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Influence of water eutrophication on the macrophytic vegetation of Lake Lugano

J.-B. Lachavanne, J. Perfetta and R. Juge

Laboratory of Aquatic Ecology and Biology, University of Geneva, 18, ch. des Clochettes, CH-1206 Geneva (Switzerland)

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ABSTRACT

The influence of water eutrophication on the macrophytic vegetation of Lake Lugano (Lago di Lugano) is demonstrated using two complementary procedures:

- A comparative study of the flora, floristic diversity and abundance of vegetation of the three main basins (Northern, Southern, and Ponte Tresa) differing in their geographical and limnological (trophic) characteristics. Our findings are briefly compared with the observations made on other Swiss lakes.
- A description of the qualitative and quantitative evolution of macrophytes based on the comparison of our results of 1980 and 1987 with those of Steiner in 1912. These three studies correspond to different trophic levels and provide trends to link the evolution of vegetation and flora to the phenomenon of eutrophication.

1. Introduction

It is generally accepted, in particular since Vollenweider (1970), that water eutrophication leads to an increase of primary production and to modifications in the community's composition: i.e., appearance and proliferation of organisms indicating nutrient-rich waters and simultaneous disappearance of species typical of oligotrophic waters.

The consequences of water eutrophication on the macrophytic vegetation of lakes have been amply described, in particular by Suonimen (1968), Morgan (1970), Ryan et al. (1972), Wium-Andersen (1974), Jupp and Spence (1977), Wallsteen (1981), Lachavanne (1982, 1985), Burgermeister and Lachavanne (1984), Lachavanne et al. (1984), Juge et al. (1985), Lachavanne et al. (1986 a and 1986 b). These studies clearly show that, up to a certain trophic level, water eutrophication first promotes an increase of macrophytic colonization. But beyond this level, a qualitative and quantitative decrease is observed, which can be drastic in some cases, especially for submerged plants.

Taking into account the studies of Baldi et al. (1949), Jaag (1958, 1964) and Vollenweider (1965), Barbieri et al. (1989) estimate that the accelerated water eutrophication of Lake Lugano began in the 1940s.

In the early 1980s, Lake Lugano was characterized by a variety of conditions, from eutrophic to highly eutrophic. Some areas, such as Agno for example, were clearly in a hypertrophic state. The lake trophic level has not notably changed since then, although the concentration of total phosphorus in water has slightly decreased. New investigations in 1987 revealed that changes had not yet clearly appeared in the macrophytic communities.

The comparative study of Lake Lugano riparian flora and vegetation at different periods of time characterized by contrasted trophic conditions enables to show the influence of eutrophication on these organisms (Steiner, 1912; Lachavanne and Perfetta, 1981).

The comparison of the abundance of macrophytes in Lake Lugano with that of other Swiss lakes (Lachavanne et al., 1986b) also gives an estimation of the trophic level.

2. Methods and techniques

In 1980, macrophytes of Lake Lugano were studied by a systematic prospection and mapping of the shores from a boat and by scuba diving; one year later, verifications were carried out. In 1987, profiles of vegetation were taken again. Survey methods and data processing have been described by Lachavanne and Wattenhofer (1975) and Lachavanne et al. (1985b).

3. Results

3.1. Influence of eutrophication on the macrophytic flora of Lake Lugano

3.1.1. Evolution of the floristic composition

The evolution of the macrophytic flora and vegetation of Lake Lugano was described by comparing previous data to our own 1980 and 1987 observations. Some caution is required in the interpretation, the data being incomplete and heterogeneous: part of it was found in publications concerned with aquatic flora (Steiner, 1912) and regional floras (Chenevard, 1910; Becherer, 1960), as well as in plant collections (Botanical Institutes of the Universities of Lausanne, Fribourg, Bern, Neuchâtel and Zurich, Conservatory and Botanical Garden of Geneva and the Swiss Federal Institute of Technology – Zurich).

The changes of the macrophytic flora of Lake Lugano which have occurred between the beginning of the century – oligotrophic state according to Barbieri et al. and Mosello (this issue) 1980 – highly eutrophic to hypertrophic state – are presented in Table 1.

For the Charophytes, Corillon's nomenclature (1957) is adopted, and for the Phanerogams, the *Flora europea* nomenclature (Tutin et al. 1964–1980).

Table 1. Evolution of Lake Lugano floristic composition from the beginning of the century to 1980 (+ = presence, − = absence)

	Past Observations	1980 Observations
Emergent plants		
Acorus calamus L.	+	−
Alisma lanceolatum With.	+	−
Alisma plantago-aquatica L.	+	−
Carex sp.	+	+
Elatine hydropiper L.	+	+
Eleocharis acicularis (L.) Roem. and Schult.	+	+
Eleocharis palustris (L.) Roem. and Schult.	+	−
Eleocharis sp.	+	+
Iris pseudacorus (L.)	−	+
Littorella uniflora (L.) Asch.	+	−
Phragmites australis (Cav.) Trin.	+	+
Scirpus lacustris (L.) Palla	+	+
Scirpus mucronatus (L.) Palla	+	−
Scirpus supinus (L.) Palla	+	−
Scirpus tabernaemontani (Gmelin) Palla	+	+
Sparganium erectum ssp. *erectum* L.	+	−
Sparganium erectum ssp. *neglectum* (Beeby) Schinz and Thell.	+	−
Sparganium emersum Rehmann	+	−
Typha angustifolia L.	+	+
Typha latifolia L.	+	+
Phalaris arundinacea L.	+	+
	20	11
Floating-leaf plants		
Nymphaea alba L.	+	+
Polygonum amphibium L.	+	−
	2	1
Submerged plants		
Charophytes:		
Chara aspera Wildenow	+	−
Chara contraria A. Br.	+	−
Chara delicatula Agardh	+	−
Chara globularis Thuill.	−	+
Chara intermedia A. Br.	+	−
Nitella flexilis Agardh	−	+
Nitella opaca Agardh	+	−
Nitella syncarpa (Thuill.) Chev.	+	−
	6	2
Bryophytes:		
Amblystegium riparium (Hedw.) B. S. G.	−	+
Cinclidotus aquaticus (Hedw.) B. S. G.	−	+
Cinclidotus fontinaloïdes (Hedw.) P. Beauv.	−	+
Fontinalis antipyretica L.	+	+
Rynchostegium riparioïdes (Hedw.) Card.	−	+
	1	5

Table 1 (continued)

	Past Observations	1980 Observations
Phanerogams:		
Elodea canadensis Michaux	+	+
Egeria densa (Planchon) Caspary	−	+
Groenlandia densa (L.) Fourreau	+	−
Lagarosiphon major (Ridley) Moss	−	+
Myriophyllum alterniflorum D. C.	+	−
Myriophyllum spicatum L.	+	+
Najas marina L.	+	+
Najas minor All.	+	−
Potamogeton crispus L.	+	+
Potamogeton lucens L.	+	+
Potamogeton x decipiens Nolte	+	+
Potamogeton gr. *pusillus* L.	+	+
Potamogeton pectinatus L.	+	+
Potamogeton perfoliatus L.	+	+
Ranunculus aquatilis L.	+	−
Ranunculus trichophyllus Chaix	−	+
Ranunculus fluitans x trichophyllus	+	−
Vallisneria spiralis L.	+	+
Zannichellia palustris L.	+	+
	16	14
Free plants		
Ceratophyllum demersum L.	+	+
Ceratophyllum submersum L.	+	−
Lemna minor L.	+	−
Spirodela polyrrhiza (L.) Schleiden	+	−
Trapa natans L.	+	−
Utricularia minor L.	+	−
	6	1
Total:	51	34

Other species found on the lakeshores:

Carex gracilis Curtis
Cyperus longus L.
Epilobium hirsutum L.
Juncus inflexus L.
Lysimacchia vulgaris L.
Lythrum salicaria L.

3.1.2. Evolution of the floristic diversity

By comparing past data to recent ones, the evolution of the main taxa and vegetation types can be assessed. Table 2 summarizes the evolution of the macrophytic flora of Lake Lugano and leads to the following remarks:

- On the whole, the evolution of the flora of Lake Lugano is negative. According to past observations, at least 51 species colonized the shores at the beginning of the century. Our observations indicate 34 species only. Despite the fact that 10 new species have been recently identified in the lake, the disappearance of 27 species reveals a serious decrease in floristic diversity, corresponding to an impoverishment of 33%.
- Lost species belong to emergent as well as submerged plants.
- Among the submerged rooted plants, Charophytes have suffered the greatest depletion.
- Because both past and recent data concerning Bryophytes are lacking, it is impossible to draw conclusions about their evolution in Lake Lugano.
- Among Phanerogams, there has been an important loss of emergent and free-floating plants.
- The new species do not compensate for those which where lost and the specific variation – which takes into account the total number of species – amounts about 60% and corroborates the deep changes that have occurred in Lake Lugano since the beginning of the century.

A comparison of the floristic diversity of the three main basins shows some differences. The Southern basin is the richest, with 30 species; the Northern basin has 24 and the Ponte-Tresa basin only 17, which is directly related to a very high trophic level in this area. The situation in the Ponte-Tresa basin occurrs despite potentially better bottom and slope conditions for the establishment of macrophytes.

Table 2. Evolution of the floristic diversity and assessment of the evolution of Lake Lugano main taxa. * = (2) + (3)/(1)

	Total number of species (1)	Species in the past	Present species	Still present species	Species found again (2)	Newly found species (3)	Specific variation (%)*
Charophytes	8	6	2	0	6	2	100
Bryophytes	5	1	5	1	0	4	80
Rooted Phanerogams:							
emergent	21	20	11	10	10	1	52
floating	2	2	1	1	1	0	50
submerged	19	16	14	11	5	3	42
free	6	6	1	1	5	0	83
Total:	61	51	34	24	27	10	
%	100			39.3	44.3	16.4	61

3.2. Influence of eutrophication on the abundance of macrophytes

3.2.1. Distribution of the aquatic vegetation in Lake Lugano

According to the results of 1980, the amount of macrophytic vegetation on the shores of Lake Lugano is very low (see Fig. 1). The most important submerged plant communities of the lake are found in the Southern basin, in the area of Melide. The absence of emerging vegetation and the small number of submerged plants in the Northern basin can be partly explained by its steep shores. Together, the Northern and the Ponte-Tresa basins only account for 19% of the total vegetation (Table 3). The complete absence of submerged plants in the Ponte-Tresa basin offers evidence of the extremely unfavourable trophic conditions.

The trophic conditions increase gradually from the Northern, then South-West, and finally in the Ponte-Tresa region near the emissary. It is more difficult to show evidence of such a gradient from the abundance of macrophytic vegetation, because of the strong influence of the nature and slope of the shore on the colonization by plants.

Three main factors interact to limit the macrophytic vegetation:

- the very steep slope of the shores (often very narrow banks)
- the texture of the substrate (mainly stony and rocky)
- the trophic conditions of the water, confining the macrophytes to the first 3 or 4 meters (due to insufficient light penetration).

The depth of colonization (Table 4) gives a good overall indication of the degree of water-eutrophication and the resulting phytoplanktonic development.

The maximal depth of macrophytic colonization reflects the trophic gradient more accurately than the vegetation abundance.

Table 3. Percentage of macrophytic vegetation in the different basins of Lake Lugano

Abundance (%)	Lake Lugano	North Basin	South Basin	Ponte-Tresa Basin
emergent vegetation	35	0	29	6
submerged vegetation	65	13	52	0
Total:	100	13	81	6

Table 4. Evolution of maximal depths reached by macrophytes in Lake Lugano

	Observations by Steiner (1912) depth (m)	Observations 1980 depth (m)	
		average	range
Northern basin	10	5	1 to 8
Southern basin	4.5	3	1 to 6
Ponte-Tresa basin	4.5	2.5	1 to 3

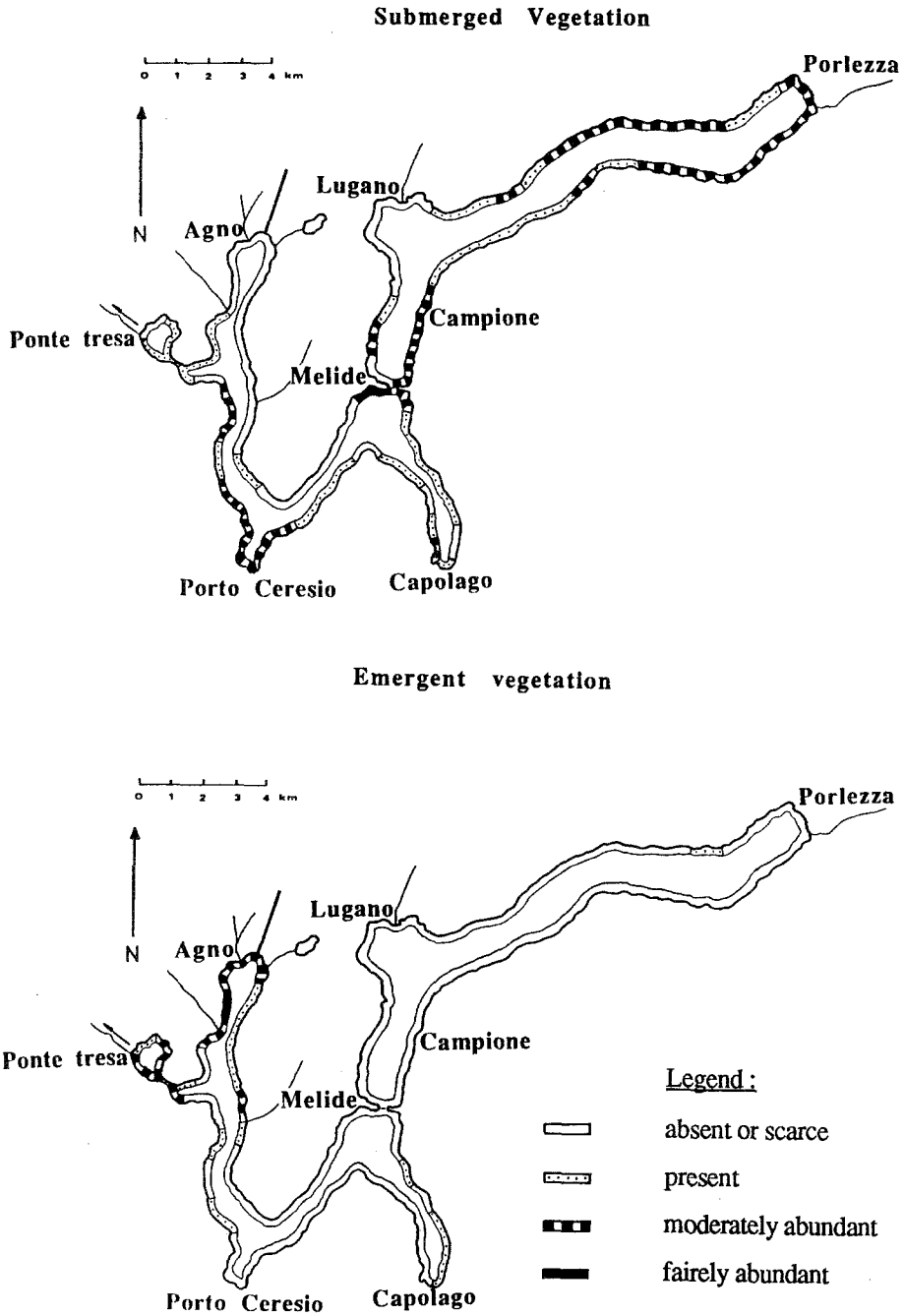


Figure 1. Distribution of abundance of macrophytic vegetation in Lake Lugano in 1980

3.2.2. Evolution of macrophytic vegetation of Lake Lugano

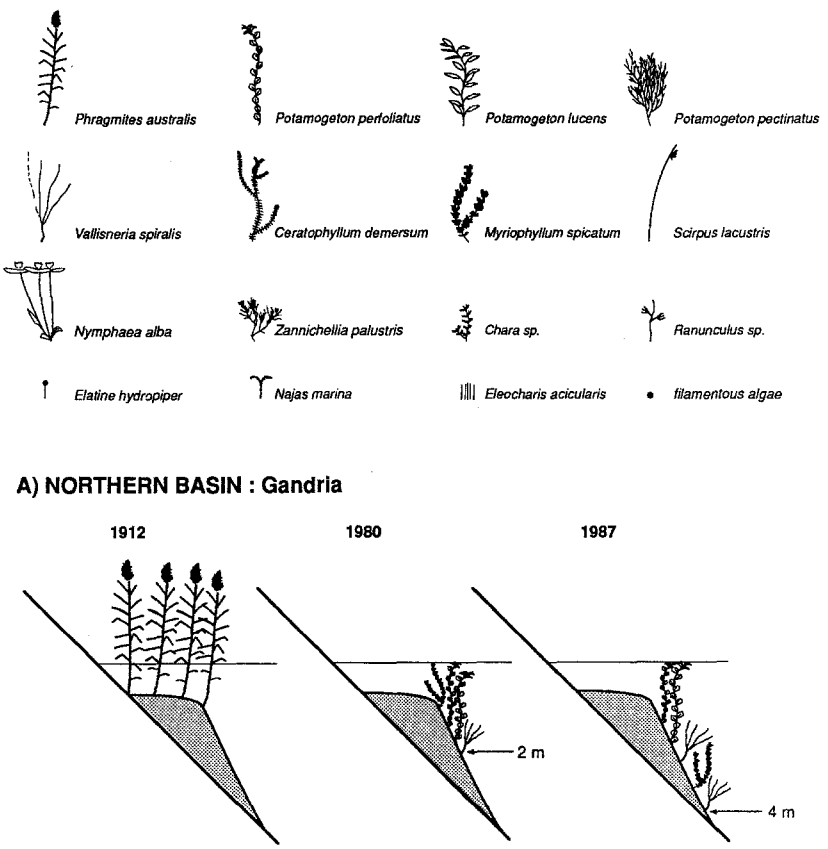
The quantitative evolution of plant communities in different areas was estimated by comparing the vegetation profiles discribed by Steiner in 1912 with the profiles established during the 1980 and 1987 surveys.

These profiles concern more or less extended areas of shores. Therefore, they have to be regarded as synthetic representations of the vegetation for these areas rather than as the result of a phytosociological study of profiles.

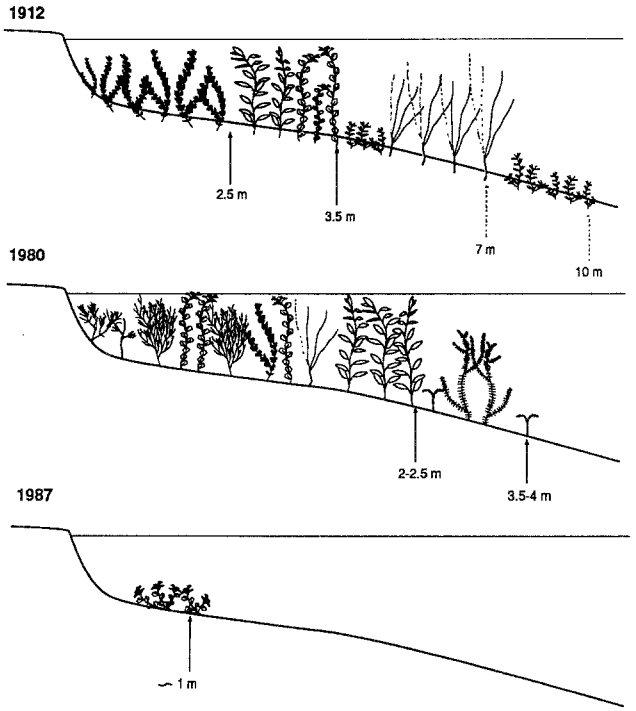
The schematic shore topography given by Steiner (op. cit) was used for the description of the present state. However, it is probable that the shoreline has changed since the beginning of the century, especially because of man-made transformations (the Melide dam, for example).

Figure 2 shows examples of the vegetation changes in three areas of shores belonging to different basins (only the dominant species are represented).

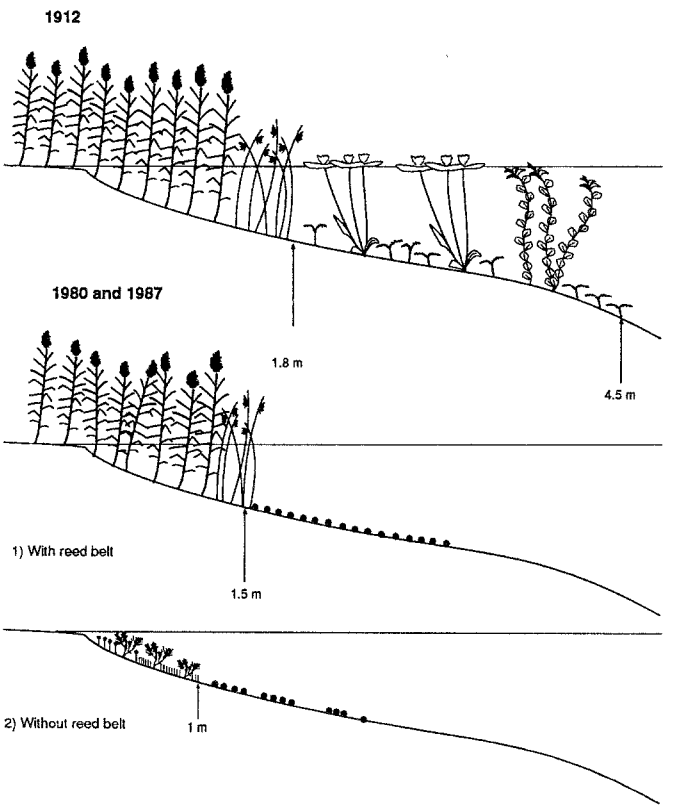
Figure 2. Evolution of the aquatic vegetation in three areas of Lake Lugano since the beginning of the century (only dominant species are represented):



B) SOUTHERN BASIN : Melide



C) PONTE-TRESA BASIN : north shore



The comparison between past and recent profiles reveals the following evolution:

- Some species have decreased considerably (*Phragmites australis*, *Scirpus lacustris*, *Potamogeton lucens*); some have almost completely disappeared (*Nymphaea alba*, *Characeae*) while others are new to the area (*Zannichellia palustris*).
- In the past, the distribution of the aquatic vegetation was more homogeneous. Wherever the topography of the shore would allow, the communities spread out more or less continuous belts, depending on plants requirements and on water depth. In 1980, and even more in 1987 – as far as can be estimated on the basis of only a few profiles –, only traces of these structures remain, consisting of either narrow ribbons, small stands or isolated patches.
- A very clear bathymetric decline of the macrophyte colonization – especially by Charophytes – has been noted in all three basins (Table 4), although past observations, which were made only from the lake surface, probably underestimated the maximum colonized depth.
- All the profiles show an important decrease in the area covered by submerged vegetation and its density. This evolution is particularly important between 1980 and 1987, especially in the region of Melide, where only a few poorly developed specimens of *Potamogeton perfoliatus* still subsist.

4. Discussion and conclusions

The comparative analysis of macrophyte surveys at two different trophic states – oligotrophic in 1912, and, depending on the basin, eutrophic to hypertrophic in 1980s –, reveals the influence of eutrophication on the macrophytic flora and vegetation of Lake Lugano.

The important decrease in the floristic diversity, added to a strong decline, and in some cases, the complete disappearance of the submerged vegetation, are the principal effects of eutrophication on the macrophytes. This evolution is in agreement with what is already known about the influence of eutrophication on aquatic vegetation, and has also been observed recently in numerous Swiss lakes subject to accelerated eutrophication (Burgermeister and Lachavanne, 1980, 1984; Juge et al., 1985; Lachavanne, 1985; Lachavanne et al., 1986a and 1986b; Lachavanne et al., 1989).

In 1980, the abundance of macrophytic vegetation in Lake Lugano was very low compared to that of other Swiss lakes. For Lake Lugano, the average abundance index I_V [1] amounted to only 17 per kilometer of shore, compared to 47 for the eutrophic Baldeggersee (1980), 229 for Sempachersee and Halwillersee (1978), 387 for Greifensee (1977), 776 for Pfäffikersee (1977), 1774 for Lake Morat (1976), and even 2719 for the Lake of Neuchâtel (1979).

This extremely low index can be related to the generally unfavourable conditions of the shores for the colonization by macrophytes (narrow banks, coarse substratum, artificial shoreline), but even more to the very high trophic conditions which, in some areas of the lake, have exceeded the level submerged vegetation can accept.

[1] I_V = colonised area S (m^2) × density of the vegetation (expressed as an index between 1 and 5).

The factors responsable for the decline of submerged macrophytes in eutrophic lakes are the result of both the proliferation of phytoplanktonic and periphytic algae – such as shadowing or competition for nutritive elements – and the substratum enrichment in organic matter.

The decrease of total phosphorus concentration in the lake superficial layer (0–20 m of depth, after the circulation period), – shown by Barbieri et al. in 1989 –, did not influence the macrophytic vegetation growing in the different basins of the lake.

With a total concentration in phosphorus decreasing from 99 to 67 mg P tot./m^3 between 1981 and 1987, there has been a general improvement in the state of the Northern basin. This is witnessed by the decrease in phytoplanktonic production (Polli and Simona, this issue) followed by the increase in the depth of macrophyte colonization (from 2 to 4 meters because of better light conditions, Fig. 2A).

On the other hand, despite the decrease in the concentration of total phosphorus in the Southern basin (from 139 to 117 mg P tot./m^3 between 1981 and 1987), the decline of the littoral vegetation has persisted, to the extent that most submerged plant communities have disappeared almost completely.

The lack of positive response of macrophytes to the decrease of phosphorus in the Southern basin can be explained by the still very high concentration in phosphorus (117 mg P tot./m^3) and by the fact that trophic conditions in the littoral water can be locally much worse than in the pelagic waters. These conditions can be caused by various uncontrolled pollution sources (houses unconnected to the sewage network, overflor of storm water in the sewers, etc).

Whatever the case, the decrease in phosphorus concentration which began during the past decade, is not yet sufficient to enable the development of normal macrophytic vegetation, with its different biological types, in particular, the submerged ones.

The evolution of the macrophytic flora and vegetation of Lake Lugano has consequences on the whole lake ecology. Indeed, macrophytes play a fundamental ecological role for numerous animal species in the littoral zone (habitat, shelter, feeding and reproduction), and only a drastic fall in the water trophic level will allow the littoral ecosystems of Lake Lugano to be restored in their structural and functional integrity.

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