis Piguet			0.03		54	
Nais variabilis Piguet			6.9		12163	
Nais communis Piguet			0.02	0.04	31	26
Nais pseudobtusa Piguet			3.4		5986	
Dero obtusa Udekem			0.002		3	
Dero sp.				0.35		210
Aulodrilus pluriseta (Piguet)				0.004		2
Immature Tubificidae with hair chaetae				0.01		9
Immature Tubificidae without hair chaetae				0.005		3
Enchytraeidae			0.001		2	
CLADOCERA	4	8	66.5	11.5	116991	6977
Bosmina longirostris (O.F. Müller)				0.4		220
Simocephalus vetulus (O.F. Müller)				0.05		29
Chydorus sphaericus (O.F. Müller)			66.1	6.5	116397	3938
Acroperus harpae (Baird)				3.0		1820
Alona quadrangularis (O.F. Müller)				1.2		746
Alona rectangula Sars			0.2	0.05	293	31
Alona guttata (Sars)			0.07	0.07	126	43
Biapertura affinis (Leydig)				0.2		150

(Continued on next page)

Table 4. List of taxa associated with aquatic vegetation in Lake Nemi: number of taxa, percentage presence and annual mean number of counted individuals. *(Continued)*.

Lake NEMI	Number of taxa 1981/82	Number of taxa 2001/02	Percentages 1981/82	Percentages 2001/02	Annual means 1981/82	Annual means 2001/02
Diaphanosoma leuchtembergianum Fischer			0.1		176	
COPEPODA	5	7	4.6	54.8	8112	33268
Macrocyclops albidus (Jurine)			1.0	17.1	1777	10371
Eucyclops serrulatus (Fischer)			0.3	1.2	506	750
Eucyclops macruroides (Lilljeborg)			2.0	3.9	3523	2379
Paracyclops fimbriatus (Fischer)				0.04		26
Cyclops abyssorum Sars			0.4	14.8	751	8997
Mesocyclops leuckarti (Claus)			0.9	17.7	1555	10708
Harpacticoida				0.06		37
OSTRACODA	2	2	2.6	0.2	4653	134
Cypridopsis vidua (O.F. Müller)			2.1	0.2	3737	106
Candona sp.			0.5	0.05	916	28
ISOPODA	0	1	0	0.005	0	3
Proasellus coxalis (Dollfus)				0.005		3
DECAPODA	1	0	0.00008	0	0.1	0
Palaemonetes antennarius (Milne Edwards)			0.00008		0	
EPHEMEROPTERA	2	0	0.003	0	6	0
Caenis luctuosa (Burmeister)			0.003		5	
Cloeon cognatum Stephens			0.0003		1	
ODONATA	4	5	0.08	0.2	135	100
Erythromma viridulum (Charp)			0.001		2	
Coenagrion lindeni (Selys)			0.03		59	
Ischnura elegans (Vander Linden)			0.04		73	
Trithemis annulata (Palisot de Beauvais)				0.02		11
Coenagrion sp.				0.05		29
Cercion sp.				0.07		45
Anax sp			0.0004	0.001	1	1
Anisoptera indet				0.02		15
HETEROPTERA	1	0	0.002	0	4	0
Micronecta sp.			0.002		4	
DIPTERA CHIRONOMIDAE	12	9	8.3	20	14545	12149
Culicoidinae			0.02		32	
Orthocladiinae indet.				19.3		11690
Psectrocladius sordidellus Zetterstedt			5.2		9102	
Cricotopus ornatus			0.02		37	
Cricotopus sylvestris			0.6		1088	
Psectrocladius				0.009		5
Nanocladius			0.02		39	
Labrundinia				0.3		167
Pentaneurini			0.005		9	
Procladius			0.02		39	
Tanipodinae indet.				0.006		4
Tanytarsus				0.01		7

(Continued on next page)

Table 4. List of taxa associated with aquatic vegetation in Lake Nemi: number of taxa, percentage presence and annual mean number of counted individuals *(Continued)*.

	Number of taxa		Percentages		Annual means	
Lake NEMI	1981/82	2001/02	1981/82	2001/02	1981/82	2001/02
Paratanytarsus			0.1		233	
Microtendipes				0.002		2
Endochironomus			0.02		36	
Polypedilum convictum gr.			0.006		11	
Glyptotendipes			2.0		3527	
Chironomus				0.02		11
Parachironomus			0.2	0.4	393	230
Cladopelma				0.06		34
DIPTERA CERATOPOGONIDAE	0	1	0	0.01	0	6
Ceratopogonidae indet.				0.009		6
DIPTERA ALIA	0	1	0	0.001	0	1
Diptera indet.				0.001		1
TRICHOPTERA	4	2	0.04	0.3	63	170
Ecnomus tenellus (Rambur)			0.03	0.05	50	28
Tinodes waeneri (L.)			0.00008		0	
Orthotrichia costalis (Curtis)			0.007	0.2	12	142
Oxyethira sp.			0.0002		0	
LEPIDOPTERA	1	1	0.007	0.01	13	7
Pyralidae indet.			0.007	0.01	13	7
COLEOPTERA	1	0	0.001	0	2	0
Coleoptera indet.			0.001		2	
ACARINA	0	1	0	1.3		765
Oribatei				1.3		765
HYDRACARINA	2	7	0.01	0.3	19	167
Limnesia maculata (O.F. Müller)			0.009		16	
Limnesia sp.				0.1		87
Unionicola sp.				0.007		4
Neumania sp.				0.07		42
Lebertia sp.				0.004		2
Forelia sp.				0.04		25
Acercus sp.				0.003		2
Arrenurus sp.			0.002	0.007	3	5
GASTROPODA	3	3	0.1	1.3	170	790
Physa acuta (Draparnaud)			0.02	0.2	29	151
Lymnaea auricularia (L.)			0.08		140	
Bithynia tentaculata (L.)			0.0006	0.3	1	152
Helisoma duryi (Wetherby)				0.8		487
BRYOZOA	0	1	*		*	
Plumatella casmiana Oka			*		*	
	61	71			176001	60662

viewed as the primary reason for the amelioration in plant diversification and enlargement in depth of the colonized area. The great importance of this improvement can be appreciated if we consider, as estimated by Jeppesen et al. (1994), that at least 30% of the lake littoral must be covered by plants in order to maintain a high water clarity condition, which is essential to support macrophyte development itself and, as a direct consequence, to establish a diversified invertebrate community. The finding

Table 5. Invertebrate species richness and Shannon diversity at the stations of Lake Nemi.

Stations		1 C	2 G	3 S	4 Q	5 N	6 M	Total
Species richness	1981/82	39	44	38	44	—	32	61
	2001/02	51	52	46	48	52	51	71
Diversity (H)	1981/82	1.4	2.5	3.2	2.5	—	1.5	2.2
	2001/02	3.1	3.2	2.7	3.2	3.2	3.4	3.4

of Charales represents a significant sign of nutrient reduction in the water, in agreement with evidence supplied by several authors (Pereyra-Ramos, 1981; Blindow, 1992; Kufel and Ozimek, 1994) who demonstrated that these algae are important bioindicators of oligotrophic conditions owing to their high sensitivity to rich sediments and low transparency.

The parameters related to fauna structure evidenced a substantial improvement in invertebrate species richness and diversity calculated both on total fauna (from 61 to 71 and from 2.2 to 3.4 respectively) and at the sampling stations (Table 7). The Index of Community Structure (ISC) displayed a remarkable positive reduction (from 55.5 to 23.5), which indicates a relevant increase in number of faunal groups with abundances over 0.1%. This index (Mastrantuono, 1993) was the only proposal of a simplified metric to evaluate lake littoral quality without a more detailed invertebrate identification. It is based on all meio- and macrobenthic groups, considered at a taxonomic level up to family. The index is calculated as the ratio of "number of rare faunal groups/total number of groups", assuming as rare a percentage presence less than 0.1% of total fauna. The assumption for the formulation of this index was the observation that an environmental deterioration leads to a quantitative reduction or complete disappearance of the rare invertebrates, which are generally more sensitive to food chain modifications that follow trophic changes. Over time, this index has proved to be useful, although it actually represents a supplementary element of environmental diagnosis that, when considered with other metrics, contributes to a reliable indication of the ecological status in the freshwater system.

A very interesting parameter in a trophic evaluation is without doubt the density of individuals, given the simple assumption: low quantity of food-low quantity of organisms. In this study semiquantitative samples were collected; this measure is expressed as "annual mean number of counted individuals/number of stations/number of meters (in depth) colonized by plants", in order to obtain a truly comparable datum between different years and studies. In 2001/02 a drastic reduction of the fauna abundance was observed in the lake (Table 7), with a number of individuals lower than in other lakes of Central Italy (Mastrantuono and Mancinelli, 2002). This low number of invertebrates is in agreement with the low trophic input in the water, as indicated by the phosphorus content measured in the summer period of 2000 (Table 2). This phenomenon, which can be defined as a true "oligotrophication process", was well indicated by the complete decline both in percentage and in density of the microfilterer cladoceran *Chydorus sphaericus* (Table 4), considered as one of the best indicators of meso-eutrophic conditions for its ability to filter fine suspended organic matter (Berzinš and Bertilsson, 1989; de Eyto, 2001), and which in 1981/82 dominated the entire invertebrate community. At the same time, the increase in number of cladoceran species observed in 2001/02 (Table 7) suggested an amelioration in the diversity of phytoplanctonic and epiphytic algae. In

Table 6. Annual mean number of counted individuals associated with aquatic vegetation at the stations of Lake Nemi in the two periods of study.

Annnual means	1 C	2 G	3 S	4 Q	5 N	6 M	*Total fauna*
1981/82 0-4m	56538	25777	11951	27858	—	53877	176001
2001/02 0-4m	7205	6086	5901	5160	4352	7507	36211
2001/02 4-8m	4359	5156	782	2933	5281	5941	24451
2001/02 0-8m	11564	11242	6683	8093	9633	13449	60662

Table 7. Parameters useful for a quality evaluation. Percentage values are calculated on annual means. Total fauna represent the annual mean number of individuals/nr of stations/nr of meters colonized by aquatic vegetation. ISC: (nr. of zoological groups having %<0.1/total nr. of groups) x 100; *: present.

Lake Nemi	1981	2001
Belt colonized by vegetation (m)	0–3 m	0–8 m
Nr. of identified aquatic plants	5	9
Charales	—	*
Nr. of taxa	61	71
Shannon diversity (H)	2.2	3.4
Shannon diversity (range at the stations)	1.4–3.2	2.7–3.4
ISC	55.5	23.5
Total fauna	11733	1264
Nr. of cladoceran species	3	8
Chydorus sphaericus (%)	66.1	6.5
Chydorus sphaericus (%, range)	37.9–80.3	1.0–13.1
Oligochaetes (%)	13.1	3.7
Acarina	0.01	1.6
Gastropoda	0.1	1.3

fact, as clearly demonstrated by traditional but still valid research (Gliwicz, 1969, Kořínek et al., 1985), these microcrustaceans comprise species characterized by micro- or macrofiltering habits, and only a diversification of algal populations can increase their species richness. An amelioration in the algal food sources can be enhanced by increased water clarity, reduction of suspended organic matter in the water and more extended macrophyte colonization, which supplied a wider surface for epiphytic algae (Cattaneo et al., 1998). Indeed, the number of cladoceran taxa have been found to increase in parallel with water quality improvements (Mastrantuono and Mancinelli, 2002), and for this reason we think that they represent one of the more reliable indicators in the evaluation of ecological status.

Other invertebrates included among the diagnostic descriptors are oligochaetes, typically linked to meso-eutrophic conditions also in littoral zones (Krieger, 1984; Warren et al., 1995), and which showed a substantial decrease both in percentage and in number of individuals (Table 4). In contrast, gastropods and mites, organisms highly related to the presence of macrophyte substratum, showed a considerable increase in 2001/02 both in percentages and in numbers (Table 7). This phenomenon can be related to the macrophyte recovery. The decline of molluscan taxa with decreasing water quality both in lakes and running water is a theme widely stated by several authors (Costil and Clement, 1996; Harman, 1997; Mouthon and Charvet, 1999), but clear evidence for the use of water mites as indicators of unpolluted waters was so far provided primarily for running waters (Cicolani and Di Sabatino, 1991; Cicolani et al., 1991).

Conclusions

In summary, the results of this comparison of plant-associated assemblages between 1981-2001 have demonstrated the full value of these assemblages in lake recovery assessment. The selected descriptors worked as a real "integrated ecoframe" and displayed good validity and complete agreement in the indication of an advanced recovery process, which can be defined as a phase of "oligotrophication". This phenomenon, supported by the gradual waste diversion, was probably further enhanced by the considerable water level reduction of about five meters that occurred in the last few years. In fact Lake Nemi, with its volcanic morphology, displays a steep bottom profile throughout most of the perimeter, so the water level diminution causes a marked drift of organic matter from littoral to profundal sediments and this can enhance the "oligotrophication" in littoral zones. Therefore, in spite of the remarkable improvement of water quality observed in the lake, if water withdrawal continues over the potential catchment basin, we can expect in the short term a new phase of worsening in the ecological condition of littoral biological communities. In fact all sites will be affected by a substantial reduction in depth of the area colonizable by aquatic plants, with the consequence of a destabilization of the faunal structure. Owing to the key role played by littoral invertebrates as sources of biodiversity, and their importance in the lake food chain, it may be asserted that today water level reductions can be viewed as a new and more significant threat to several littoral lacustrine zones in Mediterranean areas and as a factor in their deterioration, with a cascade effect on the entire water body.

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