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Article · January 1992

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ABSTRACT

The global picture of the main morphometric and water quality characteristics of the 221 Italian reservoirs covering an area of at least 0.2 km² is given. A large part of the reservoirs are used for potabilization purposes, especially on the main islands (Sicily and Sardinia), where the more important cases of eutrophication have been found. Some of these situations are examined in greater detail, both from the point of view of algal population dynamics and from the ones of the phosphorus budget and the comparison between theoretical and experimental nutrients loads.

Key words: reservoir, eutrophication, phosphorus load

1. INTRODUCTION

Hydrobiological studies on Italian reservoirs go back to over half a century ago; in fact, in the 30s certain issues regarding these environments had already been brought into focus (Pasquini 1924; Brunelli 1928, 1930; Parenzan 1937). Around 1950, further studies were undertaken by Ferrero (1953), Cannicci (1955), Facinelli (1955) and especially Sommani (1950, 1952, 1956, 1957), who developed the theme in a very advanced way for the time.

From a geographical, physical and biological point of view, many Italian reservoirs were successively described by other Authors (e.g., Tonolli & Tonolli 1951; Moroni 1961) but it is only after 1960 that this type of research assumed a different profile, with strongly applicational finalities.

This approach is to be linked to the fact that the reservoirs, until then built for hydroelectrical purposes and, in some cases, for irrigation (and therefore not requiring the highest quality standards), in many parts of Italy began to be

P. Guilizzoni, G. Tartari and G. Giussani (Eds)
Limnology in Italy
Mem. Ist. ital. Idrobiol., 50: 337-363, 1992

seen with growing interest as unique sources of drinking water. According to a census undertaken in the 80s by IRSA (Water Research Institute of the National Research Council), among 249 Italian reservoirs 12% are used for drinking purposes, 69% for the production of electricity and 19% for irrigation, with many cases of multiple uses (Gaggino *et al.* 1985).

A first series of studies in this perspective (Bo *et al.* 1968; Marchetti 1968, 1972; Alamanni *et al.* 1971; Cioglia & Figus 1970), was followed by an intense period of investigations stimulated both by the growing social needs and by the Finalized Programmes of the National Research Council, a period which ended with the "Meeting on man made Lacustrine Basins" (Sassari, 4-6th October 1977), which undoubtedly represented a milestone in the deepening of the knowledge in this field (in this respect, see the works by Barbanti *et al.* (1979) on the Omodeo basin; Bo (1979) on the Bidighinzu basin; Marchetti (1979) and Cotta-Ramusino & Rossaro (1979) on the Liscia Reservoir; Calderoni *et al.* (1979) on the Pertusillo Reservoir; Paganelli *et al.* (1979) on the Corlo Reservoir; of Bonomi & Salmoiraghi (1979a) on the Suviana Reservoir.

Starting from the 80s, hydrobiological studies on the Italian reservoirs have intensified, mainly in connection with the worsening of the problem of eutrophication.

2. GEOGRAPHICAL DISTRIBUTION AND MAIN CHARACTERISTICS OF THE ITALIAN RESERVOIRS

A tentative evaluation of the distribution of the main characteristics of the Italian reservoirs can be based on the data collected by IRSA (Gaggino *et al.* 1985), corrected and updated in the most important cases (Tab. 1). On the basis of these results, regarding 221 reservoirs with a surface of more than 0.2 km^2, the geographical distribution is as follows: Northern Italy, 88; Central Italy, 56; Southern Italy, 19; Sicily, 27 and Sardinia, 31. Central Italy includes the administrative regions of Emilia-Romagna, Toscana, Umbria, Marche, Lazio, Abruzzo and Molise. In the case of a large number of reservoirs shown in the table, the surface is not known but, on the basis of large information which need to be verified, is assumed to be equal to or larger than the threshold for inclusion in the census.

Regarding the volumes, data are not available for a number of the minor ones, but the total volume of the remaining more important ones (214) is estimated at about 7.5 10^9 m^3. Considering that the total volume of the Italian lakes (both natural and man-made) is about 140 10^9 m^3, it can be deduced that reservoir waters represent no more than 5%. These volumes (Fig. 1) are distributed in the national territory as shown in table 2.

The bigger part of the volumes enclosed in reservoirs is situated at altitudes lower than 500 m a.s.l.

Tab. 1. Physiographical characteristics of Italian reservoirs with surface >0.2 km^2. P: waters used for potabilization purposes.

RESERVOIRS	Altitude (m a.s.l.)	Lake Area (km^2)	Basin Area (km^2)	Volume (m^3 10^6)	Mean Depth (m)	τ_w (years)
Valle d'Aosta (6)						
Beauregard	1710	10.9	91	72	6.6	-
Cignana	2158	0.7	64.4	16.1	23	-
Inferiore	2542	0.2	7.6	-	-	-
Place Moulin	1969	1.7	137	106	62.3	-
Pietra Rossa	2553	0.7	1.6	-	-	-
Verney	2088	0.2	3.5	19.3	-	-
Piemonte (18)						
Agaro	1597	0.7	11.1	20	28.5	-
Alpe Cavalli	1490	0.6	26	8.3	13.8	-
Camplìccioli	1352	0.3	34	8.7	29	-
Camposecco	2331	0.4	4.1	5.6	14	-
Castello	1586	0.3	140	12.5	41.7	-
Ceresole Reale	1582	1.6	62.5	36.4	22.7	-
Cingino	2262	0.2	4.9	4.5	22.5	-
Fate	1300	-	25	0.12	-	-
Larecchio	1836	0.2	3	2.7	13.5	-
Lavagnina (P)	332	0.3	18.3	2.7	9	-
Miste	925	0.2	50.9	1.4	7	-
Morasco	1815	0.6	38.8	17.6	29.3	0.3
Piantalessio	1917	0.5	15.9	23.3	46.6	-
Piastra	957	0.3	246	12	40	-
Rochemolles	1973	0.2	26	3.8	19	-
Rossett	2703	0.2	0.5	-	-	-
Sabbione	2460	0.5	18.9	26	52	-
Spina	394	0.2	1	1.5	-	-
Liguria (7)						
Brugneto (P)	777	1	25	25.1	25.1	-
Brusalletta (P)	390	0.3	9.8	4.6	15.3	-
Giacopiane	1020	0.3	16.8	4.8	16	-
Ortiglieto	324	1.2	500	1	14.2	-
Osiglietta	637	0.6	116	13	21.7	-
Tenarda (P)	1322	0.2	3.3	1.3	6.5	-
Val Noci (P)	537	0.3	7.2	3.3	11	-
Lombardia (14)						
Alpe Gera	2126	1.2	62.9	62	51.7	1.9
Barbellino	1862	0.5	22.3	18.9	37.8	0.5
Belviso	1485	1	27	52	52	-
Campomoro	1967	1	69.7	10.6	10.6	0.1
Cancano	1900	2.4	264	124	51.7	0.6
Del Gallo	1816	5.8	292	166	28.6	-
Dosazzo	2083	0.2	10.9	1.3	6.5	1.2
Idroscalo	108	0.8	-	-	-	-
Publino	2135	0.3	22.1	5	16.7	-
San Giacomo	1949	1.9	57.3	64.3	33.8	1.2
Scais	1494	0.2	52.7	9	45	0.1
Val di Lei	1930	4.3	47.9	198	46	-
Valvestino	504	0.8	154	47.5	59.4	-
Venina	1823	0.3	20.1	11.3	37.7	0.5

to be continued

Tab. 1. continued

RESERVOIRS	Altitude (m a.s.l.)	Lake Area (km^2)	Basin Area (km^2)	Volume (m^3 10^6)	Mean Depth (m)	τ_w (years)
Trentino Alto Adige (24)						
Careser	2603	0.5	10.4	15.6	31.2	-
Gioveretto	1850	0.7	112	19.6	28	-
Fedaia	2053	0.6	19.7	16	26.7	-
Fontana Bianca	1872	0.2	66.7	1.3	6.5	-
Landro	1406	0.2	46.2	-	-	-
Malga Bissina	1788	1.4	75.5	60	42.8	-
Malga Boazzo	1224	0.8	151	11.8	14.8	-
Mollaro	347	-	1098	0.9	-	-
Monguelfo	1055	-	430	4.8	-	-
Nèves	1856	0.6	34.8	15.4	25.7	-
Novale	1365	0.2	-	-	-	-
Paneveggio	1458	0.7	129	31.6	45.1	-
Pian Palù	1800	0.5	48.6	15.5	31	-
Ponte Pià	468	0.2	583	2.6	13	-
Pra da la Stua	1041	0.5	37.3	1.5	3	-
Rio di Pusteria	722	-	2688	2	-	-
Quaira	2249	0.3	75	12.4	41.3	-
Selvaggio	2532	0.2	1.7	-	-	-
Speccherù	808	0.3	14.3	10	33.3	-
Stramentizzo	787	0.5	729	9.1	18.2	0.02
Val Noana	1015	0.3	134	7.8	26	-
Val Schener	565	0.4	433	8.4	21	-
Vernago	1690	1.2	70.3	43.2	36	-
Zoccolo	1141	1.3	181	33.7	25.9	-
Veneto (10)						
Corlo	260	2.5	640	48.2	19.3	0.02
Cadore	685	2.3	818	68.5	29.8	-
Mis	427	1.6	340	41.1	25.7	0.12
Santa Caterina	826	0.3	225	7	23.3	-
Senaiga	402	0.2	07	5.9	29.5	-
Stua	696	0.2	27.5	3.4	17	-
Pontesei	800	0.3	151	5.8	19.3	-
Val Gallina	678	0.2	14.4	6.4	32	-
Valle di Cadore	706	0.2	380	4.3	21.5	-
Vodo di Cadore	855	-	323	1.4	-	-
Friuli (9)						
Barcis	404	1	392	22	22	-
Caprizi	508	-	189	-	-	-
Cà Selva	516	1.2	39.6	42	35	-
Cà Zul	516	-	-	9	-	-
Predil	959	0.5	34.6	0.3	0.6	-
Tramonti	313	1.4	220	25	7.8	-
Sauris	977	1.6	139	70	43.7	-
Vajont	720	2.1	-	-	-	-
Verzegnis	456	0.2	647	3.6	18	-
Emilia Romagna (8)						
Brasimone (P)	830	0.4	14.5	6.7	16.7	-
Fontanaluccia (P)	773	-	44	2.7	-	-

to be continued

Tab. 1. continued

RESERVOIRS	Altitude (m a.s.l.)	Lake Area (km^2)	Basin Area (km^2)	Volume (m^3 10^6)	Mean Depth (m)	τ_w (years)
Mignano (P)	33	-	87.2	15.5	-	-
Molato (P)	360	-	83	13	-	-
Quarto (P)	350	-	2.1	6.7	-	-
Ridracoli (P)	557	1	73	33	33	-
Santa Maria (P)	508	-	29.5	0.4	-	-
Suviana (P)	470	-	46.7	76	-	-
Toscana (11)						
Corfino	512	-	24	0.9	-	-
Grammolazzo	600	-	38.9	3.8	-	-
Levane	166	-	2047	49	-	-
Paduli	1160	-	3.6	3.4	-	-
La Penna	204	-	2251	9.8	-	-
Poggio Perotto	80	-	21.6	4.8	-	-
Ponte Cosi	311	-	295	2.9	-	-
Rocchetta Teglia	402	-	29.6	5	-	-
San Cipriano	153	-	16	3.3	-	-
Santa Luce	52	-	40.4	4.3	-	-
Vagli	530	-	40	30	-	-
Umbria (3)						
Aia	112	-	93	5.6	-	-
Alviano	78	-	-	3.5	-	-
Corbara	136	-	6075	207	-	-
Lazio (9)						
Basso Nera	56	-	-	53	-	-
Maroggia	410	-	23.2	6.3	-	-
Ponte d'Abbadia	70	-	675	5.7	-	-
Ponte Fiume	73	-	3300	6	-	-
Salto	541	-	771	278	-	-
San Casciano	381	-	24.3	4.5	-	-
Scandarello	873	-	48.5	12.5	-	-
Selva	887	-	4.8	2	-	-
Turano	539	-	475	163	-	-
Marche (10)						
Delle Grazie	222	-	614	2	-	-
Fiastra	640	-	88	21	-	-
Furlo	180	-	644	1.8	-	-
Polverina (P)	400	-	-	4	-	-
Pieve Favero	296	-	-	4.4	-	-
San Lazzaro	117	-	-	0.7	-	-
S.Maria Belforte (P)	238	-	-	0.6	-	-
Sassocorvaro	220	-	227	7.5	-	-
Talvacchia	510	-	128	14.3	-	-
Tavernelle	60	-	-	1	-	-
Abruzzo (8)						
Barrea	973	-	272	23	-	-
Campotosto	1320	-	47.5	324	-	-
Montagna Spaccata	1069	-	20.9	7	-	-
Penne	255	-	136	8.8	-	-

to be continued

Tab. 1. continued

RESERVOIRS	Altitude (m a.s.l.)	Lake Area (km^2)	Basin Area (km^2)	Volume ($m^3\ 10^6$)	Mean Depth (m)	τ_w (years)
Piaganini	395	-	198	0.8	-	-
Provvidenza	1060	-	50	1.5	-	-
Sangro (P)	256	-	863	64	-	-
S.Domenico al Sagit.	305	-	12	1	-	-
Molise (6)						
Casoli	253	-	232	21	-	-
Castel S.Vincenzo696	-	2.7	5.5	-	-	
Guardialfiera	128	-	1040	137	-	-
Letino	906	-	50	14	-	-
Persano	40	-	2.4	2.5	-	-
San Pietro	463	-	70	14.5	-	-
Campania (2)						
Gallo	840	-	8.9	7.2	5	-
Torre Ganga	1250	-	-	-	-	-
Calabria (6)						
Ampollino	1271	5.5	77	64.5	11.7	-
Angitola (P)	45	1.9	154	11.5	6	-
Ariamacina	1319	0.8	44	1.7	2.1	-
Arvo	1278	8.2	77	70.9	8.6	-
Cecita (P)	1142	12.8	155	107.2	8.4	-
Tarsia (P)	52	3.3	-	16	4.8	-
Basilicata (9)						
Abate Alonia	199	-	408	20	-	-
Gannano	89	0.8	1490	2.6	-	
Moro lucano	567	-	35	5.8	-	-
Monte Cotugno (P)	252	18.5	804	530	28.6	-
Pertusillo (P)	531	7	531	155	22.1	-
Ponte Fontanelle	538	-	350	59	-	-
San Giuliano	102	10.1	16.3	107	10.6	-
Serra del Corvo	269	-	246	28	-	-
Votturino	1420	-	6.8	2.8	-	-
Puglia (3)						
Capaccioti	187	-	62	48	-	-
Ficocchia	960	-	9	3.4	-	-
Occhito (P)	198	14.2	1012	250	17.6	-
Sardegna (31)						
A.Flumendosa (P)	802	3.2	180	61.4	19.2	0.52
Bau Pressiu (P)	249	0.2	29	6.2	31.0	1
Benzone	150	0.27	89	1.1	4.0	0.007
Bidighinzu (P)	334	1.67	52	12.2	7.3	0.93
Casteldoria (P)	25	0.4	2378	8.3	20.8	0.013
Cedrino	127	1.13	631	30	26.5	0.12
Cixerri (P)	-	4.2	426	25.3	6.0	0.27
Coghinas (P)	170	17.2	1729	258.7	15.0	0.5
Corongiu II (P)	155	0.2	34	0.6	4.0	0.07
Corongiu III (P)	201	0.27	34	4.3	16.1	0.48
Cucchinadorza	318	1.1	92	17.5	15.9	0.13

to be continued

Tab. 1. continued

RESERVOIRS	Altitude (m a.s.l.)	Lake Area (km^2)	Basin Area (km^2)	Volume (m^3 10^6)	Mean Depth (m)	τ_w (years)
Cuga (P)	114	3.1	58	35	11.3	1
Govossai (P)	915	0.27	30	2.8	10.4	0.13
Gusana (P)	645	2.6	191	59.5	22.9	0.63
Is Baroccus (P)	-	1.1	95	11.9	10.9	0.53
Leni (P)	-	1.13	75	20	17.7	0.52
Liscia (P)	180	1.32	284	105	25.7	0.32
M.Flumendosa	270	4.2	572	300	23.8	0.38
M.Roccadoria (P)	-	3.5	143	55.4	15.8	1
M.Zirimilis	-	0.55	29	5	9.1	1
Monte Pranu	46	5.3	435	50	9.4	0.63
Mulargia (P)	260	10.5	179	300	23.8	0.6
Omodeo (P)	118	13.5	2077	148.6	11.0	0.28
P.Antoni (P)	-	1.2	2953	9.1	7.6	0.01
Pattada (P)	-	4.4	160	65.5	14.9	1
Posada (P)	43	3	614	27.8	9.3	0.14
Punta Gennarta (P)	257	0.62	37	9.8	15.8	1
Santa Lucia (P)	-	0.43	49	3.7	8.6	0.02
Simbirizzi (P)	-	5	9	28.5	5.7	-
Sos Canales (P)	714	0.33	16	4.3	13.2	0.62
Surigheddu (P)	50	0.53	6	2.1	4.0	1
Sicilia (27)						
Ancipa (P)	944	1.1	99	20	18	0.34
Arancio	180	3.7	205	39	10	2.2
Castello	290	1.8	81	18	10	1
Cimia	142	0.9	110	11	12	2
Comunelli	91	0.9	82	9.9	11	1.6
Dirillo (Ragoleto)	330	1.1	118	24	22	2.9
Disueri	144	0.6	239	2.3	3.8	1.2
Fanaco (P)	679	1.5	56	24	16	1.5
Gammauta	500	0.3	69	2	6.7	0.08
Garcia (P)	198	5.9	378	60	10	0.9
Gorgo	72	0.5	99	3.4	6.8	1
Guadalami	438	0.1	41	1	10	-
Nicoletti	387	1.8	62	23	13	3.8
Ogliastro	214	14	468	124	8.9	5.9
Olivo	477	1.1	60	10	9.1	1
Piana d.Albanesi (P)	612	3.1	41	33	11	2.1
Piano del Leone (P)	829	0.6	22	4.9	8.2	0.49
Poma (P)	197	6.1	164	78	13	2
Pozzillo (P)	366	7.7	577	154	20	1.9
Prizzi (P)	640	0.9	30	9.3	10	1.9
Rubino	185	1.3	76	13	10	2.4
San Giovanni	311	2.3	80	15	6.5	1.2
Santa Rosalia	379	1.3	97	20	15	1
Scanzano (P)	527	1.7	71	20	12	0.9
Trinità	69	2.4	200	26	8.3	2.6
Vasca Ogliastro	138	0.4	64	4.5	11	0.7
Villarosa (P)	394	1.3	102	17	13	11

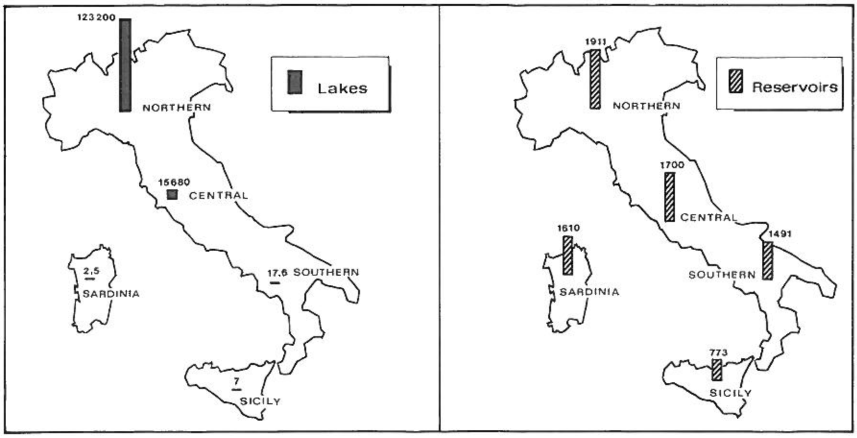

Fig. 1. Geographical distribution of the volumes (10^6 m^3) of Italian lakes and reservoirs.

The reservoirs with the biggest volumes are reported in table 3.

As a matter of fact, some of these reservoirs, for one reason or another (e.g., safety), have never reached their maximum volume, such as Lake Omodeo which was filled up to 149 m^3 10^6 and Lake Mulargia which normally does not exceed 180 (and at most 250), and Medio Flumendosa which does not exceed 160 m^3 10^6.

Tab. 2. Volumes of the natural and man-made Italian lakes.

	Vol. m^3 10^6	%
North	1,911	25
Centre	1,700	23
South	1,491	20
Sicily	773	10
Sardinia	1,670	22
TOTAL	7,511	100

Tab. 3. Volumes of the largest Italian reservoirs.

	Vol. m^3 10^6
Monte Cotugno (Basilicata)	530
Omodeo (Sardegna)	374
Campotosto (Abruzzo)	324
Mulargia (Sardegna)	300
Salto (Lazio)	278
Medio Flumendosa (Sardegna)	300
Coghinas (Sardegna)	259
Occhito (Puglia)	250
Corbara (Umbria)	207

3. CHEMICAL AND BIOLOGICAL CHARACTERISTICS OF THE ITALIAN RESERVOIRS

At present, it is not possible to give a complete picture of the chemical and biological characteristics of the Italian reservoirs, due to the lack of studies carried out with a comparative criterion. Though research has been carried out only for Sicily and Sardinia, while the available data regarding peninsular Italy do not allow deep analysis from a chemical and biological point of view. A tentative picture on the basis of the few available data was recently given by Salmoiraghi & Bonomi (1992); particular reference to it will be made below. The two main islands will be dealt with in detail in paragraphs 3.2. and 3.3.

3.1. Peninsular Italy

Regarding the phytoplanktonic component, according to Salmoiraghi & Bonomi (1992) the general picture is that of a mosaic of differentiated situations, with peculiar characteristics in a certain number of basins. On the basis of the reservoirs Valvestino, Corlo and Suviana-Brasimone in Northern Italy and Pertusillo in Southern Italy, and keeping in mind the situation of the islands, the mentioned Authors give a sequence of algal groups normally present in the various seasons, represented by Cyanobacteria, Cryptophyceae, Chrysophyceae, Chlorophyceae, Diatomeae and Dinophyceae. In general, proceeding from north to south and from lower to higher trophic conditions, an increase of Cyanobacteria and of Desmidiales such as *Closterium* and *Staurastrum* can be observed. The frequent presence of species such as *Microcystis aeruginosa* which causes potabilization problems must be mentioned, especially in the more southern reservoirs.

As for the other biological aspects of the Italian reservoirs, zooplankton is largely represented by cladocerans and rotifers in terms of species richness, density and biomass, and to a lesser degree by copepods (Salmoiraghi & Bonomi 1992). The situation is therefore the opposite of the one occurring in natural lakes, in which copepods predominate, being K strategy organisms typical of stable environments with a relatively long development time. Among the components of the zooplankton of Italian reservoirs, the smaller presence of predator species and the prevalence of phytophagous ones is very evident.

Concerning zoobenthic communities, Salmoiraghi & Bonomi (1992) pointed out that the littoral belt was generally characterized by a monotonous presence of few species of insects (Ephemeroptera, Chironomidae, etc.), molluscs (Gastropoda) and not many other organisms able to follow the variations in water level, while the deeper parts of the basin are characterized by oligochaetes and chironomid larvae, represented by different species depending on the degree of oxygen saturation of the water.

Regarding the fish populations of Italian peninsular reservoirs, Salmoiraghi & Bonomi (1992) noted that the existing situations were characterized by a high degree of artificiality due to immissions. In some cases, however, it is possible to find relatively diversified fish communities, in a few cases including uncommon species (for instance, *Acipenser naccari* in Brasimone Reservoir, according to Rossi 1988).

3.2. Sardinia

As previously stated, differently from peninsular Italy, for Sardinia data collected in a systematic way are available, although they are reliable to different degrees, in relation with the number of samples taken in each case (see also Sechi & Lugliè 1992, this volume). Among these data, only those useful to give a trophic picture will be considered here. On the basis of these data, and phosphorus concentrations in particular (Tab. 4), Sardinian reservoirs can generally be considered as being in a eutrophic condition, with only 2 cases definable as oligotrophic (Sechi 1978, 1983, 1986,1989; Barbanti *et al.* 1979; Cotta-Ramusino & Rossaro 1979; Marchetti 1979; Sechi & Cossu 1979, 1983, 1985; Sechi & Manca 1983; Sechi & Mosello 1985; Marchetti *et al.* 1986; Cossu & Sechi 1989, 1990; Mosello *et al.* 1989; Sechi & Lugliè 1989; Lugliè & Sechi 1990). An evaluation based on mean annual chlorophyll concentrations leads to the same conclusion, with rare exceptions (L. Gusana). Even lacustrine environments of lower trophic status (mesotrophic ones such as Sos Canales, Bau Pressiu, Leni and Govossai) are in practice compromised if considered on the basis of dissolved oxygen of the hypolimnic waters, which are hypoxic. This situation is probably also the result of external inputs of organic compounds originated from the catchment basins surrounding the reservoirs.

In the Simbirizzi, Casteldoria, Monte Pranu and Surigheddu reservoirs, classified as hypertrophic (the first one) and eutrophic (all the others), the high values of dissolved oxygen which were nonetheless found in the hypolimnic waters can be explained by the hydrological and morphometric characteristics, such as small depths and turnover times, allowing a rapid renewal of the consumed oxygen.

Nevertheless, in the deeper hypolimnic layer of most reservoirs, extremely low levels of oxygen are found, which can reach anoxy, causing the formation of H_2S. In some reservoirs like the Bidighinzu, Liscia, Monteleone and Roccadoria, the absence of oxygen can regard the whole water column below the depth of 7 m.

In these reservoirs, the phytoplanktonic component is dominated by Cyanobacteria, Dinophyceae and Chlorophyceae. The first group is represented by the genus *Microcystis* (*M. aeruginosa* and *M. flos-aquae*), *Anabaena* (*A. planctonica* and *A. flos-aquae*) and *Aphanizomenon* (*A. flos-aquae*). These

Tab. 4. Main trophic characteristics of the Sardinian reservoirs: [P]sp: Total phosphorus concentration (mg m^{-3}) at the overturn; [P]I: Yearly average total phosphorus concentration (mg m^{-3}); [CHL]: Yearly average chlorophyll-*a* concentration (mg m^{-3}); HO: Hypolimnic dissolved oxygen saturation (%); DA: Dominant Algae: Cya: Cyanophyceae; Chl: Chlorophyceae; Dia: Diatomeae; Din: Dinophyceae; TL: Trophic Level.

Lake	[P]sp	[P]l	[CHL]	HO	DA	TL
Corongiu III	8	-	-	>30	Dia Din	Meso
Sos Canales	10	-	-	>60	Dia Din	Oligo
Bau Pressiu	10	-	-	<5	Cya	Meso
Govossaj	10	-	-	<5	Din	Meso
Punta Gennarta	11	-	-	>20	Chl	Meso
A. Flumendosa	15	23	9	>30	Dia	Meso
Gusana	17	18	11	>50	Clo Dia	Eu
M. Flumendosa	20	10	6	>50	Dia	Meso
Posada	27	-	-	<10	Cya	Eu
Mulargia	30	20	15	<5	Cya	Eu
Cucchinadorza	32	-	-	<10	Cya	Eu
Benzone	34	-	-	<10	Cya	Eu
Surigheddu	36	-	-	>50	Chl Cya	Eu
Monte Pranu	40	-	-	>60	Cya	Eu
Pattada	50	60	16	<1	Cya	Eu
Simbirizzi	60	100	40	>80	Cya Chl	Hypereu
Cuga	65	60	13	<5	Cya	Eu
Cixerri	80	100	30	<1	Cya	Hypereu
Liscia	80	90	22	<1	Cya	Eu
Coghinas	90	100	15	<10	Cya	Eu
M. Roccadoria	90	110	14	<1	Cya	Eu
Casteldoria	100	-	-	>50	Cya	Eu
Omodeo	180	140	16	<20	Cya	Eu
Bunnari alto	200	220	15	<5	Cya Chl	Eu
Bidighinzu	350	400	29	<1	Cya	Hypereu

species appear in abundant blooms, mainly in the summer months. The genus *Oscillatoria* (*O. rubescens* and *O. tenuis*), instead, appears in the reservoirs of Flumendosa, Mulargia and Simbirizzi, and prefer the colder season. The Dinophyceae and the Chlorophyceae are represented essentially by the species *Ceratium hirundinella* and *Closterium aciculare*. Due to their large cellular volume, without reaching high densities, they often determine a higher Cyanobacteria biomass. During the cold season a greater importance is assumed by the genera *Cyclotella*, *Melosira*, *Synedra*, *Fragilaria* and *Asterionella*. In some reservoirs, *Melosira granulata* may also produce large biomass in summer.

3.3. Sicily

The Sicilian reservoirs, compared to those of Sardinia and continental Italy, are characterized by numerous differentiating elements from a hydrochemical point of view.

These differences are confirmed, among other things, by the values of conductivity, which exceeds 1 mS cm $^{-1}$ at 18 °C in most of the reservoirs. The lowest values (0.15-0.20 mS cm^{-1} at 18° C) were recorded in Lake Ancipa and the highest (4.04-5.17 mS cm^{-1}) in Lake Gorgo. The most recent data (Calvo *et al.* 1992) show conductivity values lower than 1 mS in 59% of lakes, ranging between 1 and 2 mS in 22% of the lakes and above 2 mS in the remaining 19% (Tab. 5).

The results of the analyses of the main ions (Calvo *et al.* 1992) confirm the great variability of conductivity values in the studied lakes. In figure 2 every quadrant puts in evidence the different chemical composition of the waters:

Quadrant A - Chloride-sulphate alkaline waters;
Quadrant B - Bicarbonate-alkaline waters;
Quadrant C - Chloride-sulphate alkaline earth waters;
Quadrant D - Bicarbonate-alkaline earth waters.

In table 6, with the aim of giving a picture of the conditions of the Sicilian reservoirs, the principal trophic parameters are shown. Reservoirs were ranked according to increasing total phosphorus concentration at the turnover.

Most lakes put in evidence a rapid hypolimnetic oxygen depletion during summer stratification indicated by typical clinograde curves. The shift from aerobic to anaerobic conditions, in absence of wind mixing effects, often involves all the water column and leads to impressive fish-kills which seriously compromise water management.

The trophic response in terms of chlorophyll-*a* is lower than the phosphorus concentration threshold set by O.C.D.E. (1982) at 70 mg m^{-3}. The causes of such a lower response are probably due to:

A) low water transparency values and reduction of the photic zone;
B) higher concentrations of particulate phosphorus;
C) high sedimentation rates in the phosphorus loading balance.

The high sedimentation rate varies proportionally with hydraulic loading (Q) and proves to be important in Sicilian reservoirs according to Jones & Bachman (1976) and Thomann & Müller (1987).

Critic phosphorus loading, (L_{cr}),corrected for net sedimentation ($V_s = 62.5\ Q^{0.25}$), is given by the equation:

Tab. 5. Mean annual values of algal nutrients and main ions of Sicilian reservoirs. Conductivity: mS cm^{-1}; N-NH_4, N-NO_3, P-PO_4: µg l^{-1}, Si-SiO_2:mg l^{-1}; alkalinity and other ions: meq l^{-1};

	Cond.	NH_4	NO_3	PO_4	SiO_2	Alk.	Na	K	Ca	Mg	Cl	F	SO_4	H_2S
Ancipa	0.17	12	77	4	2.0	1.55	0.45	0.04	1.30	0.37	0.28	0.01	0.35	0.01
Arancio	0.72	667	676	11	4.8	3.21	2.66	0.31	3.31	1.48	2.16	0.02	2.57	0.02
Biviere di Cesarò	0.08	31	76	7	0.6	0.58	0.28	0.02	0.87	0.13	0.27	0.01	0.40	0.02
Biviere di Gela	2.72	22	78	3	2.3	2.41	14.68	0.35	7.60	5.88	17.86	0.04	8.90	0.00
Castello	0.97	775	263	66	2.9	3.79	3.69	0.29	4.73	2.21	2.87	0.02	4.49	0.07
Cimia	2.15	199	803	5	4.0	2.43	9.84	0.46	11.63	4.99	8.81	0.05	15.66	0.01
Comunelli	2.51	331	129	10	3.4	1.46	13.58	0.49	8.29	5.89	12.44	0.04	15.63	0.00
Dirillo	0.54	60	514	11	4.1	3.01	1.20	0.30	3.63	1.11	0.90	0.02	2.20	0.02
Disueri	1.21	684	2226	267	3.6	3.98	5.04	0.55	6.04	2.28	3.60	0.02	5.84	0.01
Fanaco	0.56	199	1143	2	3.3	3.44	1.54	0.10	3.89	0.87	0.87	0.02	2.05	0.00
Gammauta	0.49	154	446	44	2.7	4.27	1.01	0.15	3.16	1.55	0.66	0.04	0.91	0.00
Garcia	0.77	221	165	3	3.6	3.36	2.89	0.18	4.02	1.28	1.95	0.02	3.34	0.00
Gorgo	4.51	33	65	11	6.1	2.74	36.66	0.45	12.36	5.26	38.65	0.06	14.10	0.02
Guadalami	0.42	111	459	7	0.3	2.55	0.89	0.09	2.28	0.75	0.61	0.01	0.91	0.01
Nicoletti	1.40	46	66	5	1.5	2.47	7.62	0.36	5.35	3.23	2.25	0.03	12.51	0.00
Ogliastro	2.74	173	1710	9	2.9	3.05	13.82	0.50	12.45	5.79	11.81	0.06	20.06	0.00
Olivo	0.90	71	69	5	1.6	3.97	3.64	0.24	3.76	2.90	2.68	0.03	3.81	0.01
Pergusa	33.61	788	157	47	1.6	20.26	265.63	23.44	1.43	129.48	310.63	0.03	90.54	0.03
P. degli Albanesi	0.38	349	412	3	0.4	2.66	0.92	0.09	2.42	0.80	0.62	0.01	0.95	0.02
Piano del Leone	0.42	160	546	5	2.4	3.09	0.82	0.08	3.26	0.44	0.49	0.01	0.99	0.01
Poma	0.73	73	994	5	1.4	3.54	2.67	0.16	3.39	1.83	2.07	0.02	2.65	0.00
Pozzillo	1.11	91	355	9	1.6	3.03	5.73	0.22	4.35	2.28	4.32	0.02	5.05	0.01
Prizzi	0.47	86	503	7	2.5	3.32	1.31	0.09	3.28	0.56	0.64	0.02	1.39	0.01
Rubino	1.05	18	711	5	1.0	2.46	4.82	0.15	3.85	1.54	4.02	0.03	4.72	0.01
San Giovanni	1.50	658	283	9	2.7	1.90	5.31	0.47	8.57	2.39	3.72	0.03	12.61	0.02
Santa Rosalia	0.44	125	279	9	3.4	3.39	0.94	0.08	3.04	1.01	0.71	0.03	0.99	0.03
Scanzano	0.5	300	1283	5	2.3	3.09	1.41	0.08	3.29	0.72	1.06	0.02	1.38	0.01
Soprano	1.84	7671	57	847	12.7	4.10	7.31	1.73	8.74	3.08	5.05	0.01	12.98	0.02
Trinità	1.86	26	419	2	3.8	2.34	5.74	0.33	13.03	3.77	4.80	0.04	17.53	0.01
Vasca Ogliastro	0.32	28	177	5	3.4	2.74	0.70	0.03	2.10	0.77	0.57	0.01	0.40	0.01
Villarosa	2.26	524	276	3	1.0	2.93	11.51	0.64	8.47	5.31	9.09	0.03	14.86	0.01

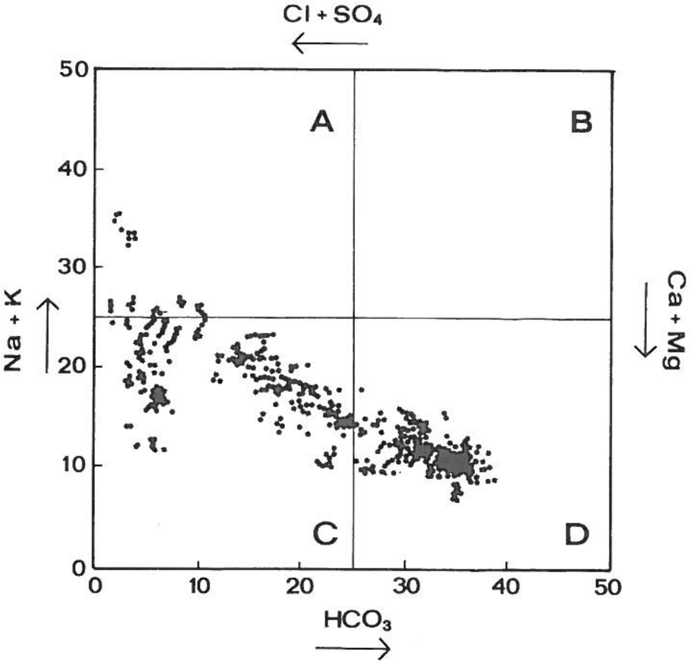

Fig. 2. Pattern showing the different chemical composition of Sicilian reservoirs (meq l^{-1}).

$$L_{cr} = 10.46 \text{ Chl-}a_{cr}^{0.68}(62.5Q^{0.25} + Q) \qquad (1)$$

Equation (1) was in better agreement with the evaluation of the trophic state of Sicilian lakes by Calvo & Viviani (1991) rather than with equations in literature (Chapra & Tarapchak 1976; Vollenweider 1976), which overestimate the trophic state.

The comprehensive evaluation of the parameters taken into consideration allowed the classification of most of the lakes (82%) as eutrophic and hypereutrophic. Only Lake Ancipa is classifiable as oligotrophic.

Correlation analyses put in evidence highly significant relationships between phytoplankton biomass, chlorophyll-*a* and total phosphorus (Barone *et al.* 1992). These parameters were confirmed as suitable for the trophic classification of Sicilian waters. On the contrary, the Secchi disc transparency values did not show any significant relationship with the other trophic state parameters. Transparency seems to be strictly related to the hydrological disturbance typical of most of the Sicilian territory and to the high inputs into the water bodies of dissolved and particulate matter from the catchment area.

The nutrients' values found in the different Sicilian reservoirs cover a wide range, as shown in table 5. Nitrate is, in most lakes, the dominant form of

Tab. 6. Main trophic characteristics of Sicilian reservoirs: [P]sp: Total phosphorus concentration (mg m^{-3}) at the overturn; [P]l: Yearly average total phosphorus concentration (mg m^{-3}); [CHL]: Yearly average chlorophyll-*a* concentration (mg m^{-3}); HO: Hypolimnetic oxygen content (%); DA: Dominant Algae; Chl: Chlorophyceae; Cya: Cyanophyceae; Cry: Cryptophyceae; Dia: Diatomeae; Din: Dinophyceae; Eug: Euglenophyceae; TL: Trophic Level.

Lake	[P]sp	[P]l	[CHL]	HO	DA	TL
Ancipa	9.3	9.7	1	>70	Cry Dia	Oligo
Nicoletti	15	35	3	<5	Dia Din	Meso
Comunelli	16	45	-	-	Chl Cya	Eu
Oliva	16	33	6	<1	Dia Din	Meso
Pozzillo	18	50	11	>30	Cya Dia	Eu
Rubino	19	29	7	-	Cya	Eu
Piano del Leone	20	47	10	>30	Dia Eug	Meso-Eu
Poma	20	51	6	<20	Chl	Meso-Eu
Garcia	21	51	6	>50	Cry Dia Din	Eu
Cimia	23	54	6	<5	Chl Cry	Eu
Trinità	23	83	17	<30	Cya Eug	Eu
P. degli Albanesi	24	47	14	<1	Cry Dia Chl	Eu
Santa Rosalia	24	56	7	<1	Chl	Meso-Eu
Fanaco	30	54	4	<1	Dia Din	Meso-Eu
Vasca Ogliastro	32	107	3	<20	Dia	Eu
Guadalami	35	39	6	<1	Cry Din	Meso
Ogliastro	38	41	1	>50	Chl	Meso
Castello	40	109	23	<5	Chl Cry Din	Eu
Prizzi	40	53	7	>30	Dia Eug	Eu
Dirillo	47	61	10	<1	Chl Dia	Eu
Scanzano	49	62	14	<5	Chl Din Eug	Eu
Villarosa	53	64	30	<1	Chl Cya	Eu
Gorgo	59	81	46	-	Cya Dia	Hypereu
San Giovanni	67	81	53	<1	Cya	Hypereu
Arancio	79	166	195	<5	Cya	Hypereu
Gammauta	104	182	73	-	Cya Dia	Hypereu
Disueri	298	1094	148	-	Eug	Hypereu

inorganic nitrogen; moreover ammonia often occurs in high concentrations.

Soluble phosphorus concentrations show, on an average basis, low values which are equal to 10% of total phosphorus; this is mainly due to a presence of particulate phosphorus (Calvo & Viviani 1991) which is higher than reported in literature for Sicilian inland waters (O.C.D.E. 1982).

Dissolved silicic acid concentrations generally show the highest values in the rainy season (autumn-winter). When spring begins and diatom blooms occur, silica supplies are reduced to under about 1 mg l^{-1}.

The nitrogen-phosphorus ratio shows that most Sicilian lakes are phosphorus limited (Calvo *et al.* 1992).

Altogether, an increase in nutrients loading was verified at the end of the stratification period, in absence of rainfall and water contributions from the catchment area. This suggests a large contribution of internal loading in the dynamics of nutrients.

Finally, regarding the biological characteristics, a first series of studies on Sicilian reservoirs, undertaken for zoogeographical reasons (Berzins 1954; Faranda 1977; Margaritora *et al.* 1982; Pesce & Galassi 1987) was followed by the results of recent studies aimed at the trophic interactions between the plant and animal components of the planktonic communities (Barone & Naselli Flores 1990; Barone *et al.* 1991, 1992; Naselli Flores & Barone 1992).

The distribution of dominant phytoplanktonic species suggests, especially in reservoirs, a succession pattern based on an inflow-outflow model, rather than the circulation-stratification model described for lentic ecosystems (Sommer 1987). Similar assemblages were recorded in the periods characterized by maximum and minimum holding, respectively; in particular, Diatomeae dominate the communities in spring and winter and Chlorophyceae in summer and autumn (Olivieri *et al.* 1982; Barone 1983, 1985; Calvo *et al.* 1984; Barone & Naselli Flores 1990). Moreover, in the periods with maximum hydrological stability, a strong influence of herbivorous zooplankton on edible phytoplankton was pointed out by means of correlation analysis (Barone *et al.* 1991).

This evaluation of a generally high trophic state of Sicilian lakes is supported by the spring dominance of small centric diatoms and Cryptophyceae and by the temporal distribution of phytoplankton size classes: pioneer forms are particularly significant in both inflow and outflow periods (Barone & Naselli Flores 1990).

In the more eutrophicated lakes, the Cyanobacteria (e.g., *Anabaena planctonica, Anabaena spiroides, Microcystis aeruginosa, Microcystis wesenbergii, Planktothrix agardhii, Limnothrix planctonica*) develop mostly in summer, often forming surface scums (Barone & Naselli Flores 1989). In lakes characterized by impoundment due to greater outflows, Euglenophyceae are most abundant in autumn.

The distribution of dominant zooplankters also shows a cyclic trend, with the alternance of small and large herbivores. In particular, small fast-growing filter feeders (e.g., *Bosmina longirostris, Ceriodaphnia quadrangula, Brachionidae*, dominate in spring and autumn, whereas large ones (e.g., *Copidodiaptomus numidicus, Daphnia* spp) dominate in summer; the general prevalence of large herbivores in the warmer season suggests a low predation pressure exerted by planktophagous fishes (Barone & Naselli Flores 1990; Barone *et al.* 1991).

Phytoplanktonic diversity, calculated with the Shannon-Wiener index, showed values in agreement with the trophic state of the water bodies. In particular, correlation analysis showed a decrease in phytoplankton diversity with an increase in trophic state. Moreover, assuming zooplankton biomass as a grazing index, a negative coefficient was found when correlating phytoplankton diversity with zooplankton biomass; this suggested a decrease of phytoplankton structural complexity with the increase in grazing pressure.

The structural complexity of the zooplankton, besides, does not seem particularly affected by trophism, but rather by water temperature, food availability and predation (Barone & Naselli Flores 1990; Barone *et al.* 1991; Naselli Flores & Barone 1992).

4. PROBLEMS OF THE ITALIAN RESERVOIRS AND CONSEQUENCES ON THEIR USES

From the picture which has been given in the previous paragraphs, it is clear that the main, if not exclusive, problem of Italian reservoirs is, with few exceptions, that of water eutrophication.

In general, the key problem of Italian reservoirs is represented by an excess in inputs of nutrient salts of anthropic origin which is worsened, in certain areas, by unfavourable climatic conditions.

Most of the high-altitude reservoirs in the Alps and the Apennines are excluded from this problem; cases of higher trophic status occur seldom even at lower altitudes (the Suviana-Brasimone system in the Apennines bordering Tuscany and Emilia-Romagna is mesotrophic, according to Bonomi & Salmoiraghi, 1979a, 1979b, 1980; Salmoiraghi *et al.* 1981).

Regarding the Southern part of peninsular Italy, the problem of eutrophication seems extremely limited; however, it must be said that this area has not been thoroughly studied from this point of view. Within this area, among the 7 main reservoirs in Calabria, only one (Lake Cecita) is known to undergo periods of hypolimnic anoxy during July-August, although its phosphorus level is very low all year round (De Domenico, pers. comm.; Provini, pers. comm.). Among the 9 main reservoirs in Basilicata, Lake Pietra del Pertusillo receives a nutrient salt load which determines a significant algal production in late winter-spring, followed by a hypoxic phase during which H_2S accumulates in the hypolimnion and persists for most of the year (Calderoni *et al.* 1979).

Most of the reservoirs on the islands, as already mentioned, are characterized by a relatively high trophic status. On the basis of mean annual total phosphorus concentrations, the situation can be summarized as shown in table 7 (with each figure representing the number of reservoirs).

Tab. 7. Trophic situation on the basis of mean annual phosphorus concentration and volume, expressed in m^3 10^6, of the Sicilian and Sardinian reservoirs.

	SICILY		SARDINIA	
	N. lakes	Volume	N. lakes	Volume
OLIGOTROPHIC	1	20	2	5
MESOTROPHIC	4	158	6	385
EUTROPHIC	17	517	15	1222
HYPEREUTROPHIC	5	44	3	66

The consequences of such a situation are not important in those cases in which the water is used for the production of electric energy and for irrigation, but they become critical when the water is needed for potabilization. In these cases, the negative effects of eutrophication are localized:

a) in the epilimnion, prevalently with the development of Cyanobacteria, among which *Microcystis* generally assumes a dominant role;

b) in the hypolimnion, with the production of reduced compounds, particularly H_2S (Fig. 3).

This deterioration of both surface and deep waters renders their potabilization difficult during a good part of the year and determines the production of water having poor characteristics from the point of view of taste, colour and smell, at high costs and adopting techniques giving rise to compounds such as trihalomethanes (regarding Sardinian reservoir, see the studies by Contu *et al.* 1988; Romano *et al.* 1991).

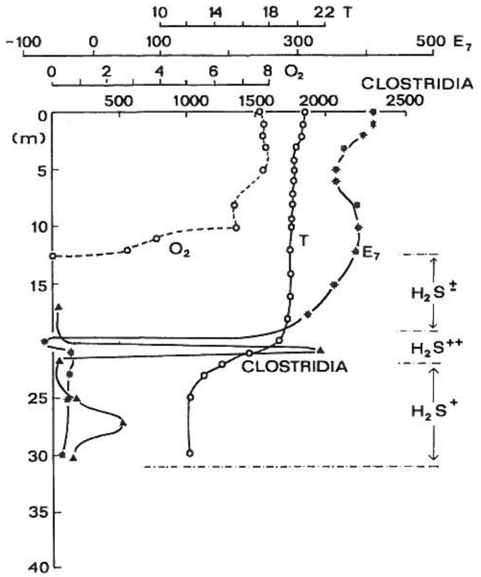

Fig. 3. Liscia Reservoir: vertical distribution of H_2S, temperature (T), redox potential (E_7), dissolved oxygen (O_2 in mg l^{-1}) and sulphur-reducing Clostridia (MPN/100 ml).

5. CASE STUDIES OF PARTICULAR INTEREST

5.1. Experimental budgets and comparisons between observed and expected loads

Specific studies were undertaken on some Italian reservoirs, firstly with the aim of evaluating the phosphorus budget and, in particular, for estimating the amount of phosphorus retained by a reservoir in relation to the input load; secondly with the aim of comparing the values of the loads estimated on the basis of theoretical criteria (expected load) with those determined experimentally (observed load). Three reservoirs were involved, two of which in Sardinia (Omodeo and Coghinas) and one in Abruzzo (Occhito), and the results are given in the following paragraphs.

5.1.1. Phosphorus budget

a) Lake Omodeo

In the case of the reservoir along the River Tirso, named Lake Omodeo, measures were undertaken of the concentrations and discharges of the four main tributaries, by means of weekly samplings covering a time span of more than one year (Marchetti *et al.* 1986; Marchetti & Provini 1989). The values obtained for total phosphorus are reported in table 8.

Considering that the four tributaries only drain 87.2% of the surface of the catchment basin, the total phosphorus load was evaluated at 74.25 t y^{-1} of input into the reservoir, figure obtained by adding 12.8% to the total load of the four tributaries.

The measurements undertaken on the waters of the emissary allowed the evaluation of the load at 52.24 t y^{-1} of phosphorus, value which allows to conclude that the reservoir retains 30% of the total load reaching the reservoir, i.e., 22 t y^{-1}.

Tab. 8. Total phosphorus carried by the tributaries to lakes Omodeo, Coghinas and estimated values (E.A.A.P. 1986) for Lake Occhito.

TRIBUTARIES	t P y^{-1}
Lake Omodeo	
Tirso	33.79
Siddo	7.89
Taloro	8.18
Murtazzolo	15.97
Lake Coghinas	
M. Ozieri	72
M. Oschiri	6.5
M. Berchidda	11
Lake Occhito	
Tappino	27.7
Occhito	4.9
Cigno	3.6
La Cattola and Fortore	6.9

b) Lake Coghinas (or Lake Oschiri)

Biweekly measurements on the three main tributaries of Lake Coghinas (Sechi & Mosello 1985) resulted in a total phosphorus load of 90 t y^{-1} (Tab. 8). Taking into account that these tributaries drain 77% of the surface of the catchment basin of the reservoir, the measured load (89.5 t y^{-1}), following the same procedure adopted for the Omodeo Reservoir, was increased by 23%, i.e., 20.6 t y^{-1}, reaching the final load of 110 t P y^{-1}. Besides this load, a relevant fraction reaches the reservoir through the untreated waste waters of a pig farm having an estimated production of 28 t of phosphorus per annum (4 kg for each of the 7,000 pigs). Considering that the measurements of the load leaving the reservoir showed a value of 52 t y^{-1}, its retention capacity amounts to 68 tons, equal to 60% of the total amount of phosphorus due to the catchment basin (86 t y^{-1}). The difference observed between this percentage and the one calculated for Lake Omodeo (30%) is considerable and probably linked to the morphometric and dynamic characteristics of the two lakes, and in particular to the turnover time.

c) Lake Occhito

For this reservoir, it was not possible to calculate the phosphorus budget due to the lack of data on the emissary, but it is interesting to consider the load estimates (Tab. 8) for the reasons which will be explained in the following paragraph.

The four tributaries drain almost the entire surface of the catchment basin.

5.1.2. Comparison between measured and observed loads

The observed (experimental) loads of the three above mentioned reservoirs were finally compared with those evaluated theoretically on the basis of statistical data relative to the different sources of phosphorus, and particularly to the human population, animal husbandry and industries in the sub-basins of each tributary, and to the areas of cultivated and not-cultivated soil. The calculation was made resorting to the criteria described by Marchetti & Provini (1989) for Lake Omodeo, by Sechi & Mosello (1985) for Lake Coghinas (Oschiri) and E.A.A.P. (1986) for Lake Occhito.

From table 9, in which the theoretical and the experimental loads are compared, it appears that, in the case of Lake Omodeo, these two values are in very good agreement, with the only exception of the sub-basin of the Taloro for which a theoretical load of 17.2 t y^{-1} was evaluated against an experimental one of only 8.2. Such a difference can be explained with the fact that the

Tab. 9. Comparison between phosphorus loads (t y^{-1}) calculated both experimentally and theoretically for three reservoirs in Sardinia.

		experimental	theorical
Omodeo			
	Tirso	33.8	31.6
	Taloro	8.2	17.2
	Murtazzolu	16.0	14.8
	Siddo	7.9	7.5
	Total	65.9	71.1
Coghinas			
	M. Ozieri	72.5	56
	M. Oschiri	6.5	13
	M. Berchidda	11.5	12
	Total	89.5	81
Occhito			
	Tappino	27.7	56.5
	Occhito	4.9	1.8
	Cigno	3.6	7.7
	La Cattola-Fortore	6.9	38.5
	Total	43.1	104.5

waters of the Taloro, before reaching Lake Omodeo, are delayed by another small reservoir, which retains about 50% of the load due to the catchment basin.

Also regarding Lake Coghinas, the agreement between theoretical and experimental loads is very good for two of the three tributaries (M. Ozieri and M. Berchidda), while for the Occhitto, the difference is so strong as to be difficult to explain easily. The Authors of the study (E.A.A.P. 1986) attribute the relatively low value of the real load to the high concentration of suspended solids which normally characterize the tributaries and which might adsorb the phosphorus, segregating it in the fluvial sediments before reaching the reservoir. Moreover, it cannot be excluded that the data used to calculate the loads (16 samples in one year) might have been insufficient to describe the real load.

5.2. Restoration measures (diversion of the loads of the Bidighinzu Reservoir)

The only italian case of reservoir restoration is the one undertaken on Lake Bidighinzu (Sardinia), which consisted of the diversion of the urban and industrial discharges previously flowing into the reservoir. The effects of this measure were followed by Luglié & Sechi (1992) since 1987, year in which the diversion began.

It is necessary to make it clear that the Bidighinzu Reservoir was eutrophic since the first year of activity, with heavy effects on the potabilization of its water, the only use for which it was planned. To reduce the effects of hypolimnic anoxy, in the area close to the taffrail an air pumping system was installed in the 60s with the aim of breaking the thermal stratification (Messina 1966).

The catchment area of the reservoir is 52 km^2 and is characterized by a low forested surface, by a considerable agricultural-pastoral activity, by the presence of an inhabited village of 3,000 people, and by agricultural-industrial activities for the treatment of $30\ 10^6\ l\ y^{-1}$ of milk.

The theoretical phosphorus load, estimated $6.3\ t\ P\ y^{-1}$ (Sechi 1986), by far superior to the allowable load ($0.6\ t\ P\ y^{-1}$) estimated by O.C.D.E. (1982).

In 1987 a conduit was built for the deviation of most of the urban and industrial discharges downstream of the reservoir. In theory, this measure should have significantly modified the load, but without significant effects on the conditions of the water, because a large contribution of the phosphorus load (about $1.5\ t\ y^{-1}$) was attributable to non-point sources (grazing, fertilizing, uncultivated soil) (Sechi 1986). With the reduced load, the phosphorus concentrations expected in the water of the reservoir ranges between a minimum of 30 and a maximum of 60 mg m^{-3}. In practice, more than a year after the measure was taken, no changes were observed regarding the trophic status of the lake. In particular, the following observations were made:

- in 1988-89, the epilimnetic values of pH exceeded 10 in July, with an increase compared to those measured previously in the same period (9 units);
- the layer between 15 m and the bottom was almost constantly anoxic, while the level of oxygen saturation at the surface reached a maximum of 300%;
- phosphorus levels remained much higher than the ones (30-60 mg m^{-3}) expected after the deviation. The orthophosphate fraction alone reached 200 mg m^{-3} in the winter months, and between March and September values of up to 600 mg m^{-3} were recorded;
- among the nitrogen compounds, maximum concentrations were reached by ammonia which, notwithstanding the blowing of air into the reservoir water, normally has concentrations of more than 1,000 mg m^{-3}, with a maximum of 2,028 mg m^{-3} (reached in July, before the beginning of the aeration);
- the average chlorophyll-*a* concentration at the surface was 32 mg m^{-3};
- transparency values measured with a Secchi disk range between 0.3 m in July to 2.4 in September, with an annual mean of 1.25 m;
- finally, the density of the phytoplankton was $1.2\ 10^8$ cells l^{-1}, as a mean

annual value, to which corresponds a biomass of 5.5 mg l^{-1}.

The picture emerging from these synthesized data is that of an environment which did not benefit from the diversion measure. It is still not clear if this is due to an insufficient lapse of time between the diversion and the restoration monitoring (keeping in mind the internal loading), or to a possible failure in carrying out the diversion.

6. CONCLUSIONS

From the above data, it emerges that the knowledge of the water quality of Italian reservoirs is too dishomogeneous and insufficient for a complete picture. It follows that also the problems related to the purposes of the reservoirs remain unknown, which is particularly serious in case of water potabilization for human consumption.

Further studies are needed to assess the water quality not only concerning the typical problems of eutrophication (decomposition of the algal biomass), but also as regards the appearance of toxic algae. The water treatment with chlorine or ozone, which causes the formation of chlorinated compounds and aldehydes exerting a mutagenic action should be considered. Finally, the determination of micropollutants would be the object of future studies, as recently found in northern Italian lakes used for the production of drinking water (Guzzella *et al.* 1989; Monarca *et al.* 1990).

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