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LIMNOLOGICAL ASPECTS OF SICILIAN RESERVOIRS: A COMPARATIVE, ECOSYSTEMIC APPROACH

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ABSTRACT

This paper is a report on the state-of-the-art of reservoir limnology in Sicily, the largest island of the Mediterranean Sea. The territory is characterised by a semi-arid climate with a dry and a wet semester occurring in the year. Evaporative losses are strong during the summer and, on an annual basis, they often exceed precipitation. Thus, reservoirs constitute an important water resource for the island to supply drinking water and to provide for agricultural needs in the periods of drought. However, despite their importance, they receive poor attention from the scientific and political communities and in the absence of any environmental policy or suitable territorial planning, their water quality is undergoing a rapid decline, principally due to the inadequate treatment of urban waste waters and to the excessive and irrational spreading of fertilizer. The convinction that reservoirs may differ significantly from lakes and the necessity to better understand what rules drive the functioning of these environments, were the engine to carry out several limnological investigations on these artificial environments with special reference to their pelagic compartment. The principal characteristics of these water bodies lie in their peculiar hydrological cycle. The absence of precipitations during summer, when the reservoirs are intensively used, and their re-filling in winter without any outflow contribute to water-level fluctuations which interfere with their thermal structure, underwater light climate and nutrient dynamics. The structure of phytoplankton assemblages is, in the absence of a severe nutrient limitation, modulated by hydrological forcing. In addition to these "bottom-up" effects some "top-down" ones, also mediated by the water-level fluctuations. These involved the strength of predation pressure exherted by fish on zooplankton assemblage. Ultimately, it has been demonstrated that these water movements influence the structure of these ecosystems profoundly and their effects have to be carefully considered when management procedures have to be developed.

Key words: reservoirs, Sicily, nutrient dynamics, phytoplankton, zooplankton.

INTRODUCTION

Sicily, comprised between 36°40' and 38°15' of latitude N, establishes one of the south borders of the European continent. This region, as many southern zones of the North hemisphere (Wetzel, 1990), is subjected to a climate with strong evaporative losses, which generally are greater than precipitation. Schematically, a dry and a wet semester occur during the year and the availability of surface water resources is further reduced by frequent droughts. Consequently, the problem of water supply for public uses, both all the year round and to accumulate enough water to go through periods of long drought, is not a recent event; actually, as far back as the 9th century, during the Arab age, a great effort was spent to build huge underground reservoirs to collect the winter rains. Many of those hydraulic works kept on providing drinking water to the main towns until the last century.

A strong increase in population density in the 1950s and the need for a more general economic development compelled the Regional Government to plan and carry out the construction of several dam reservoirs. The reservoirs were planned to accumulate the amount of water needed to meet the demand, but without any consideration about the quality of the stored water. This effort is still not completed; nevertheless, 30 reservoirs were constructed in the last forty years with the purpose to collect about $850 \cdot 10^6$ m^3. However, climatic, geomorphological and management problems slowed down the original plans and only $500 \cdot 10^6$ m^3 are today available to meet the multi-use demands of the region and its increasing needs for municipal drinking water, industrial water supply, irrigation, hydroelectric power generation and recreation.

Although a relatively small amount of water, compared to that of lakes and reservoirs located in the rest of Italy (Marchetti *et al.*, 1992), constitutes the superficial hydric reserve of the island, scientific and politic communities should devote more attention to this vital resource because of its social and economic importance. Unfortunately, water issues are widely distributed among regional drinking, electric, mining, agricultural agencies and the Ministry of the Environment, and freshwater management is primarily seen as an engineering problem of storing, pumping and distributing water (Naselli-Flores *et al.*, 1993) rather than an as environmental problem. In addition, the insularity of the region has centered Sicilian economic development on the exploitation of marine resources, both as fishing and as touristic resorts. This contributed to identify the terms aquatic-ecology and water management with marine-ecology and coast protection, focussing on these topics the attention of both the "ecologically-oriented" mass-media and of the scientific and political communities.

Thus, despite the fact that the first dam reservoir was built in 1923, only during drought emergencies reservoir ecology has received a certain impulse. In particular, a limnological investigation was carried out seasonally in 1987/88 (Calvo *et al.*, 1993) on all the Sicilian water bodies with a surface area greater than 0.2 km^2. The main objective of the research, committed by the Sicilian Regional Government, was to determine if the trophic conditions of the reservoirs were compatible with the use of the water resource. This study opened the way to further investigations on the limnology of the reservoirs, and in particular on the dynamics of their phyto- and zooplankton assemblages which revealed how these highly dynamic ecosystems may represent an open-air laboratory for better understanding the functioning of the pelagic environments.

In this paper, the limnological investigations carried out until now on Sicilian reservoirs are summarised together with the attempt to highlight their similarities and particularities when confronted with man-made aquatic environments of other mainland semi-arid zones.

MORPHOLOGICAL AND HYDROLOGICAL FEATURES

Sicily covers an area of about 25,700 km^2, forming the largest island in the Mediterranean Sea and one of the most densely inhabited (5.5 million people) regions of Italy. From a geological point of view the island may schematically be divided into two areas. The Northern zone, formed by a chain of mountains which cross the region from east to west, is characterised by numerous structural units in overthrust, mainly dolomitic and carbonate, and by metamorphic rocks; the Central and Southern zone is made up for the most part of carbonate rocks which, after the tectonic phase of the Middle Miocene, were first covered by sediment and evaporites of the Messinian and later by alluvial deposits, forming a large interior upland.

About 30% of the island is mountainous; hills constitute 50% of the whole territory and plains, distributed along the coasts and the river valleys, represent the 20% of the surface area.

The climate is tipically Mediterranean with a rainy period concentrated in 50-70 rainy days in the autumn-winter season, whereas spring and summer are characterised by a nearly complete drought. A strong annual variability (70%-80%) in the amount of rainfall is recorded, with the occurrence of cyclic periods of drought (Mosetti, 1996). The rainfall events in the drier years occur in the form of concentrated storm fronts with a short duration in time but with an exceptional intensity and a strong erosive impact. On the contrary, in the more rainy years the duration of rainfall covers a longer period of time and its intensity is generally sensibly lower.

With the exclusion of Mount Etna and the northern mountain chain, the average annual rainfall, recorded over a period of 65 years, ranges between 500 and 750 mm with minimum values on the southern coast (370 mm). Average temperature varies from 16°C to 18°C; the coldest month is January, but temperature rarely drops to 0°C. The hottest month is July with temperature values generally well above 30°C.

With regard to climatic and morphological characteristics, the drainage network is mainly formed by numerous, short, torrent-like rivers. The annual average volume of water which flows in the drainage network or infiltrates into the subsoil feeding the underground basins is about $6 \cdot 10^9$ m^3. Approximately $1.5 \cdot 10^9$ m^3 of water are utilized annually, of which $0.5 \cdot 10^9$ m^3 for domestic and industrial uses and the rest for the irrigation of cultivated land. The groundwater contributes about 10^9 m^3, the rest being provided by the reservoirs.

Table I shows the main morphological characteristics of Sicilian reservoirs, referred to their maximum holding. Their catchment areas, ranging between 20 and 577 km², are in the 65% of the cases less than 100 km².

Table I Morphological features of Sicilian reservoirs. *AD*: catchment area; *A*: surface area; *V*: volume; *Z*: maximum depth; *z*: mean depth; *P*: perimeter; *DL*: shoreline development.

Reservoirs	AD km²	A km²	V 10^6 m³	Z m	Z m	P km	DL
Ancipa	51	1.1	28	70	25	6.0	1.6
Arancio	138	3.4	33	29	10	14.2	2.2
Biviere di Gela	71	1.2	6	8	5	6.3	1.6
Castello	81	1.8	18	41	10	7.5	1.6
Cimia	70	0.9	7	29	8	5.5	1.6
Comunelli	82	0.9	6	27	7	5.0	1.5
Dirillo	118	1.1	20	46	18	7.8	2.1
Disueri	239	0.6	2	6	3	3.0	1.1
Fanaco	46	1.5	19	49	13	6.8	1.6
Furore	38	1.1	7	22	6	7.2	1.9
Gammauta	69	0.3	2	20	7	3.5	1.8
Garcia	204	5.9	60	43	10	16.0	1.9
Gorgo	45	0.6	3	11	6	3.6	1.3
Nicoletti	50	1.8	17	36	9	10.2	2.1
Ogliastro	468	14.0	124	42	9	29.0	2.2
Olivo	60	1.2	10	45	8	5.1	1.3
Piana degli Albanesi	38	3.1	25	34	8	13.5	2.2
Piano del Leone	22	0.6	3	27	5	5.0	1.8
Poma	164	6.1	68	46	11	15.2	1.7
Pozzillo	577	7.7	140	50	18	21.3	2.2
Prizzi	20	1.3	8	44	6	6.7	1.7
Rosamarina	500	5.5	121	75	22	16.1	1.9
Rubino	41	1.1	10	26	9	8.4	2.3
San Giovanni	80	2.3	15	30	7	11.5	2.1
Santa Rosalia	87	1.3	20	38	15	8.0	2.0
Scanzano	27	1.7	16	31	10	8.6	1.9
Trinità	190	2.4	18	21	7	9.5	1.7
Vasca Ogliastro	32	0.5	4.0	18	8	2.5	1.0
Villarosa	102	1.3	10	28	8	7.5	1.9

Lake surfaces only in one case exceed 10 km² and they are generally less than 2.5 km². Six reservoirs, with a volume ranging between $60 \cdot 10^6$ and $140 \cdot 10^6$ m³ store the 62% of the total impounded water of the island. About $300 \cdot 10^6$ m³ are divided in the remaining 23 reservoirs which have a capacity generally lower than $25 \cdot 10^6$ m^3. However, these values, due the variability in the intensity and duration of the rainy period, are rarely attained (Figure 1). Altogheter, only about $500 \cdot 10^6$ m^3 are stored every year and only a few lakes may reach their maximum capacity. In addition, an intense drawdown, due both to the intense summer use of water for irrigation and for drinking purposes and to strong evaporative losses (Figure 2), characterises the reservoirs causing strong intra-annual variations in volume, surface area and depth (Barone *et al.*, 1993). The effects of water losses, which may reach the 95% of the initial water reserve, are particularly evident in autumn, before the beginning of the new rainy season, when the water bodies lie at minimum holding (Naselli-Flores & Barone, 1994).

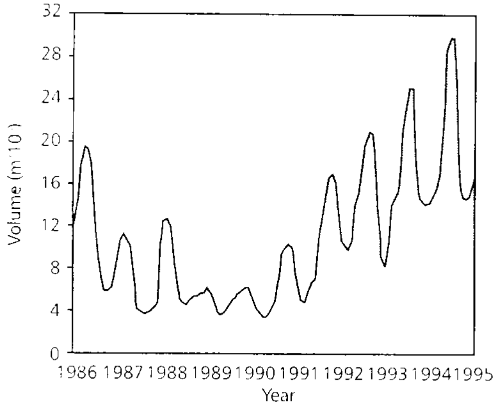


Figure 1 Seasonal variation of the volume stored in the Arancio Reservoir in the period 1986-1995.

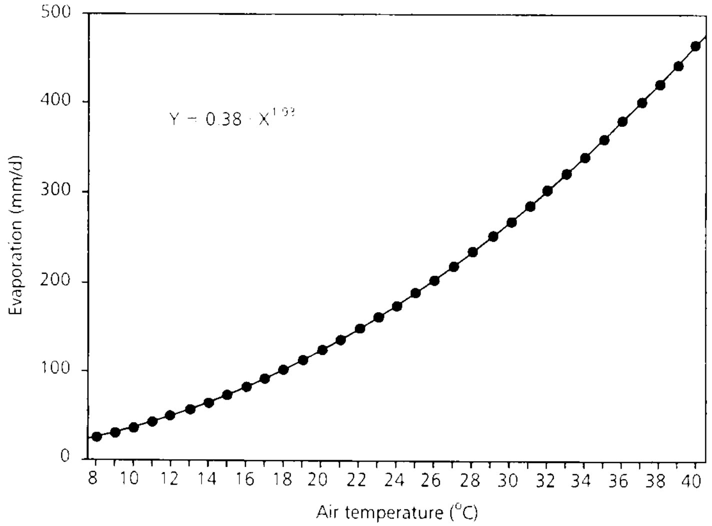


Figure 2 Evaporative losses in Sicilian reservoirs calculated according to Barone *et al.* (1993).

A simplified pattern of the hydrological cycle in the Sicilian reservoirs shows four stages, roughly corresponding to the seasonal intervals: a filling phase, from mid-November to March; a maximum level phase from April to May; an emptying phase from June to mid-September and a minimum level phase from mid-September to mid-November.

The variation in water level between the maximum and minimum phase was observed to cover a height interval of more than 15 m; this event may leave dry more than 500 m of lake bottom all around the reservoir perimeter (Figure 3) not allowing the growth of any aquatic vegetation along the shores.

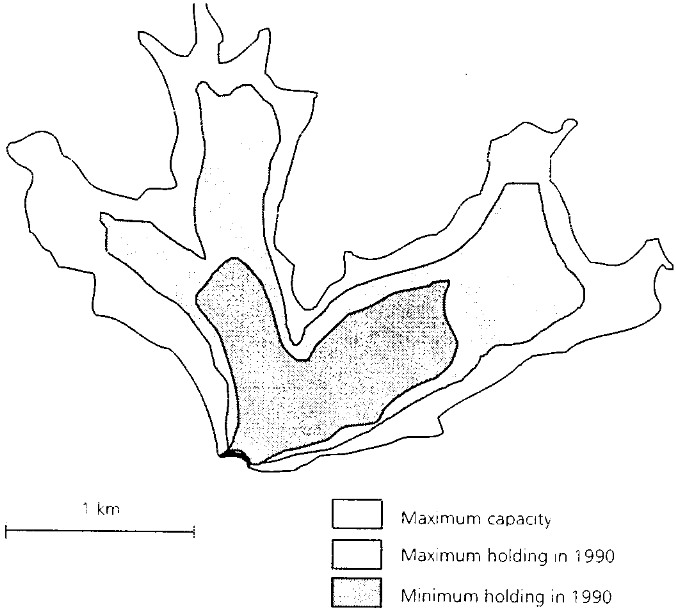


Figure 3 Map showing the surface of the Arancio Reservoir at its maximum capacity and the maximum and minimum limit reached in 1990.

As stated by Straškraba *et al.* (1993), there is a need to understand how reservoir ecosystems couple with hydrological processes. These authors identify retention time as one of the most useful hydrological parameters in reservoir limnology, especially for deep stratifying water bodies, and as an important expression of limnological differences between reservoirs in a given geographic area.

Most Sicilian reservoirs start their hydrological cycle as deep stratifying water bodies and in a short time they become shallow circulating ones because their outflows are not balanced by any inflow. Thus, the concept of water residence time in these reservoirs is a difficult one, because of the disparity between inflows and outflows and the interannual variations in stored volumes; it means that the values of this parameter calculated on an annual inflow basis may show a wide range of fluctuation. In addition, these environments are characterised by inflows and outflows separated in time;

calculations based on a monthly basis may result in infinite residence time values when there is no inflow and/or no outflow.

Although the climatic features and the hydrological cycles to which these water bodies are subject fit well with those highlighted by Thornton & Rast (1993) for the reservoirs in the semi-arid zones of the world, they show quite different morphological characteristics (Table II).

Table II Comparison of limnological data gathered in Sicilian reservoirs in 1987/88 (Calvo *et al.*, 1993) and in 1996/97 (Naselli-Flores, unpublished) to similar data gathered in other semi-arid reservoirs all over the world (Thornton & Rast, 1993). Median values and interquartile ranges are shown.

Parameter	Units	Thornton & Rast, 1993	Calvo *et al.*, 1993	Naselli-Flores, 1996/97 unpublished
Volume	10^6 m^3	42 < 157 < 346	6.5 < 16.4 < 26.5	—
Area	km^2	5 < 16 < 34	1 < 1.3 < 2.8	—
Catchment area	km^2	426 < 1,281 < 4,264	43 < 71 < 151	—
Max. depth	M	17 < 30 < 49	24 < 31 < 44	—
Mean depth	M	5 < 10 < 20	6.6 < 8.3 < 10.7	—
Area ratio	—	85 < 166 < 1572	34 < 46 < 78	—
Total P	$\mu g \cdot l^{-1}$	20 < 20 < 42	37 < 56 < 82	46 < 74 < 158
Total N	$\mu g \cdot l^{-1}$	80 < 229 < 610	—	—
DIN	$\mu g \cdot l^{-1}$	—	122 < 574 < 1,070	434 < 972 < 1,606
Ortho-P	$\mu g \cdot l^{-1}$	5 < 10 < 20	3 < 5 < 10	8 < 12 < 22
Chlorophyll *a*	$\mu g \cdot l^{-1}$	2 < 4 < 8	3 < 8 < 16	8 < 14 < 22
Secchi disk	M	0.7 < 1.2 < 2.4	0.7 < 1.0 < 1.5	0.9 < 1.6 < 2.2
DIN:SRP ratio		—	22 < 63 < 200	23 < 56 < 115

In particular, their volumes, surfaces and catchment:surface area ratio are one order of magnitude smaller compared to the reservoirs taken in consideration by these authors, whereas they show comparable mean and maximum depth values. In addition, due to the prevailing hilly morphology of the island and to the relative simplicity of the drainage network, they show an almost rounded or slightly elongated form rather than the dendritic one characteristic of most reservoirs, and their shoreline development ratio is generally lower than two.

PHYSICAL FEATURES

Thermal Structure

Operational procedures for agriculture and drinking purposes and climatic and morphometric features greatly influence the limnology of Sicilian reservoirs. Flow events are concentrated in a few winter days and in that period the outlets are not active; conversely, during summer, reservoir waters are intensively used and inflows are totally lacking.

Thus, the water bodies, potentially warm monomictic with temperature values generally ranging between 10°C (January) and 30°C (August), experience a nearly continuous circulation in those years characterised by low precipitations, or anticipate the breaking of the thermocline due to the reduction of depth. Only a few reservoirs (Lake Ancipa, Lake Rosamarina) are deep enough to maintain their thermocline throughout all the summer. Nevertheless, the location of the spillway half way up the dam wall often interferes with the stratification pattern (Calvo *et al.*, 1984) as it was observed also in Brazilian and Spanish reservoirs (Tundisi *et al.*, 1993).

Some investigations carried out on the hypertrophic reservoir Lake Arancio during a low-level period, highlighted the importance of diurnal changes in the wind intensity which allow the occurrence of stratification and destratification sequences during summer. In particular, weak stratification events were recorded on some days in July and August (Barone *et al.*, 1993) due to a lack of wind during the morning; a thermocline, generally located within the first 50 cm of depth, was formed before noon and it disappeared once the wind started blowing. This behaviour was important for biogeochemical cycles of nutrients and permitted a continuous summer release of soluble reactive phosphorus from the sediment in a period without any precipitation and with no external water input (Barone & Naselli-Flores, 1994).

Light Availability

Light penetration in water bodies is generally affected by several factors (see Van Dijk & Achterberg, 1992). In reservoir limnology a particular attention is given to the contribution from the catchment of suspended particles which increase light attenuation and may change its spectral composition. Phytoplankton chlorophyll would relate in linear fashion to attenuation coefficient, following the Beer's Law, if no detritus were present, or if the proportions of the two were constant (Yentsch, 1980). The larger amount of suspended matter in reservoirs, likely due to a general high catchment:surface ratio, derives from the high suspended particulate loads carried by rivers and it causes the occurrence of turbid waterbodies (Thornton & Rast, 1993).

Sicilian reservoirs generally show a quite low catchment:surface area ratio. Anyway, this ratio is susceptible of wide variations due to the variability in the annual degree of impoundment of the waterbodies. This variability leads to some contrasting results. Barone *et al.* (1982), refer a good correlation, in two reservoirs, between Secchi transparency and both chlorophyll *a* and total phosphorus concentrations; on the contrary, Calvo *et al.* (1984) did not find any correlation between the same parameters in another reservoir. The same lack of relationship was observed during the survey carried out in 1987/88 (Calvo *et al.*, 1993), when the degree of impoundement of the reservoirs was very low (Naselli-Flores & Barone, 1994) and a wind-induced resuspension of bottom material was likely to occur, resulting in very low values of transparency. The measures were repeated in 1996/97, when almost all the reservoirs were at their maximum holding and significant relationships were found (Naselli-Flores, unpublished) between the reciprocal values of Secchi disc transparency and the annual average concentrations of both total phosphorus ($r = 0.84$, $n = 30$, $p < 0.001$) and chlorophyll *a* ($r = 0.83$, $n = 30$, $p < 0.001$). In addition, in this last case higher levels of nutrients were recorded (Table II). As reported by Yentsch (1980), eutrophic systems are characterised by less detritus per unit phytoplankton. Moreover, the existence of a relationship between the improvement of water clarity and increasing trophic status is known for reservoirs (Thornton & Rast, 1993). Furthermore, a significant correlation was found by Barone & Naselli-Flores (1994) studying by weekly sampling an hypertrophic reservoir.

Variations in light penetration due to suspended matter were recorded in both Lake Arancio and Lake Rosamarina (Figure 4) during periods of high rainfall (Naselli-Flores, unpublished), nevertheless, these events are generally concentrated in late autumn and winter, when the phytoplankton growth is slowed down by the lower temperature of the water.

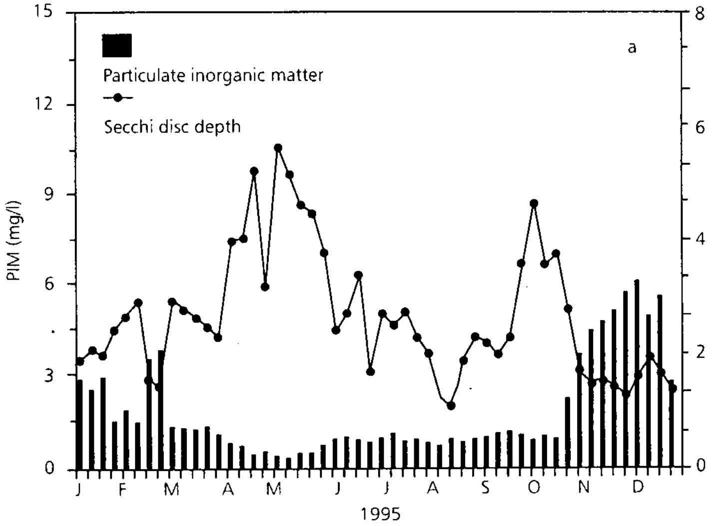
In spring and summer, on the other hand, it may be observed that water-level fluctuations, and especially summer dewatering, strongly interfere with the stratification patterns of these water bodies and with their mixing depth – euphotic depth ratio (Naselli-Flores, 1998); actually, these water movements always result in a deepening of the mixed layer and in an increased mixing depth – euphotic depth ratio. These events generally bring to an optically deep environment with important consequences on the structure of phytoplankton assemblages (Naselli-Flores, 1999).

CHEMICAL FEATURES

Major ions

In accordance with the peculiar climatic and geochemical features of the Sicilian territory and its intense usage for agricultural purposes, the basic chemical composition of reservoir water shows also a wide range of variability. The strong evaporative losses contribute to the increase of the ion concentrations during summer, giving a typical sinusoidal trend (Figure 5) to the conductivity values (Barone & Naselli-Flores, 1994). Figure 6 shows the co-distribution of the major ionic components, as recorded by Calvo *et al.* (1993): the Langelier – Ludwig diagram summarises the main hydrogeochemical features of Sicilian inland waters; each quadrant highlights the different chemical composition of the waters:

A: chloride-sulphate-alkaline waters;
B: bicarbonate-alkaline waters;
C: chloride-sulphate-alkaline-earth waters
D: bicarbonate-alkaline-earth waters.



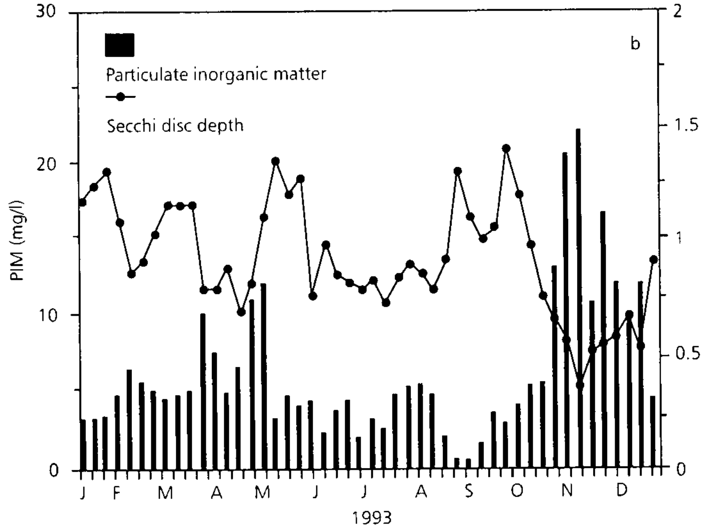


Figure 4 Seasonal trend of Secchi disc transparency and particulate inorganic matter in the mesotrophic Rosamarina Reservoir (A) and in the hypertrophic Arancio Reservoir (B).

On the whole, the reservoirs show high values of dissolved salts, comparable to those recorded by Margalef *et al.* (1976) for eastern Spanish reservoirs.

Most of the reservoirs fall into the C quadrant due to the presence of extensive outcrops of evaporites in their catchment area. The water bodies belonging to this group show ionic sequences characterised by $Na^+ > Ca^{++} > Mg^{++} > K^+$ and by $SO_{4^-} > Cl^- >$

HCO_3 and conductivity values ranging between 1.0 and 3.0 mS · cm^{-1}. They are assimilable to the Spanish reservoirs described by Armengol *et al.* (1991) as reservoirs with sulphate waters and are rather sensitive to eutrophication processes. Actually, when stratification occurs, the hypolimnetic reduction of SO_4 to H_2S removes the iron coupled with phosphate from the sediment (Barone *et al.*, 1982). Phosphate remains in solution whereas the iron precipitates as FeS_2, thus enhancing eutrophication processes.

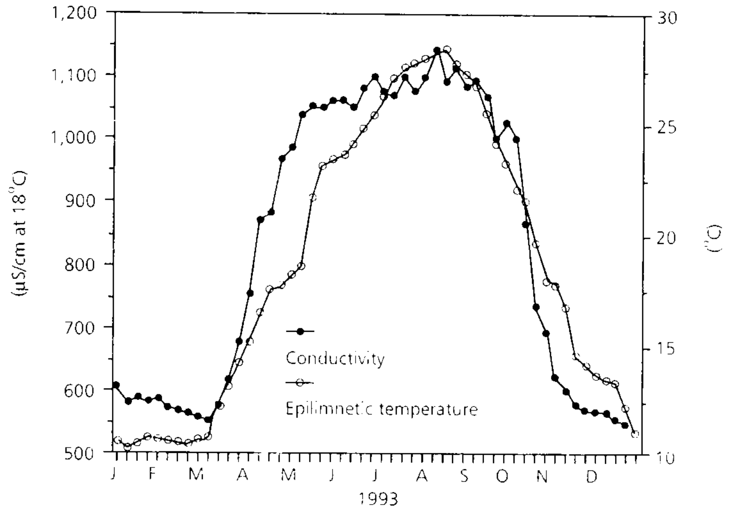


Figure 5 Seasonal trend of conductivity and epilimnetic temperature in the Arancio Reservoir.

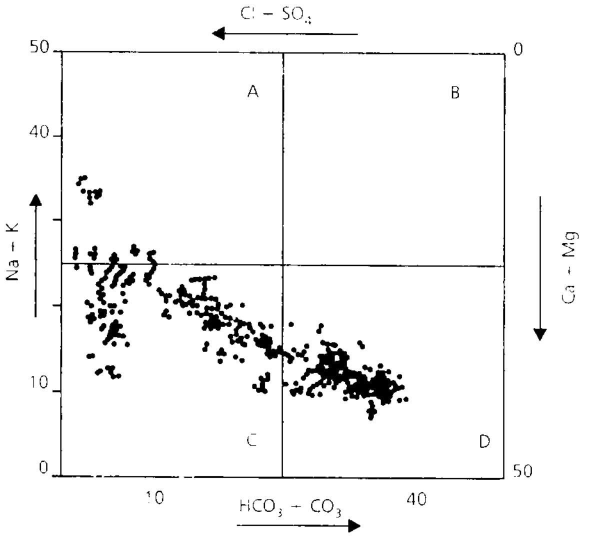


Figure 6 Langelier-Ludwig diagram showing the principal anions and cations expressed as a fraction of the total of each in meq · l^{-1}. (From Calvo *et al.*, 1993.)

The reservoirs located in the Northern zone of the island are comprised in the D quadrant and their conductivity values generally range between 0.5 and 1.0 mS · cm^{-1}. In these waters calcium always dominates the cationic sequence and bicarbonate generally dominates the anionic sequence in autumn and winter; moreover, a prevalence of sulphate may occur in summer. The ionic composition of these water bodies is similar to that highlighted for Spanish reservoirs with bicarbonate waters. In these environments, as described by Armengol *et al.* (1991), summer hypolimnetic production of H_2S is not accompanied by phosphate release from the sediment since it tends to precipitate with Ca in form of hydroxyapatite (Calvo *et al.*, 1984).

Only Lake Gorgo lies in the quadrant A; its catchment covers a sedimentary area with accumulation of evaporitic minerals and the reservoir is consequently characterised by a high content of dissolved salt; it shows high conductivity values (> 5 mS · cm^{-1}) and its cationic sequence is dominated by sodium (33 meq · l^{-1}) and the anionic one by chloride (35 meq · l^{-1}).

Algal Nutrients, Total Nitrogen and Total Phosphorus

Sicilian reservoirs receive high phosphorus and nitrogen loadings (Barone *et al.*, 1986) essentially due to the inadequate treatment of urban waste waters and to the intense agricultural activities in their cathcments. All the island reservoirs lie in the upper part of the trophic spectrum and show high values of total phosphorus; moreover, a general increase in its concentration was recorded in the water bodies less than ten years after the first survey (Table II).

Total nitrogen values are only available for two reservoirs, one hypertrophic (1,578 < 2,520 < 2,878: Barone & Naselli-Flores, 1994) and the other one meso-eutrophic (971 < 1,120 < 1,259: Naselli-Flores & Barone, 1998). Their median values and interquartile ranges, as well as those of total phosphorus, are sensibly higher than those reported for reservoirs of the semi-arid zone; actually, dissolved inorganic nitrogen (DIN) values by themselves are comparable to total nitrogen concentrations showed in Thornton & Rast (1993). Neverthless, in the above mentioned hypertrophic reservoir, the DIN:SRP ponderal ratio indicated a nitrogen limitation *sensu* OECD (1982) in summer periods, due either to a nitrogen decrease and to a phosphorus release from the sediments. However, inorganic nitrogen could not be actually limiting phytoplankton growth patterns or rates in those periods, when its absolute concentrations never decreased below 100 μg · l^{-1}.

With regard to SRP, Calvo *et al.* (1993) highlighted a much lower orthophosphate concentration for a given level of total phosphorus than that reported by OECD (1982). On the average, similar lower proportions (SRP < 20% of TP) were found by Naselli-Flores (unpublished) in 1996/97. This seems to be a common feature in the semi-arid reservoirs and reveals a higher particulate phosphorus concentration in these waters (Thornton & Rast, 1993).

From the analysis of nutrient trends of Sicilian reservoirs, both those available on a weekly basis and those coming from seasonal surveys, it is possible to see how the dynamics of dissolved inorganic nutrients are generally related to the degree of impoundement of these water bodies. A schematic pattern (Figure 7) following two alternative ways may be outlined:

1. Low water seasons: the water bodies generally do not reach a sufficient depth to form a stable thermocline. Calvo *et al.* (1993) recorded a strong depletion of nitrate in the whole water column and an increase of ammonium during summer. These authors also refer that in these low-water periods, smaller average concentrations of SRP are generally available in the water column mainly due to the presence of particulate matter which causes the adsorption of the nutrient. Barone & Naselli-Flores (1994) observed the strong depletion of nitrate, but also a sharp increase of SRP and N-NH$_4$ during summer sporadic stratification events in a shallow reservoir, due to a recycling caused by temporary anoxia (Figure 8). These events had a daily duration, developing in the morning and disappearing in the afternoon when the wind started blowing again. The values reached by SRP were otherwise higher than those recorded after the inflow had been restored. Nevertheless, hypolimnetic anoxia was abruptly overcome by the next full-circulation event.
2. High water seasons: the reservoirs tend to stratify. A dramatic summer depletion of nitrate and SRP occur in the epilimnion during summer. The hypolimnetic oxygen saturation generally tends to decrease rapidly as well as pH values, both ammonia and SRP concentrations reach high values (Naselli-Flores & Barone, 1998), and the production of H_2S is common (Barone *et al.*, 1982; Calvo *et al.*, 1984). If the stratification persists the epilimnetic nutrient levels are restored only at the beginning of the rainy season, which generally corresponds to the next circulation period, and the external input is summed to that coming from internal recycling. If the drawdown is intense, the thermocline breaks down in the middle of summer and a rapid phytoplankton growth, supported by the renewed availability of nutrients, generally takes place.

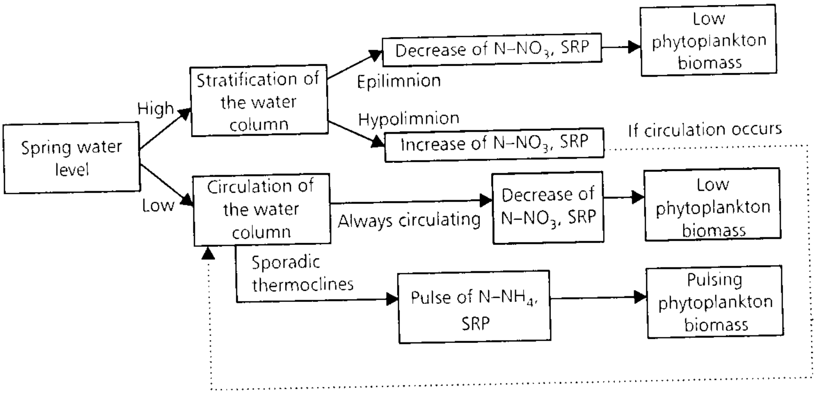


Figure 7 Schematic pattern of the summer nutrient dynamics in Sicilian reservoirs.

Significant differences were found between TP, DIN and SRP concentrations measured in 1987/88 (Calvo *et al.*, 1993) and those recorded by Naselli-Flores in 1996/97. The higher values found in the more recent survey likely depend from the accumulation of nutrients in the water bodies. Actually, despite the results of the first investigation which indicated the waste waters from urban centres as the most important source of phosphorus and nitrogen in the catchments, nothing has been done to reduce the impact of the urbanised areas on the reservoirs.

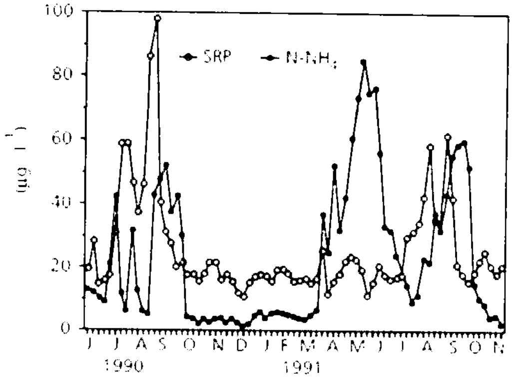


Figure 8 Seasonal trend of soluble reactive phosphorus (SRP) and ammonium (N-NH$_4$) concentrations in the Arancio Reservoir.

BIOLOGICAL FEATURES

In Sicilian reservoirs, because of their remarkable annual fluctuations in water level, those floristic and faunistic assemblages typical of the lacustrine littoral environment do not develop. Macrophytes are generally absent, the shorelines are stony and sandy, and the biological processes are mainly concentrated in the pelagic environment.

Phytoplankton Assemblages

A wide number of investigations have demonstrated that phytoplankton chlorophyll is strictly dependent on the amount of phosphorus present in a given water body (Ryding & Rast, 1994). This functional relationship is generally reported in the power form: $Chl = a \cdot TP^b$. The values of *a* and *b* may depend from the temporal interval taken into account to evaluate them (e.g. annual average values, spring or summer maxima, monthly or weekly values) or by the different composition of the total phosphorus fraction that may exist between regions.

The relationship set by OECD (1982), $[Chl\ a] = 0.28[P]^{0.96}$, has become the term of comparison of almost all the following investigations, due to the strong impact that this study has had on the knowledge and the approach to the phenomenon of eutrophication.

The first studies on phytoplankton dynamics of Sicilian reservoirs were carried out on two eutrophic water bodies (Barone, 1983, 1985). Chlorophyll *a* values and total phosphorus concentrations measured in that occasion were found in good agreement with the relationships found in the OECD study. On the contrary, Calvo *et al.* (1993) found a trophic response in terms of chlorophyll *a* generally lower than that set by OECD when total phosphorus concentration in the water column was lower than 70 μg · l⁻¹ (Figure 9).

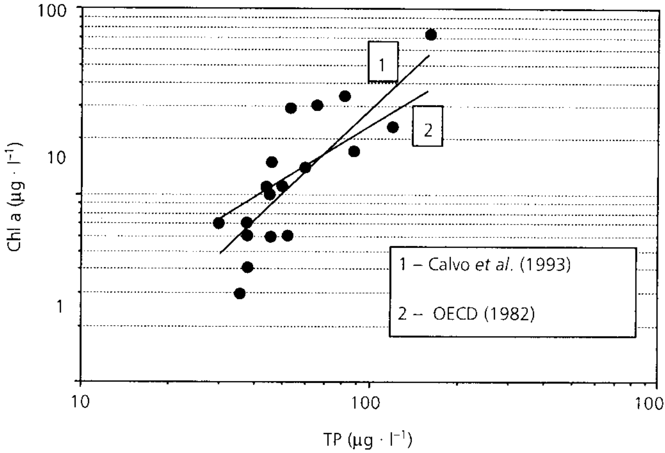


Figure 9 Comparison between the trophic response set by OECD and that found by Calvo *et al.* (1993) in Sicilian reservoirs. (Redrawn from Calvo *et al.*, 1993.)

A constantly lower response in terms of chlorophyll *a* ([Chl a] = $0.24[P]^{0.91}$) was found by Naselli-Flores in 1996/97 (unpublished). Nevertheless, by plotting the SRP-Chlorophyll *a* values found in this survey, and comparing them with the carrying capacity for phosphorus (Figure 10) calculated according to Reynolds (1997), it appears that the quantity of chlorophyll measured in Sicilian reservoirs is very close to the limit imposed by the SRP availability. Thus, as previously observed by Chapman & Thornton (1986), it may be argued that the factors governing the transfer of biologically available phosphorus to primary producers are common in aquatic ecosystems regardless of their climatic characteristics, even though the composition of the total phosphorus fractions may be different.

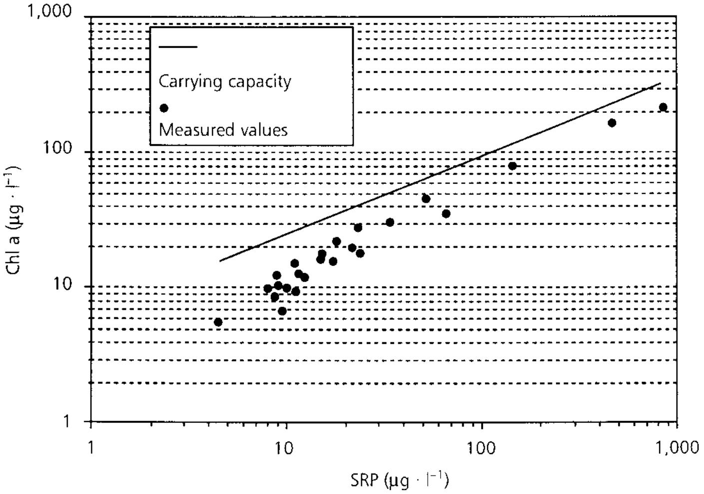


Figure 10 Plot of the SRP – Chlorophyll *a* values in Sicilian reservoirs. The line represents the carrying capacity for phosphorus calculated according to Reynolds (1997).

The quantity of phytoplankton biomass seems a clearly predictable consequence of increased nutrient availability in aquatic ecosystems; on the contrary, the factors governing the structure of the assemblages or the trend of community change rates across a trophic gradient is an open problem in phytoplankton ecology (Reynolds, 1998).

According to Reynolds (1989), a hierarchical sequence of factors, chemical, physical and biological, conditions the structure of phytoplankton assemblages. In Sicilian reservoirs the chemical factors, i.e. the nutrient availability, determine the quantity of phytoplankton biomass, but they are often uninfluent on the structure of the assemblages (Barone & Naselli-Flores, 1994; Naselli-Flores & Barone, 1994).

Reservoirs are subjected to the same external factors, sun, wind and throughflow, as natural lakes (Smith, 1992). There are, however, some differences in the hydroclimate of these environments which influence the ecology of reservoirs. One of the main differences between lakes and reservoirs lies in the fact that the latter are systems in which the management applied generally enhances the role played by physical constraints, offering a good opportunity for investigating their influences in phytoplankton dynamics.

The strength of the hydrological events was sometime considered as one important factor governing the structure of phytoplankton assemblages (García de Emiliani, 1997) and its seasonal cycles (Huszar & Reynolds, 1997). Moreover, as Harris & Baxter (1996) showed through a 16 year-long study on the Australian North Pine Dam, in deep reservoirs in which the seasonal pattern of temperature stratification is strong but modulated by interannual changes in the strength of stratification, irregular hydrological events over-ride the seasonal cycle of phytoplankton biomass yielding irregular patterns of variability.

Probably, these irregularities could be explained as the effect of alternation between the characteristics of deep and shallow lakes within a relative short period of time. In particular, Naselli-Flores (1998) observed that in Sicilian reservoirs the greater the variability is, the higher is the persistence of a large number of rarer, fast-growing species, "ready to develop" when the conditions of the environment become suitable (Padisák, 1991).

Furthermore, it was often recognised that changes in the stability of the water column, in time intervals of about 10 d, are responsible for changes in the composition and maintenance of the diversity (Reynolds & Reynolds, 1985) and that the biomass and the taxonomic composition of the phytoplankton can change in a few days with changes in the mixing layer (Capblancq & Catalan, 1994; Dos Santos & Calijuri, 1998).

Some studies carried out on a weekly basis for several years on Sicilian reservoirs showed that the secondary effects induced by increased nutrient availability (e.g. increased phytoplankton biomass, selective grazing, reduction of euphotic depth and increased z_{mix}/z_{eu} ratio), along with the specific morphology and hydrology of the water bodies, have to be considered important factors in promoting the development of a specific phytoplankton (Naselli-Flores & Barone, 1995).

With regard to hydrology, it is well known that the filling phase may regulate phytoplankton growth through both the dilution effects caused by flooding and the increased nutrient availability (Kimmel *et al.*, 1990). On the contrary, poor attention was dedicated to the effects generated when the reservoir water starts discharging.

Naselli-Flores & Barone (1998), sampling on a weekly basis two reservoirs, observed that the hydrological forcing caused by the drawdown strongly influences the seasonal pattern of temperature stratification and transformes potentially monomictic lakes into polimictic shallow ones, in which the loss rates of organisms by sinking are reduced (Lindenschmidt & Chorus, 1998) and nutrient recycling is enhanced by the easier transfer of shallow sediments into the water column (Reynolds, 1996). In particular, the authors highlighted that the annual variation of volume caused a continuous variation of the mixing zone and consequently of the mixing depth/euphotic depth ratio; they suggested that phytoplankton structure of these environments could be regulated by physical constraints, enhanced by human activity, to which the different water bodies are subjected directly (e.g. morphology and use of stored water) and indirectly (e.g. modifications in underwater light climate caused by increased biomass and/or by deepening of the mixed layer).

In the light of these observations, Naselli-Flores (1999) revisited the data by Calvo *et al.* (1993) on phytoplankton assemblages of Sicilian reservoirs; he noted that some water bodies, which showed a different trophic state, shared very similar assemblages. On the contrary, environments which were ranked, according to OCDE (1982), in the same trophic category could strongly differ in the structure of their assemblages.

The drawdown caused by the intense summer usage, to supply water for drinking and irrigation, did not generally allow in these reservoirs the formation of the thermocline or it anticipated its breaking in early summer. This way, the reservoirs, both those in the upper part of the trophic spectrum, with high phytoplankton biomass and low transparencies, and the mesotrophic ones, with higher transparencies, were subjected to an increase of their mixing depth. The event may be considered equivalent to the contraction of the euphotic depth due to an increase of phytoplankton biomass which generally reflects a shift toward a higher trophic state (Habib *et al.*, 1997).

A modification in the hydroclimate of the reservoirs, despite the trophic characteristics displayed, always resulted in a drastic change in the structure of phytoplankton assemblages (Figure 11). In particular, if circulation was anticipated to early summer, the organisms which formed the spring assemblages (dinoflagellates, cryptomonads) were replaced by phytoplankton species with adaptive mechanisms which enabled them to regulate their buoyancy (gas-vacuolated cyanobacteria), to tolerate unbalanced ($z_{mix} > z_{eu}$) dark/light cycles (*Closterium* spp., *Mougeotia* sp.) or to live on a minimal income of light energy (*Planktothrix* spp.); otherwise, in those reservoirs where water-level fluctuations were unable to influence stratification, the assemblages kept on maintaining the spring structure or followed their "normal" seasonal dynamics. Moreover, some reservoirs characterised by a summer plankton dominated by associations adapted to frequent shading, suffered a dewatering so strong that it significantly reduced their depth; this way they exhibited a decrease in their z_{mix}/z_{eu} and entered the group dominated by dinoflagellates and cryptomonads.

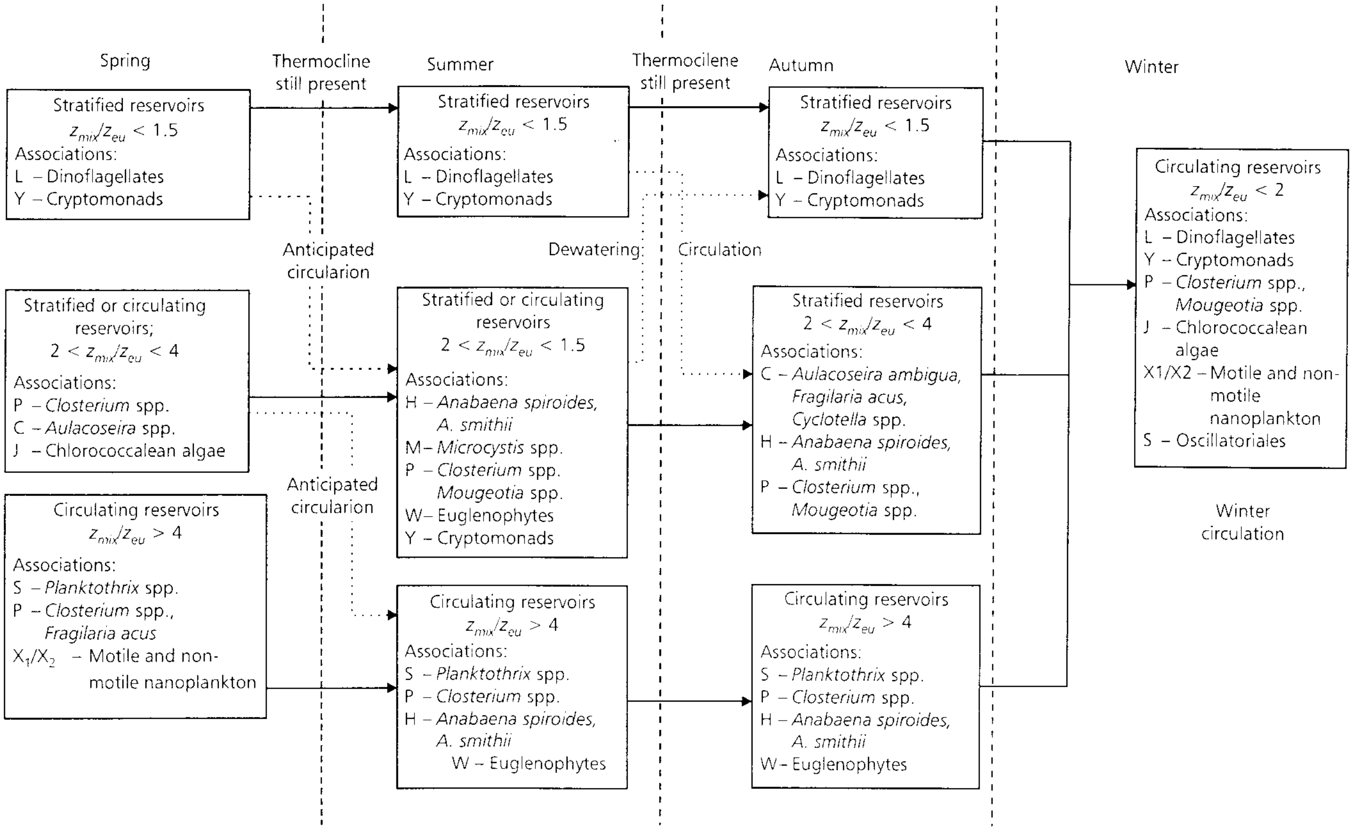


Figure 11 Schematic pattern of the seasonal variation of the structure of phytoplankton assemblages in the Sicilian reservoirs. The associations mentioned are those proposed by Reynolds (1997).

More and more often the patterns of mixing and stratification are indicated in literature as one important factor governing the structure of phytoplankton assemblages. In particular, Dasí *et al.* (1998) identify these patterns as the factor which segregates phytoplankton life-forms in Spanish hard-water reservoirs. Berman & Shteinman (1998) highlighted how mixing can have a critical impact on phytoplankton succession and the population composition of the algal assemblage; moreover, Charpin *et al.* (1998) showed that physical factors that lead to seasonal cycles of mixing and stratification may considerably affect the photosynthetic physiology of phytoplankton through their effects on available irradiance. In addition, Rivkin (1985) observed that the photosynthate partitioning is species-specific in natural populations.

Thus, it could be argued that a change of the mixed layer which influences the structure of the underwater light field may lead to a modification in the structure of phytoplankton assemblages, since the physiological requirements of their species may not be supported by the new underwater light conditions.

Phytoplankton in lakes and reservoirs is exposed to light fluctuations at different time scales; some are irregular and unpredictable as those due to clouding, others are daily fluctuations due to the sinus-shaped course of sunlight, others are seasonal fluctuations. In addition, these organisms are subjected to an exponentially increasing and decreasing irradiance if transported through the mixed layer. Nicklisch (1998) showed that specific growth rates of several species belonging to cyanobacteria, diatoms and Chlorophyceae changed significantly under different time structures of illumination with a balanced dark/light cycle ($z_{mix}/z_{eu} = 1$).

Reynolds (1997) showed how mixing times in natural environments depend on both wind speed and epilimnion depth. Under comparable wind conditions, the variations of the mixing depth – euphotic depth ratio causes a modification in the rate of time that a phytoplanktonic alga has to spend in the dark as it travels in the mixed layer. Thus, if an assemblage is formed by species which maximise their opportunities of growth under a certain rate of time of dark/light cycles, a variation in the ratio between the mixing zone and the euphotic zone may require a special photoadaptation of a given species to enhance its opportunities of growth or, ultimately, it determines its replacement. Actually, it is well known that some phytoplanktonic algae are better adapted than others to well-mixed or turbid environments (Reynolds *et al.*, 1994).

Furthermore, the quality of turbidity has to be considered. In those water bodies characterised only by phytoplankton turbidity, the species with a higher degree of relative entrainment (Reynolds, 1997) will be favoured, since they have a greater probability to remain and travel in the mixed layer and more or less regularly they will be exposed to light. On the other hand, Holz *et al.* (1997) recorded a shift from high phytoplankton turbidity to high sediment turbidity as a response to aging of Pawnee Reservoir. At the same time, its phytoplankton assemblage shifted away from buoyant cyanophytes, toward flagellates, which were able to better avoid the shading caused by sediments and optimize their position in the euphotic zone via active phototaxic swimming.

With regard to the role played by nutrient availability in Sicilian reservoirs, a difference was noted between those water bodies subjected to stronger vertical movements, and those which were not used, or were subjected to smaller water-level fluctuations (Naselli-Flores, 1998). In these environments, which also ranged from mesotrophy to hypertrophy, nutrient availability seemed to play a major role; they maintained their thermocline during summer, more constant values of *zmix/zeu* and showed more stable assemblages during the period of study. Some results, obtained through weekly sampling on two reservoirs, one subject to water-level fluctuations and the other one more stable because not yet used (Naselli-Flores & Barone, 1998), showed that the hydraulic stability of the lacustrine environment suppressed dramatic irregularities in the seasonal cycle of phytoplankton which, in this way, appeared regulated mostly by nutrient availability.

In particular, the polimictic behaviour induced by dewatering may allow the release of nutrients from the sediment and favour summer phytoplankton pulses. Furthermore, Barone & Naselli-Flores (1994) observed that the Shannon diversity function reflects these pulses which generally increase their frequency in those periods characterised by a lower hydrological stability (Figure 12). Thus, they argued that the daily variation in flushing rate may ultimately act as an intermediate disturbance for phytoplankton allowing the coexistence of small edible r-strategists with larger inedible species (see Padisák *et al.*, 1993).

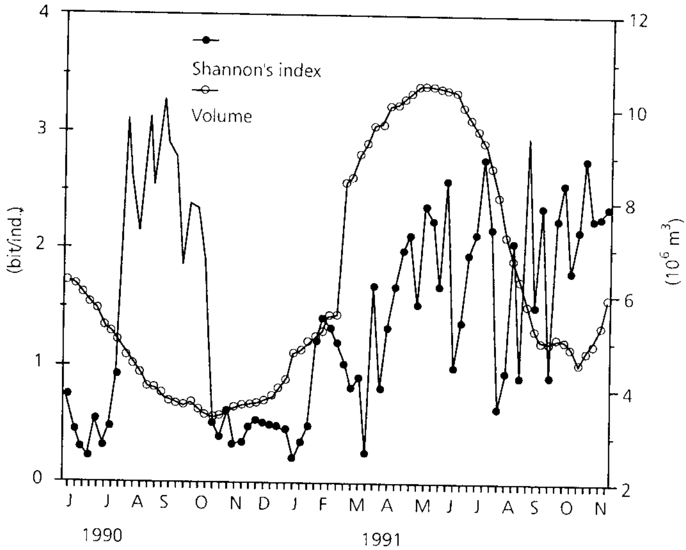


Figure 12 Seasonal trend of Shannon diversity function and stored volume of the Arancio Reservoir.

All the results collected until now on Sicilian Reservoirs suggest the possibility that the influence of nutrients on the structure of the assemblages is higher in the lower part of the trophic spectrum or in those environments characterised by higher water stability during the year. In contrast, as trophic state or the use of stored waters increase, physical parameters are enhanced and become more important in promoting the development of a specific phytoplankton assemblage adapted to the modified physical environment.

Consumer Assemblages

Zooplankton occupies a strategic position in pelagic food webs. The structure of its assemblages depends from predation pressure by fish (Brooks & Dodson, 1965) and it may strongly influence the phytoplankton composition by both selective grazing and nutrient recycling (Carpenter & Kitchell, 1993). Also in this case the factors influencing zooplankton growth, such as food availability, food competition and predation pressure (Ravera, 1996) do not generally differ in lakes and reservoirs, even though it was highlighted that some differences due to the higher turbidity could affect the biological performances of these organisms (Marzolf, 1990).

With regard to fish, it has to be underlined that autochthonous populations in Sicilian inland waters generally comprise river fish able to live also in marine environments. Only a few species present in the island, such as the small blennid *Salaria fluviatilis* and *Salmo macrostigma*, a Mediterranean trout, are strictly linked to freshwater environments. The building of dam reservoirs was accompanied by a massive introduction, uncontrolled and often accidental, of fish species by fishermen. Among these introduced species, the small cyprinid *Rutilus rubilio* was the most successful and it has rapidly colonised many Sicilian freshwater habitats, reservoirs included, resulting now the only species present in some stations where, before, many other species were present (Ferrito & Tigano, 1995). Other species such as *Micropterus salmoides* and *Lepomis gibbosus*, both native to North-America, are registering an increasing success (Naselli-Flores, unpublished).

A study on the distribution patterns of freshwater zooplankton in Sicily (Naselli-Flores *et al.*, 1998) highlighted that the island, from a biogeographical point of view, can be divided into two zones. The north zone appeared to be mostly dominated by Palearctic, Holoarctic and Cosmopolitan taxa (e.g. *Daphnia longispina*, *Ceriodaphnia quadrangula*, *Bosmina longirostris*), with summer development of the Turanic-Mediterranean species *Diaphanosoma lacustris*. The reservoirs located in the central and south zone showed more distinctive Mediterranean distributional patterns of the species with the West-Mediterranean *Copidodiaptomus numidicus*, the Mediterranean *Metacyclops planus* and many thermophilous rotifer species such as *Brachionus falcatus*, *Epiphanes macrourus*, *Keratella tropica*, *Hexarthra mira*.

The presence of warm stenothermous species and the absence of predacious cladocerans may be regarded as typical of tropical regions (see Dumont, 1994). At the same time zooplankton composition of Sicilian reservoirs is characterised by some features common in temperate regions such as the occurrence of a wide number of *Daphnia* s.l. species and the presence of entities typical of higher latitude (e.g. *Cyclops furcifer*, *Kellicotia longispina*). These considerations, along with the recognition of 21 different chorological categories in the zooplankton assemblages, suggest that Sicily represents an area which behaves as an active transition zone for these organisms.

The assemblages of Sicilian reservoirs are most frequently dominated by cladocerans and rotifers. Barone *et al.* (1991) refer a general higher occurrence of large-bodied species in summer and winter and a significant positive correlation between edible phytoplankton and herbivorous zooplankton biomass values. In particular, the dominance of large cladocerans was recorded in those reservoirs that were subject to strong fluctuations in water level (Naselli-Flores & Barone, 1994).

A link between water-level fluctuations, zooplankton dynamics and zooplanktivorous predation pressure was pointed out by Naselli-Flores & Barone (1997) who studied, during a period of three years, the population dynamics of planktonic cladocerans the highly productive Arancio Reservoir.

The investigated water body exhibited values of wet weight phytoplankton biomass generally above 10 mg · l^{-1} with peaks over 70 mg · l^{-1}; the assemblage was generally dominated by large inedible algae (*Closterium* spp., *Mougeotia* sp.). Transparency values were generally below 1 m. A *Daphnia hyalina* population usually started to increase in the winter season, reached its highest density values (30 ind · l^{-1}) at the end of spring and then fairly quickly decreased again. In contrast, population densities in 1991 were high during summer, reaching values above 70 ind · l^{-1} at the end of July.

A strong flooding, which caused a large flow of allochthonous matter, affected the reservoir at the end of winter 1991. In a few days the water body doubled its volume and Secchi depth was reduced to values below 0.25 m in the first half of March. This caused the dilution of the dominant large planktonic algae and allowed the development of small Chlorococcales. Though these taxa were characterised by high growth rates, biomass values remained low for a considerable period causing a long clear water phase with Secchi depth values of about 6 m (Barone & Naselli-Flores, 1994). Apart from the increase of *D. hyalina*, the accumulation of biomass was also limited by the appearance of a *Daphnia magna* population, not present in other years, which peaked in spring.

Along with the density values, also the average body lenght of ovigerous *D. hyalina* significantly increased (Figure 13), passing from 750 to 1,200 μm, as well as the number of their parthenogenetic eggs. All these changes suggested a variation in the predation pressure on the zooplankton assemblage. As a consequence, in the same year the usual August peak of edible phytoplankton, mainly represented by small chlorococcalean algae, was delayed until the autumn when *Daphnia* density was below 3 ind · l^{-1}.

The analysis of the fish of the reservoir showed the dominance exerted by *Rutilus rubilio* (Italian roach), a small cyprinid which constituted over 95% of the fish biomass. Since no secondary carnivores were present in the reservoir, according to Persson *et al.* (1993), the strong predation pressure by planktivores likely caused an increase in zooplankton mortality and preserved phytoplankton from overexploitation.

R. rubilio generally spawns at the beginning of March. In 1991 this event occurred contemporary to flooding and the hatching success and early survival of the fry in that year was strongly decreased.

It has been generally reported that drawdown may seriously damage nursery areas and dry out the eggs (Kubečka, 1993). In some other cases however, it was observed that the increased siltation, associated with the filling of the reservoir, seriously damages the spawned eggs and does not allow the hatching (Hassler, 1970). This way the impact of fry on zooplankton may become virtually absent.

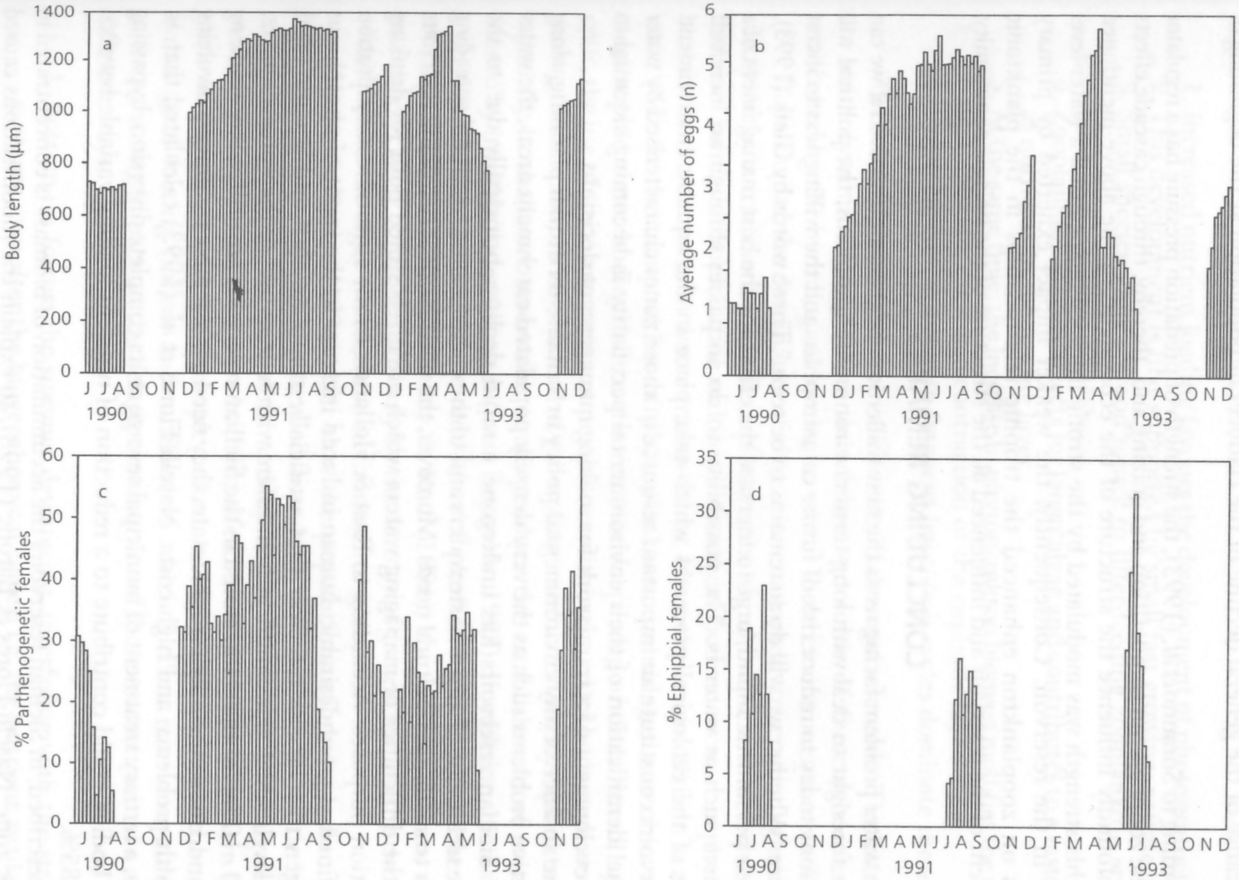


Figure 13 Seasonal variations in average body lenght (a), average number of eggs per female (b), percentage of ovigerous females (c) and percentage of ephippial females (d) in the *Daphnia hyalina* population of the Arancio Reservoir. (Redrawn from Naselli-Flores & Barone, 1997).

Actually, the analysis of the gut content of the fry caught in this Sicilian reservoir demonstrated that *Daphnia hyalina* is the most important prey item in the diet of underyearling *R. rubilio*, whereas the adults feed mainly on detritus and benthic preys; as observed by Zalewski *et al.* (1990) in temperate reservoirs, the fry predation was likely the cause of the general decline of the cladoceran population at the beginning of summer.

According to Soranno*et al.* (1993), the strength of predation pressure has a regulator effect on the zooplankton competition and grazing and, thereby, through cascade effects it may profoundly influence the structure of the ecosystem. In the above-mentioned example, this strength was modulated by the strong inflow which caused a water-level instability in the reservoir. Consequently, the weaker impact exherted by primary carnivores on zooplankton enhanced the trophic relationships in the planktonic compartment of the reservoir and influenced all the structure of the pelagic community.

CONCLUDING REMARKS

"The water problem facing us as the new millenium begins can be solved if we can muster the foresight to deal with long-term environmental problems, the political will to take actions today to reduce risk of future catastrophes, and the willingness to invest in our future. Whether we will do so remains to be seen." These words by Gleik (1993), despite their pessimistic sound, urge to increase the effort for the best management of a vital resource such as water is. The possibility to do so passes through an increased knowledge of the ecological processes which take place in the aquatic environment. Since reservoirs constitute an important resource in those zones characterised by water scarcity, the identification of their environmental peculiarity is becoming essential to plan the development of a framework for making management decisions.

In the absence of any environmental policy or suitable territorial planning, along with objective problems such as the very densely populated catchment areas, the water quality of Sicilian reservoirs has undergone a rapid decline, principally due to the inadequate treatment of urban waste waters and to the excessive and irrational spreading of fertilizer to sustain agricultural needs. Moreover, the multipurpose use of the reservoirs increases the difficulties of managing waters which are often stored both for drinking and irrigation purposes. According to Rast & Holland (1988) cultural eutrophication can be defined as an undesirable, human induced increase in the input of phosphorus and nitrogen to a lake or reservoir that artificially stimulate algal and aquatic plant growth to levels which can significantly interfere with human uses of the water resources. About $200 \cdot 10^6$ m^3 of the water stored in the Sicilian reservoirs are utilized for drinking purposes and, due to their high trophic state, they need considerable treatment, involving public health problems, and high costs. Naselli-Flores *et al.* (1993) calculated that, in most cases, a tertiary treatment of municipal sewage or its complete diversion, bypassing the water bodies, could contribute to a reduction of nutrient loading variable between 40% and 85%.

As described, in Sicilian reservoirs the accumulation of biomass is concentrated in the pelagic zone; Naselli-Flores & Barone (1998), to explain the modifications caused in the structure of phytoplankton assemblages by an increasing trophic state, suggested that the secondary modifications induced by the uprise in nutrient availability, e.g. increased phytoplankton biomass, selective grazing, reduction of euphotic depth and increased mixing depth/euphotic depth ratio, promotes the development of a specific phytoplankton. From a qualitative point of view the process in the pelagic environment could be summarised as follow:

1. Increased nutrient loading favours the development of photosynthetic biomass.
2. This development is first supported by small fast growing, r-strategist algae.
3. Small species supply a food source to filter-feeding zooplankton and cause an increase in animal biomass.
4. Zooplankton grazing selects for larger algae and contributes to a faster recycling of nutrients in the mixing layer.
5. At the same time, the increase in phytoplankton biomass modifies the underwater light climate, causing a contraction of the euphotic layer.
6. Larger species, adapted to frequent light/dark cycles dominate the assemblage.

The scheme proposed can be valid for both lakes and reservoirs. The latter, however, are more dynamic environments than lakes and some of these processes are often accelerated by the hydrological forcing to which these environments are subjected.

In particular, the dominance of large species adapted to frequent light/dark cycles, sustained by a contraction of the euphotic zone should represent an index of "aging" due to an increased trophic state and, consequently, to both an increase in phytoplankton biomass and a decrease in water transparency. Nevertheless, in Sicilian reservoirs the same shift in the composition of phytoplankton assemblages was observed also in mesotrophic water bodies due to the summer deepening of their mixed layer. In this optic, the use of some management procedures within the water body such as epilimnetic mixing (Straškraba, 1996), instead of promoting a reduction in phytoplankton biomass, especially in shallower reservoirs, could produce the establishment of an assemblage formed by inedible ruderal species (*sensu* Reynolds, 1997). In addition, biomanipulation tools directed toward the simple reduction of planktivorous fish could be unfruitful; actually, as suggested by McCauley & Kalf (1981), the overexploitation of primary producers is likely controlled not only by the density of grazers but also by the inedibility of the planktonic algae which these environments select.

Harris & Baxter (1996) refer that the populations of phytoplankton in North Pine Dam (Australia) were influenced over long time periods by subtle interannual changes in hydrographic conditions and by strong hydrological forcing (inflow and outflow) which, in that case, were both manifestations of El Niño Southern Oscillation phenomenon. From all the examples cited in this paper it seems that the cyclic hydrological forcing (inflow and outflow) to which Sicilian reservoirs are subjected, exherts a strong impact on the pelagic community of these environments in at least two different ways:

1. Bottom-up forces: the summer dewatering, interfering with the stratification patterns may alter the biogeochemical cycles, i.e. the nutrient availability, and the underwater light climate of the reservoirs, both of which affect phytoplankton structure and succession.

2. Top-down forces: the spring flooding may interfere with the reproductive success of fish. As a result, predation pressure exherted by fish fry on zooplankton is reduced and, ultimately, it also affects phytoplankton. This last process in Sicilian reservoirs was enhanced by a dilution effect which allowed the development of an "edible" phytoplankton assemblage.

This last observation could lead to a form of biomanipulation through hydraulic regulation by interconnecting reservoirs in pairs. Indeed, in Sicilian reservoirs this network still exists since the Management Boards "decant" water from a reservoir to another in the period of water scarcity or to fill a water body which serves an area where the water demand is more urgent. Opportunely directed, this kind of operation, along with the institution of a territorial planning in the catchment, could become a management tool to improve the water quality in these environments. Moreover, the reversibility of the procedure and its relatively low cost are in agreement with the recommandations set by Straškraba (1996).

Finally, Sicilian reservoirs, due to their morphology, do not show a clearly identifiable longitudinal gradient which allows a division in riverine, transition and lacustrine zones. From the analysis of the seasonal dynamics of plankton, however, which in some way reflect the rapid aging of these environments, they could be defined "high speed lakes" rather than "river-lake hybrids". Their speediness makes this kind of environments particularly helpful to better understand the processes which take place in freshwater ecosystems and to develop limnological theory.

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