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The zooplankton of Lake Tovel

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SUMMARY - *The zooplankton of Lake Tovel* - The zooplankton of Lake Tovel was studied from November 2001 to November 2004. Rotifers are the numerically dominant component all year round with the majority of taxa having higher densities in the main basin than in the smaller Red Bay. The rotifer genera *Polyarthra* sp., *Filinia* sp., *Synchaeta* spp. and *Asplanchna* sp. dominate the zooplankton. Among crustaceans, *Bosmina longirostris* was more abundant than *Daphnia longispina* and copepods in both basins. The dynamic hydrology of the lake influences the relationship of rotiferan and cladoceran biomass in the main basin through water inflow to the Red Bay. Under high inflow rotifers can have a higher biomass than crustaceans, while low water inflow favours cladoceran biomass. On the basis of the three year data set, it is hypothesised that water inflow also influences the relationship between phytoplankton and zooplankton. The different density and abundance of taxa in the Red Bay and in the Main Basin underline the different limnological characteristics of these two basins.

RIASSUNTO - *Lo zooplancton del Lago di Tovel* - Lo zooplancton del Lago di Tovel è stato studiato da novembre 2001 a novembre 2004. Come Baldi (1941) aveva già evidenziato, il Lago di Tovel è "un lago a rotiferi": numericamente questi sono dominanti sui crostacei in entrambi i sottobacini in cui il lago può essere distinto, il Bacino Principale e la Baia Rossa (= bacino a sud). La maggior parte dei taxa zooplanctonici presenta densità più alte nel Bacino Principale. Fra i rotiferi *Polyarthra* sp., *Filinia* sp., *Synchaeta* spp. e *Asplanchna* sp. sono i generi dominanti. Fra i crostacei *Bosmina longirostris* mostra densità superiori a quelle di *Daphnia longispina* e dei copepodi. Come biomassa, il rapporto tra rotiferi e cladoceri nel Bacino Principale è influenzato dal flusso delle acque in entrata: nei periodi di elevata portata sono componente dominante i rotiferi, mentre con portate ridotte dominano i cladoceri. In base ai dati biologici acquisiti si ipotizza che il regime degli afflussi influisca in modo determinante sulle reti trofiche (fitoplancton - zooplancton). Le differenti densità e presenza di taxa nella Baia Rossa e nel Bacino Principale sottolineano le diverse caratteristiche dei due sottobacini.

Key words: Lake Tovel (TN-Italy), zooplankton, water inflow, rotifers, crustaceans
Parole chiave: Lago di Tovel (TN-Italia), zooplancton, acqua in entrata, rotiferi, crostacei

1. INTRODUCTION

The zooplankton association of Lake Tovel was examined by prior investigators (Largaiolli 1907; Baldi 1941; Arrighetti & Siligardi 1979; Boni *et al.* 1983; Bertolli & Franceschini 1998) and was monitored during the last years in an attempt to provide a continuous and complete picture of the lake (Corradini *et al.* 2001). The pelagic species present in the lake are all found in high altitude lakes (Giussani *et al.* 1986) and are typical for oligotrophic lakes of temperate climate regions (Ruttner-Kolisko 1974).

Since Baldi's (1941) extensive studies, carried out from 1937 to 1941, Lake Tovel has been considered a rotifer lake due to the high abundance of rotifers in contrast to crustaceans. In terms of biomass rotifers can not compete with larger crustaceans (Herzig 1987; Ivanova 1987), but their short development time (reproduction cycle) gives rotifers a decisive time advantage, when food conditions for development are favourable (Walz 1995). The relationship among suspension feeding rotifers, cladocerans and copepods is important as they compete for food resources of similar size (Herzig 1987). Through exploitative competition both cladocerans (Conde-Porcuna *et al.* 1994; Wetzel 2001) and copepods (Wetzel 2001) are able to suppress rotifers, while only large *Daphnia* (> 1.2 mm) can suppress rotifers by interference competition (Wetzel 2001). Many studies have shown that the crustacean population is not the only factor restricting the occurrence and vertical distribution of rotifers. Temperature, oxygen content, pH and the availability of suitable food are important factors in determining rotifer density and biomass (Hofmann 1977; Urabe 1992). Among abiotic factors, light and temperature limit the abundance of cladocerans (Margaritora 1983) as well as of copepods (Dussart & Defaye 2001).

This work is in fulfilment of one of the objectives of the SALTO project: the in depth study of species composition as a means to evaluate the structure and seasonal dynamics of the zooplankton of Lake Tovel.

2. MATERIAL AND METHODS

Lake Tovel (A= 0.38 km^2, V= 7.4 10^6 m^3, z_{max}= 39 m, z_{mean}= 19 m) is situated in the Adamello-Brenta Natural Park (Trentino, N-Italy) at 1178 m above sea level. Information about geomorphology and trophic status is given in detail in Corradini *et al.* (2001). The lake is frozen from winter to early spring.

The zooplankton survey was conducted at five fixed stations (stations B, F, E, A, D) in the lake (Fig. 1). Zooplankton samples were collected from November 2001 to November 2004. Sampling intervals for station A and B were biweekly in 2002 with exceptions due to atmospheric conditions, and monthly in 2003 and 2004. For station F, E and D samples were sporadically taken only in 2003. The depth intervals for the different stations were surface, -1 m, -2 m, -5 m, then every five meters until 3 m above the bottom. These samples were taken with a 3 l Ruttner bottle, filtered through a 10 µm plankton net and fixed with formalin (1%). For estimating sampling standard error five replicate samples were taken in autumn 2003 at a depth of 0 m, -5 m, -15 m, -25 m and -35 m with the Ruttner bottle. Quantitative integrated water column samples were taken by vertical hauls from a depth of -35 m to surface with a 70 µm plankton net with a truncated cone opening (17 cm diameter - Hydrobios). Care was taken to insure a constant slow speed while raising the net; a 100% filtration efficiency was assumed.

Littoral samples were taken at eleven fixed sites along the shore (Fig. 1) in April, July, August, September, October and December 2003. These samples were taken along transects (length 50 m) along the shore at a depth of approximately -0.5 m to -1 m with a 20 µm plankton net and fixed with alcohol (20%).

Rotifers were identified according to Koste (1978), Braioni & Gelmini (1983) and Nogrady & Segers (2002), cladocerans according to Margaritora (1983) and copepods according to Einsle (1996). Data for *Cyclops strenuus* includes adults, copepodites and nauplii. Zooplankton counts were done with a Wild Macroscope M420 using a gridded petri dish. The whole sample was counted due to the low density of species. Rotifer biovolume was calculated and transformed to dry weight according to Bottrell *et al.* (1976). Crustacean dry weight was estimated according to Bottrell *et al.* (1976) for *Bosmina longirostris*, *Daphnia longispina* and *Cyclops strenuus* and according to Rosen (1981) for *nauplii*.

The opportunity of having access to original samples from Baldi's 1937-1941 sampling campaigns permitted their re-examination utilizing current rotifer taxonomy and comparison with present data.

For comparison of sampling accurancy between bottle and net a regression analysis was performed using ln (x+1) transformed data.

3. RESULTS

Different aspects regarding the zooplankton in Lake Tovel are treated, including a comparison of Baldi's investigation (1937-1940) with ours (2001-2004), differences between the Red Bay and the Main Basin, zooplankton composition and the relationship "water inflow - rotifers - cladocera - phytoplankton" in the Main Basin. A separate paragraph is given to the sampling method as sampling is a fundamental aspect of our work.

3.1. Sampling method

The results of five replicates of discrete samples indicate that at depths where species have their highest density our estimates show a coefficient of variation (adjusted for small values of n according to Sokal & Rohlf 1981) from 10% up to 22%, depending on the species. Density estimates of rare species showed a higher coefficient of variation than that of abundant species. At depths different from the density peak counts vary markedly. A comparison of the mean density of individuals estimated by the Ruttner bottle and by the Apstein net showed that both methods are well correlated but showed a better agreement for the more abundant *Bosmina longirostris* than for the less abundant *Daphnia longispina* (Tab. 1). While the density pattern is quite similar with both sampling methods for *Bosmina longirostris* and *Daphnia longispina* (Fig.

Tab. 1 - R^2 and p values of the linear regression between mean number of individuals caught by bottle and plankton net.

Tab. 1 - R^2 e valori p della regressione lineare tra il numero medio di individui presi con la bottiglia e con il retino.

	R^2	p
Bosmina longirostris	0.92	< 0.001
Daphnia longispina	0.58	< 0.001

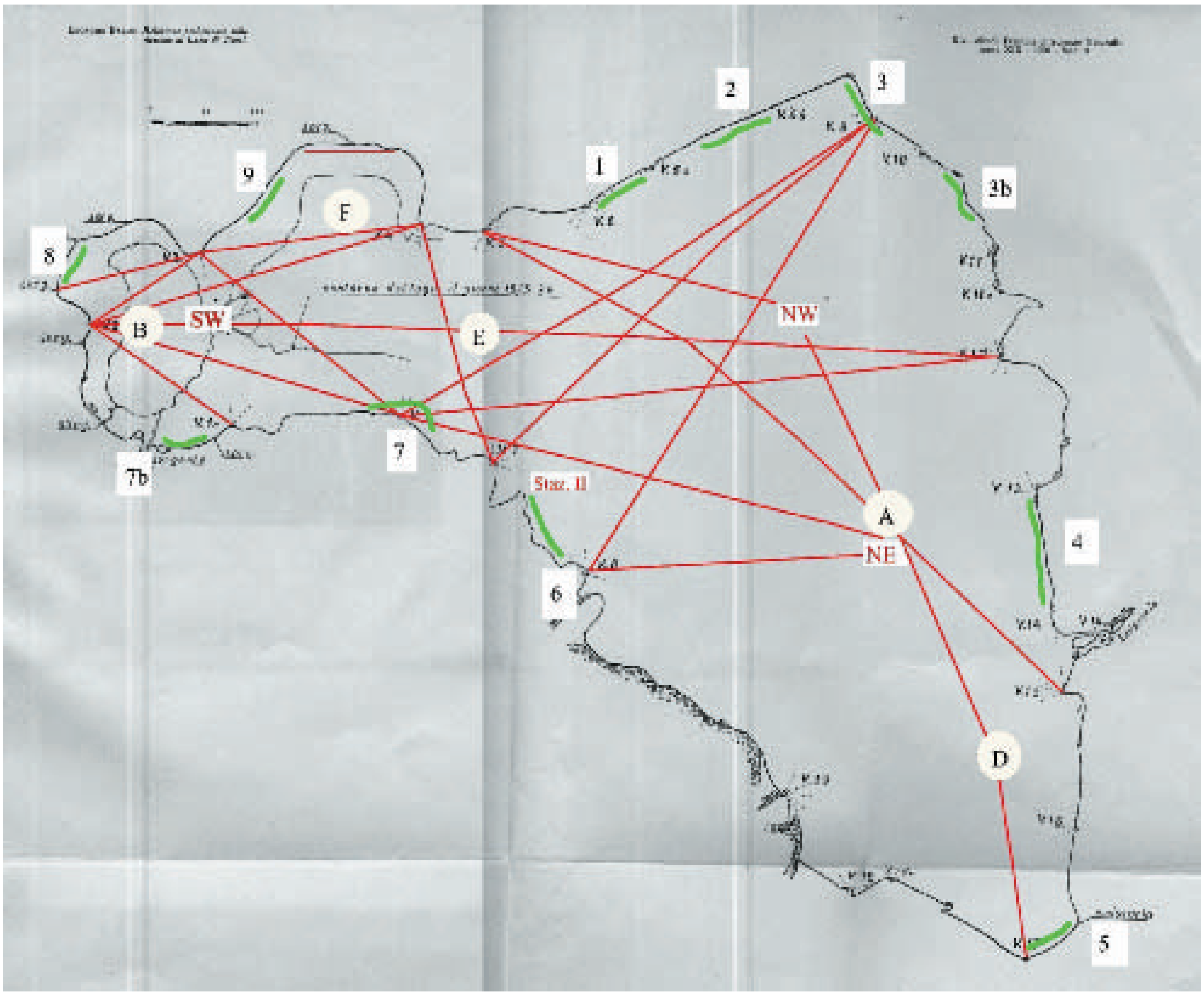

Fig. 1 - Map of Lake Tovel: black letters indicate the sampling stations, black numbers indicate the transects of littoral sampling of our study. The red lines and the red letters indicate the transects and stations of Baldi's sampling (1937-1940).
Fig. 1 - Mappa del Lago di Tovel: le lettere in nero indicano le stazioni dei campionamenti del plancton, i numeri in nero i transetti di campionamento del litorale del nostro studio. Le linee in rosso indicano i transetti e le lettere in rosso le stazioni di campionamento di Baldi (1937-1940).

2), the mean density estimated by bottle sampling was often higher than by net sampling. During the sampling period the copepod *Cyclops strenuus* was a rare species present sporadically with very low densities. It was therefore not surprising that there was little correlation in the density estimates of *Cyclops strenuus* between the two sampling methods, bottle and net.

3.2. Comparison of Baldi's investigation (1937-1940) with our investigation (2001-2004)

The tasks and aims, combined with different sampling instruments and techniques (Tab. 2), between Baldi (1941) and this study did not permit a direct comparison of data. For example Baldi took both horizontal samples along transects and vertical samples from layers, e.g. -20 m to -15 m, while we took samples at fixed stations and fixed depths, e.g. -20 m, -15 m. Littoral samples were sporadically taken by Baldi at irregular intervals, while we took them at regular intervals at fixed stations (Fig. 1). By re-examining Baldi's samples from the period 1937-1940 we were able to add seven species to Baldi's species list of rotifers (Tab. 3) and we could determine some of Baldi's genera of rotifers to species level. Comparing the number of rotifer and crustacean taxa found in Baldi's samples with the present study we could increase the number of taxa from 39 (Baldi) to 56 (present) (Tab. 3).

According to Baldi (1941) the rotifer *Asplanchna priodonta* was an abundant species in his samples,

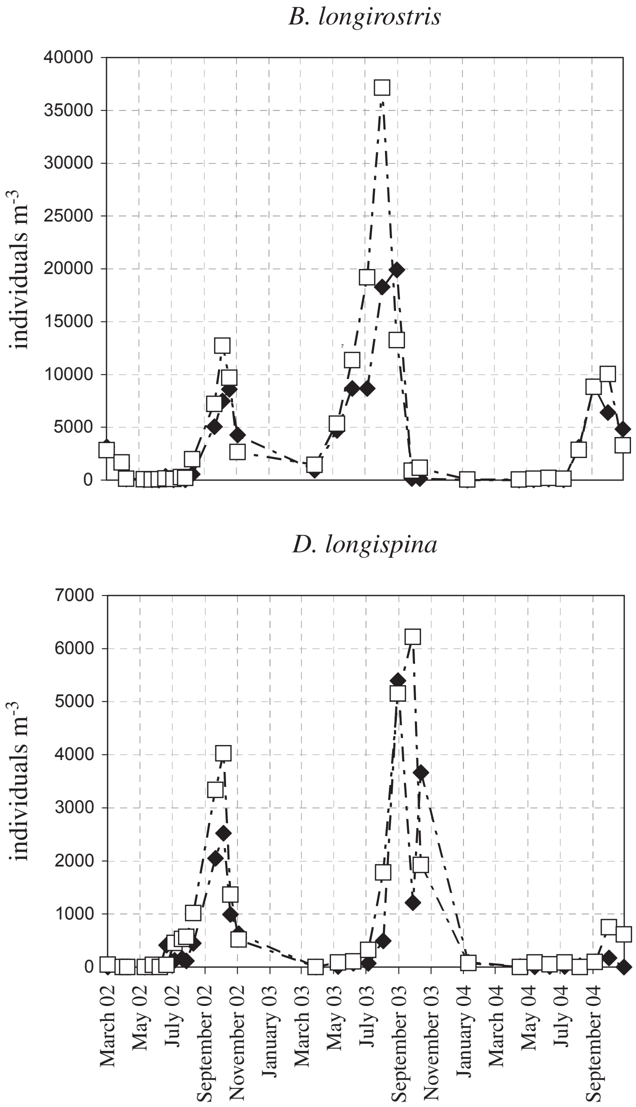

Fig. 2 - Mean numbers of individuals of *Daphnia longispina* and *Bosmina longirostris* estimated by plankton net (filled circles) and by Ruttner bottle (open quadrats).
Fig. 2- Densità media di individui rilevata tramite il retino (bolli neri) e tramite la bottiglia (quadri vuoti) per Daphnia longispina e Bosmina longirostris.

Tab. 2 - Sampling instruments used by Baldi (1937-1940) and SALTO (2001-2004) for different types of samples.
Tab. 2 - Attrezzature di campionamento di Baldi (1937-1940) e SALTO (2001-2004) per i diversi tipi di campioni.

Type of sample	Baldi	SALTO
Plankton samples	Clark-Bumpus sampler	Ruttner bottle and net 10 µm
	Apstein net 60 µm	Apstein net 70 µm
Bottom samples	Eckman Birge grab	Not sampled
Shore samples	Plankton net Apstein 60 µm	Plankton net 20 µm

however we were not able to find any specimen in the subsamples which were re-examined. Nevertheless a high abundance of *Synchaeta* gr. *stylata pectinata*, a group which Baldi did not mention in his work, was noted in these subsamples. Individuals of *Cyclops* sp. were found by Baldi (1941) at every sampling occasion, while we found them at irregular intervals in time and depth. The cladocerans *Simocephalus vetulus*, *Alonella exisa* and *Acroperus harpae* rare and sporadic species for Baldi, were also recorded by Bertolli & Franceschini (1998), but not by us. The abundance of *Bosmina longirostris* from Baldi to present seems to have increased markedly: in Baldi's samples we found only an empty carapace, but during our investigation it was the most abundant cladoceran in the lake.

3.3. *Differences between Red Bay and Main Basin*

Zooplankton consisting of rotifers and cladoceran and copepod crustaceans always had a higher mean abundance (individuals m^{-3}) in the Main Basin (station A) than in the Red Bay (station B), except in summer 2002. When considering biomass instead of density, this difference increased markedly (Fig. 3). In both stations rotifers had higher mean densities (individuals m^{-3}) than crustaceans. The crustacean community consisted mainly of *Bosmina longirostris* and incidentally of *Daphnia longispina* and copepods both at stations A and B.

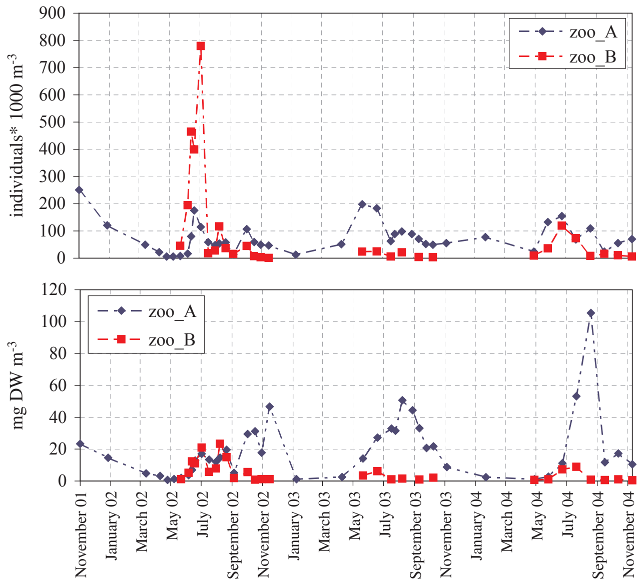

Fig. 3 - Density as individuals m^{-3} (upper panel) and biomass as mg dry weight m^{-3} (lower panel) of zooplankton at stations A (= zoo_A) and at station B (= zoo_B)
Fig. 3 - Densità dello zooplancton alla stazione A (= zoo_A) e B (= zoo_B) in individui m^{-3} (panello di sopra) e in mg peso secco m^{-3} (panello di sotto).

Tab. 3 - List of rotifer and crustacean taxa for Lake Tovel found by Baldi (1937-1940) and SALTO (2001-2004). ○ indicates mention in Baldi (1939, 1941), • indicates presence in Baldi's samples, + indicates this study, * only an empty lorica or carapace found, = indicates synonym, ? indicates doubtful identification of *Asplanchna priodonta* by Baldi (see text). R.B. = Red Bay; NE B. = North Eastern Basin (Main Basin).

Tab. 3 - Lista dei taxa di rotiferi e crostacei trovati sia da Baldi (periodo 1937-1940) che nel corso del progetto SALTO (periodo 2001-2004). ○ indica trovato da Baldi (1939, 1941), • indica presenza nei campioni di Baldi, + indica trovato in questo studio, solo una lorica vuota o un carapace vuoto trovato, = indica sinonimo, ? indica identificazione dubbia di Asplanchna priodonta da Baldi (spiegazione nel testo). R.B. = Baia Rossa, NE B. = Bacino Nord Est (Bacino Principale).*

phylum Rotifera (Fauna Europaea 2004)	**Baldi**	**SALTO**	**location**
Keratella cochlearis (Gosse)	○	+	R.B. NE B.
Keratella quadrata (O.F. Müller)	○	+	R.B. NE B.
Keratella quadrata var. *curvicornis*	○	+	R.B. NE B.
Keratella quadrata var. *valga*	○	+	R.B. NE B.
Floscularia sp. = *Collotheca* sp.	○	+	R.B. NE B.
Polyarthra platyptera = gr. *dolichoptera vulgaris*	○	+	R.B. NE B.
Notholca longispina = *Kellicottia longispina* (Kellicot)	○	+*	R.B.
Polyarthra - amictic egg	○	+	R.B. NE B.
Polyarthra - resting egg	○	+	R.B. NE B.
Filinia longiseta (Ehrenberg)	○	+	NE B.
Asplanchna priodonta (Gosse)	○?	+	R.B. NE B.
Brachionus urceolaris (O.F. Müller)	○		R.B. NE B.
Euchlanis sp.	○		NE B.
Monostyla sp. = *Lecane* sp.	○		NE B.
Trichocerca sp.	○		R.B. NE B.
Distyla sp.= *Lecane* s. str.	○	+	R.B. NE B.
Lecane gr. *lunaris* (Pejler)	○	+	R.B. NE B.
Lecane subtilis (Harring & Myers)	○	+	R.B. NE B.
Lecane luna (O.F. Müller)	○	+	R.B. NE B.
Notholca gr. *labis acuminata*	○	+	R.B. NE B.
Notholca squamula (O.F. Müller)	○	+	R.B. NE B.
Trichocerca cavia (Gosse)	○	+	R.B. NE B.
Trichocerca longiseta (Schrank)	○	+	R.B. NE B.
Euchlanis dilatata (Ehrenberg)	○	+	R.B. NE B.
Ascomorpha ecaudis (Perty)	•	+	R.B. NE B.
Bdelloidea	•	+	R.B. NE B.
Cephalodella gibba (Ehrenberg)	•	+	R.B. NE B.
Cephalodella ventripes (Dixon-Nuttall)	•	+	R.B. NE B.
Cephalodella ventripes v. *angustior* (Donner)	•	+	R.B. NE B.
Lepadella ovalis (O.F. Müller)	•	+	R.B. NE B.
Synchaeta gr. *tremula oblonga*	•	+	R.B. NE B.
Synchaeta gr. *stylata pectinata*	•	+	R.B. NE B.
Trichotria pocillum (O.F. Müller)	•	+	R.B. NE B.
Monommata longiseta (O.F. Müller)	•	+	NE B.
Brachionus angularis (Gosse)		+	R.B. NE B.
Cephalodella sp.		+	R.B. NE B.
Cephalodella megalocephala v. *rotundus*		+	R.B. NE B.

phylum Rotifera (Fauna Europaea 2004)	**Baldi**	**SALTO**	**location**
Testudinella patina (Hermann)		+	R.B. NE B.
Filinia terminalis (Plate)		+	R.B. NE B.
Gastropus stylifer (Imhof)		+	R.B. NE B.
Lecane flexilis (Gosse)		+	R.B. NE B.
Lepadella ovalis (O.F. Müller)		+	R.B. NE B.
Lepadella patella (O.F. Müller)		+	R.B. NE B.
Proales sp.		+	R.B. NE B.
Proales decipiens (Ehrenberg)		+	R.B. NE B.
Brachionus diversicornis (Daday)		+	NE B.
Cephalodella forficula (Ehrenberg)		+	NE B.
Dicranophorus forcipatus (O.F. Müller)		+	NE B.
Encentrum incisum (Wulfert)		+	NE B.
Lecane closterocerca (Schmarda)		+	NE B.
Lindia janickii (Wiszniewski)		+	NE B.
Notommata glyphura (Wulfert)		+	NE B.
Pleurotrocha petromyzon (Ehrenberg)		+	NE B.
Philodina sp.		+	NE B.
Rotaria sp.		+	NE B.
Colurella sp.		+	R.B.
Colurella uncinata f. *deflexa* (Ehrenberg)		+	R.B.
Lepatella sp.		+	R.B.
subclass Copepoda (Fauna Europaea, 2004)			
nauplii	○	+	R.B. NE B.
Cyclops strenuus (Fischer)	○	+	R.B. NE B.
Eucyclops serrulatus (Fischer)	○	+	R.B.
Macrocyclops fuscus (Jurine)	○		R.B.
suborder Cladocera (Fauna Europaea, 2004)			
Chydorus sphaericus (O.F. Müller)	○	+	R.B. NE B.
Daphnia gr. *longispina hyalina*	○	+	R.B. NE B.
Macrothrix hirsuticornis (Norman & Brady)	○	+	R.B. NE B.
Alona affinis (Leydig)	○	+	R.B. NE B.
Bosmina longirostris (O.F. Müller)	○*	+	R.B. NE B.
Alonella excisa (Fischer)	○		R.B.
Acroperus harpae (Baird)	○		R.B.
Simocephalus vetulus (O.F. Müller)	○		R.B.

The different taxa of rotifers had higher mean densities at station A though *Polyarthra* gr. *dolichoptera vulgaris* had higher mean densities at station B in summer 2002.

The difference according to species composition between the Red Bay and the Main Basin is confirmed by the varying and low values of the similarity coefficient of Jaccard for the years of investigation (Tab. 4).

3.4. The zooplankton composition in the Main Basin

As already noted by Corradini *et al.* (2001), the genera *Polyarthra* sp., *Filina* spp., *Synchaeta* spp. and *Asplanchna* sp. are the most common zooplankton taxa in Lake Tovel (Tab. 5). These and other taxa present in the lake are cold stenothermal or eurythermal species adapted to low water temperatures. Nevertheless taxa density changed markedly in station A from 2002 to 2004 (Tab. 5). With respect to 2002, in 2003 an increase of *Gastropus stylifer*, *Bosmina longirostris* and *Daphnia longispina* and a decrease of *Asplanchna priodonta*, *Ascomorpha ecaudis, Polyarthra* gr. *dolichoptera vulgaris* and of *Synchaeta* gr. *stylata pectinata* occurred. In 2004 *Filinia* gr. *longiseta terminalis* almost disappeared and *Asplanchna priodonta* and *Keratella cochlearis* increased markedly.

New recorded species for Lake Tovel were mainly near shore rotifers including some rare species such as *Encentrum incisum* and *Lindia janickii*.

3.5. The relationship water inflow - rotifers - cladocera - phytoplankton in the Main Basin

In Obertegger *et al.* (2005) the relationship zooplankton - water flow was based on water inflow measured at a gauge placed on the main tributary, S. Maria stream, one kilometer above the lake (Ferretti & Borsato 2004). In this study we use inflow data directly to the lake (Borsato & Ferretti 2006): water flow which reach the lake with a time delay and with smoothed peaks because the karstic zone above the lake acts as a buffer. The concept of disturbance caused by inflow holds true independent of the data set used for water inflow data.

The pattern of water inflow to the Red Bay, which consists mainly of underwater-springs with a mean temperature between 4 and 5 °C, was different

Tab. 4 - Jaccard similarity coefficient between the Red Bay and the Main Basin. Jaccard calculated for the species composition of zooplankton, of crustaceans + rotifers and of rotifers for the whole year.
Tab. 4 - Coefficiente di similarità di Jaccard tra la Baia Rossa e il Bacino Principale. Jaccard calcolato per la composizione delle specie dello zooplancton, dei crostacei + rotiferi e dei rotiferi per tutto l'anno.

	similarity coefficient of Jaccard	
year	zooplankton	rotifers
2002	0.76	0.63
2003	0.67	0.52
2004	0.54	0.46

Tab. 5 - Mean density of the different taxa in individuals m^{-3} for the different years at the stations A and B. Mean calculated for the whole water column and for the whole year.
Tab. 5 - Densità media dei diversi taxa in individui m^{-3} per le diverse annate alle stazioni A e B. Media calcolata per tutta la colonna d'acqua e per tutto l'anno.

	A			B		
taxon	2002	2003	2004	2002	2003	2004
Asplanchna priodonta	6435	2205	11211	756	295	464
Ascomorpha ecaudis	537	131	97	10	0	0
Bosmina longirostris	2803	12128	2737	1926	918	287
Daphnia longispina	619	1966	191	240	104	23
Cyclops strenuus	419	73	291	189	363	12
Filinia gr. *longiseta terminalis*	15526	25832	4274	168	1199	0
Gastropus stylifer	484	13608	1126	128	679	6
Keratella cochlearis	473	107	912	12	353	1229
Keratella quadrata	313	310	169	26	0	23
Polyarthra gr. *dolichoptera vulgaris*	19325	2728	13086	146067	7489	27522
Synchaeta gr. *stylata pectinata*	2251	894	2759	2751	169	4238
Synchaeta gr. *tremula oblonga*	7282	22428	31575	292	1941	766
rotifers	62533	70032	76536	151428	12364	34560
cladocera	3422	14094	2928	2167	1022	310

in 2002, 2003 and 2004 (Borsato & Ferretti 2006). During a period of very high inflow (>1000 l s^{-1}), such as in spring 2002, both zooplankton and phytoplankton maintained low densities. Rotifer abundance was similar in summer 2002, 2003 and 2004, while cladocera showed low densities in 2002 and 2004 and high densities in 2003. Peak abundance for cladocera was generally reached in autumn (2002 and 2004 in October, 2003 in late August). In 2002, with a continuous high water inflow, rotifer biomass exceeded that of cladocerans for the whole summer. In the year 2003 with a low water inflow rotifer biomass exceeded that of cladocerans only once. In summer 2004 rotifer biomass exceeded crustacean biomass, markedly showing its highest biomass values for the period. Phytoplankton biovolume was higher in 2002 and 2004 and showed a marked decrease in 2003. Generally rotifer biomass decreased with decreasing phytoplankton as they are connected by predator-prey relations. On the other hand a decrease in phytoplankton biomass resulted in a delayed decrease of cladocerans. Increase of cladoceran abundance coincided with low water inflow, which occurred generally in autumn, except in 2003 when cladocerans had already increased in July. Remarkably in 2003 *Daphnia longispina* and *Bosmina longirostris* showed an alternating biomass between themselves (*Bosmina longirostris* decreased, *Daphnia longispina* increased) (Fig. 4).

4. DISCUSSION AND CONCLUSION

4.1. Sampling method

Our results regarding the comparison of sampling efficiency of the Ruttner bottle and of the plankton net indicate that even if the bottle is not always considered adequate for estimating crustacean density (Downing & Riegler 1984), in our conditions and for this lake sampling efficiency of the bottle for *Bosmina longirostris* and *Daphnia longispina* is comparable to the net. The strong linear relationship between bottle and net, the density peaks found with both methods and higher densities obtained with the bottle, all indicate that in the case of Lake Tovel pelagic cladoceran density can be better estimated by the bottle than by the net. For a rare species such as *Cyclops strenuus* in Lake Tovel, acurate density estimates are always difficult.

According to sampling error, replicates samples showed that density peaks of species could be recorded with sufficient accuracy. Even if no replicates were taken during normal sampling, high densities are always well estimated. Unfortunately low densities are always difficult to estimate independentely of the number of replicates and compared to other lakes (IASMA 2000), Lake Tovel is generally characterised by low zooplankton density.

4.2. Comparison of Baldi's investigation (1937-1940) with our investigation (2001-2004)

The different sampling methods used and the different purpose of Baldi's and this investigation allowed only a qualitative comparison of data. Taken this into consideration, the presence of *Asplanchna priodonta* and *Synchaeta* gr. *stylata pectinata* in Baldi's and in our samples can have different causes. According to us Baldi probably mistook *Synchaeta* gr. *stylata pectinata* for *Asplanchna priodonta*, understandable given the taxonomic keys available at the time. First, in figures 21, 33 and 74 (Baldi 1941) *Synchaeta* gr. *stylata pectinata* is clearly visible with its round shape, foot and its auricles, but no *Asplanchna priodonta* is visible in these figures. A second important point is that Baldi did not mention *Synchaeta* gr. *stylata pectinata* in his work although it was the dominating species in his re-examined planktonic samples. Nevertheless this does not esclude that *Asplanchna priodonta* was present in the lake in low densities or was periodically absent, as happened during the period 2002-2004.

4.3. Differences between Red Bay and Main Basin

The higher density and biomass in the Red Bay with respect to the Main Basin during summer 2002 was the result of the high abundance of *Polyarthra* gr. *dolichoptera vulgaris* in the Red Bay. This rotifer seems to have a decisive advantage over other species in the Red Bay when there is a period of high water inflow. In summary a comparison of zooplankton species composition and distribution in the Red Bay and in the Main Basin underlines the different limnology of these two habitats. The shallowness of the Red Bay that results in a steep temperature gradient and high irradiance values combined with the inflow of cold spring-water probably limits the occurrence of certain taxa.

4.4. The zooplankton composition in the Main Basin

In the Main Basin *Synchaeta* spp., *Polyarthra* gr. *dolichoptera vulgaris*, *Keratella cochlearis*, *Asplanchna priodonta* and *Filinia terminalis* were common species. According to Ruttner-Kolisko (1974) these species are representative of oligotrophic lakes of temperate climatic regions and are well adapted to the low water temperature present in Lake Tovel. The increase of *Gastropus stylifer* in 2003 was probably the result of higher temperatures and reduced disturbance in the lake (factors probably also responsible for the increase of *Bosmina longirostris* and *Daphnia longispina*). The changing density of other taxa might be related to competition, to changes in algae density and/or to hydrological conditions.

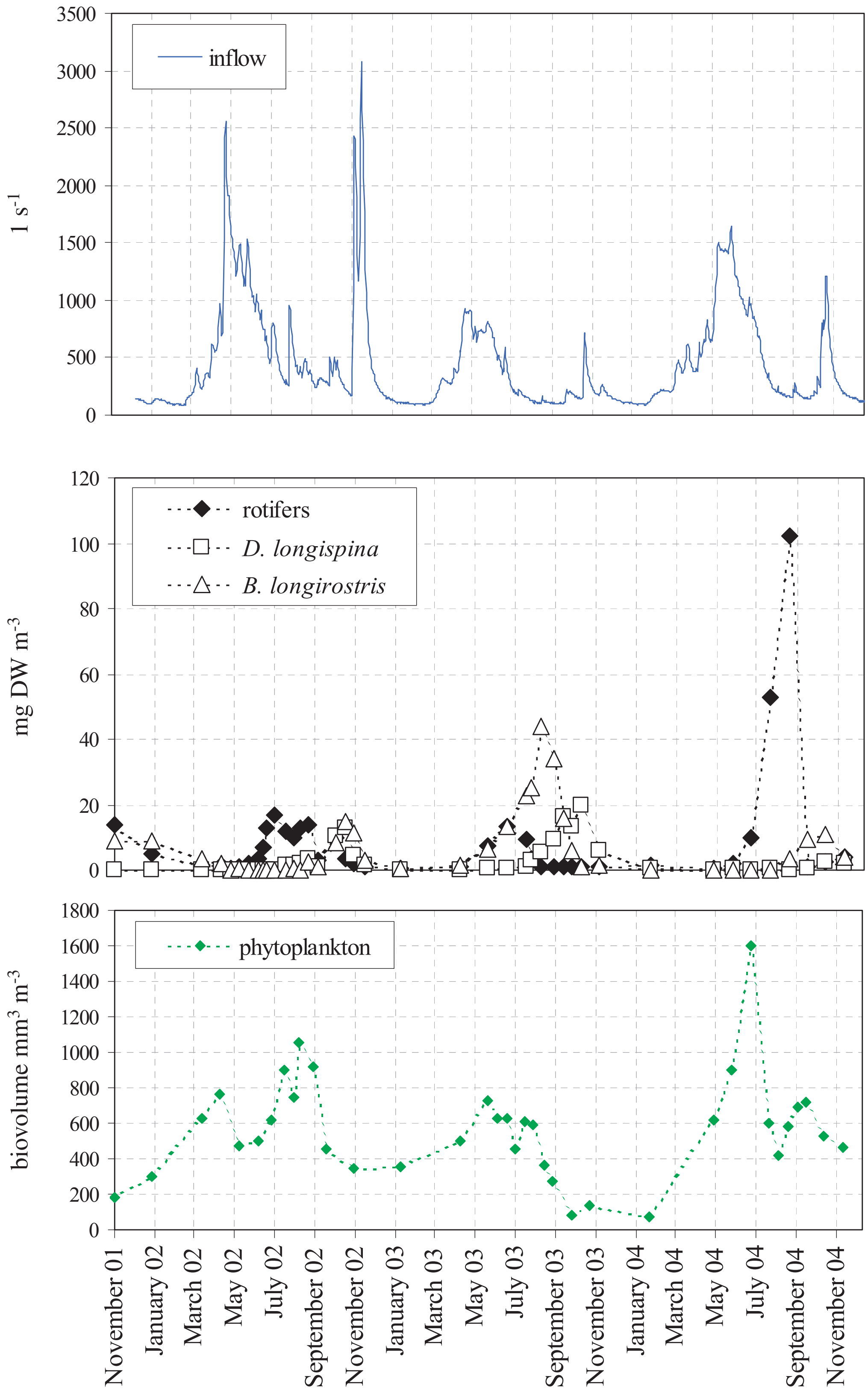

Fig. 4 - Upper panel: water inflow (Borsato & Ferretti 2006); middle panel: biomass (mg dry weight) of rotifers, of *Bosmina longirostris* and of *Daphnia longispina*; lower panel: phytoplankton biovolume (mm^3m^{-3}) (Tolotti *et al*. 2006) for the years 2002, 2003 and 2004.

Fig. 4 - Riquadro superiore: portata dell'acquifero (Borsato & Ferretti 2006); riquadro centrale: biomassa (mg peso secco) di rotiferi, di Bosmina longirostris e di Daphnia longispina; riquadro inferiore: dati di biovolume di fitoplancton (mm^3m^{-3}*)* (Tolotti *et al*. 2006) *per le annate 2002, 2003 e 2004.*

4.5. *The relationship water inflow - rotifers - cladocera - phytoplankton in the Main Basin*

Changes in the abundance of rotifers and crustaceans were related to water inflow and not to water level of the lake, the former being a more sensitive parameter than the latter. The periods of very high water inflow in spring 2002 led to washing-out effects of plankton. Density fluctuations of rotifers were not directly attributable to water inflow as abundance is the sum of all pelagic rotifers regardless of their species specific response to changing hydrology. The biomass of rotifers and cladocerans in 2002, 2003 and 2004 was however directly linked to disturbance in water inflow. In agreement with the moderately high water inflow in summer 2002 and 2004, rotifer biomass could exceed cladoceran biomass in Lake Tovel. In contrast to Ivanova (1987) and Herzig (1987) we hypothesised (Obertegger *et al.* 2005) that predation by fish, as stated by the size efficiency theory of Brooks & Dodson (1965) was not the determining factor controlling the abundance of crustaceans. In Lake Tovel the only planktonic feeding fish is the Artic charr (*Salvelinus alpinus*) and stomach content analysis has shown it to be adapted to a chironomid and plecoptera based diet (Betti 2003). In fact, oligotrophic Lake Tovel does not support large fish populations and therefore another factor controlling the zooplankton community was proposed. Water inflow probably causes enough disturbance in the lake to influence zooplankton. Rotifers can better manage disturbance, because of their much lower generation times than crustaceans. Only under more lake-like characteristics e.g. low water inflow, as it is generally the case in autumn, cladocerans are able to increase in density and to establish their populations. In summer/autumn 2003 both inflow and phytoplankton decreased and rotifers could be suppressed by cladocerans by exploitative competition because rotifers have higher food threshold levels and lower filtration rates than cladocerans (Sommer 1994). The relationship between *Bosmina longirostris* and *Daphnia longispina* was also influenced by the decrease of phytoplankton. Under limited food conditions *Bosmina* sp., having a lower filtration rate than *Daphnia* sp. (Lair 1991), could also be outcompeted by exploitative competition.

This study showed that water inflow is a major driving force in governing the zooplankton association in Lake Tovel and has underlined the significant limnological differences between the Red Bay and the Main Basin.

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