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Phytoplankton and zooplankton species distribution in the high altitude lakes of the Piora Valley (Canton Ticino, Switzerland)

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Abstract. Species composition of phyto- and zooplankton assemblages in four lakes of altitude between 1850 and 2377 meters in the Piora valley were studied in July 2010. All the lakes were dominated by diatoms and chlorophytes, both recorded with a similar number of taxa, except in Lake Tom, where a lower number of taxonomic units were found among the chlorophytes. The taxonomic composition of the phytoplankton assemblage was basically the same in all the lakes sampled. The zooplankton composition was evaluated both on the samples collected during the 2010 survey and on samples collected in previous years from lakes of the same area. Totally ten lakes were compared. The taxonomic composition varied not only among the lakes, but, as can be expected, also within each lake during the different years. In terms of zooplankton diversity, the highest species richness was found in Lake Cadagno. Rotifers were the most represented as a number of taxa in all the lakes sampled, except in Lake Pecian. The rate of change in species composition along the altitudinal gradient points to an altitudinal threshold partitioning the lakes into two groups characterized by relatively different zooplankton assemblages. However, whether is altitude the major structuring factor for zooplankton species composition in the Piora lakes, or (likely) local factors are more effectively acting in each site is a question that cannot be answered by this preliminary study.

Distribuzione delle specie fito- e zooplanctoniche nei laghi di alta quota della Val Piora (Cantone Ticino, Svizzera)

Riassunto. La composizione in specie delle associazioni fito- e zooplanctoniche di quattro laghi della Val Piora compresi in un intervallo altitudinale da 1850 a 2377 m è stata oggetto di uno studio condotto nel mese di luglio 2010. L'analisi dell'associazione fitoplanctonica ha evidenziato una dominanza delle diatomee e delle cloroficee in tutti i laghi esaminati. Inoltre, in tutti i laghi il numero di unità tassonomiche era simile, ad eccezione del Lago Tom con un minor numero di taxa di cloroficee. Pertanto, la composizione tassonomica del fitoplancton appariva sostanzialmente omogenea. La composizione dello zooplancton è stata valutata sia dall'analisi dei campioni raccolti nel 2010 che dall'analisi di campioni raccolti in anni precedenti nei laghi dell'area di studio. In totale sono stati confrontati dati ottenuti da 10 laghi evidenziando differenze nella composizione tassonomica sia tra laghi che tra anni diversi. Nel Lago Cadagno è stato rinvenuto il maggior numero di specie. I rotiferi rappresentano la maggioranza delle specie in tutti i laghi, ad eccezione del Lago Pecian. La sostituzione di specie lungo il gradiente altitudinale sembrerebbe indicare una soglia che segnerebbe la ripartizione dei laghi in due gruppi caratterizzati da una composizione tassonomica relativamente differenziata. Tuttavia, questo studio preliminare non ha la pretesa né la possibilità di valutare se l'altitudine sia il fattore più determinante per la composizione tassonomica dello zooplancton nei laghi della Val Piora oppure se, come probabile, caratteristiche locali, tipiche di ciascun lago, abbiano maggiore rilevanza.

Keywords: plankton, alpine lakes, alpine biodiversity, southern Swiss Alps

INTRODUCTION

The scientific interest in zooplankton communities of high altitude alpine lakes dates back to more than one century, when most studies were devoted to the naturalistic description of ecosystems with a main focus on species composition and geographical distribution (see TOLOTTI *et al.*, 2006). Later on the focus was deviated on ecological characterization of species and of their interactions and alpine lakes started to be used as natural "laboratories" thanks to the environmentally driven simplicity of their trophic food web. This particular feature being still attracting, further interest arose around alpine lakes as sensitive "reference" systems in the studies of global climatic change and anthropogenic impacts (e.g. PSENNER, 2002) and as biodiversity reserves (e.g. MANCA & ARMIRAGLIO, 2002). Nevertheless, information on alpine lakes is still scattered and poor, except for a few environments intensively studied in the frame of the AL:PE, MOLAR and EMERGE EU Projects (TOLOTTI *et al.* 2006). In spite of their relevant socio-economic value and of the related resource exploitation, the lakes lying in the Piora Valley belong to the majority of almost unknown ecosystems. Information on planktonic assemblages is totally lacking for most lakes, and is very poor even for Lake Cadagno which has been intensively studied for the chemical and microbiological aspects mainly related to its peculiar meromictic character. Indeed, only few studies reporting information on the plankton of Piora lakes were found, mostly dealing with Lake Cadagno, but offering only a partial view of actual species richness. Indeed, only two of the previous studies were mainly focused on zooplankton diversity assessment (Lake Cadagno: Winder *et al.* 2001, Lake Ritóm: Borner, 1920), while other studies dealt with harpacticoid fauna (Graeter, 1899) and pseudofossil cladoceran remains (Boucherle & Züllig 1988). Although information on phytoplankton taxonomic composition in Piora lakes is available since the beginning of the last century (Meister, 1912; Schanz *et al.*, 1988), the data on microalgal biodiversity are very scanty. Among the few relevant surveys in the Piora region, the studies conducted in Lake Cadagno by Guettinger & Straub (1998), which was focused on diatom flora and the research by Schanz *et al.* (1988), could be remembered. Other studies dealing with phytoplankton assemblages in Lake Cadagno were addressed to ecosystem processes, such as sedimentation (Schanz & Stalder, 1998), primary production in relation to food web (Friedl, 1987; Camacho *et al.*, 2001) and phytoplankton response to UV-radiation (Callieri *et al.*, 2001; Neale *et al.*, 2001). No scientific records can be found on phytoplankton flora of the lakes Segna and Campanitt. It seemed therefore important to contribute to better understanding of these environments by adhering to the "48 hours biodiversity in the Piora Valley" through a qualitative survey of the plankton assemblages in ten lakes differing by morphometric, physico-chemical and trophic characteristics. While this study does not pretend to be exhaustive, it represents a contribution to improve the knowledge of zooplankton and phytoplankton species richness in high altitude alpine lakes.

STUDY AREA, MATERIALS AND METHODS

The lakes surveyed within this study are located in the Piora Valley (Canton Ticino, Switzerland) above the timberline (except for Lake Ritóm) at an altitude ranging from 1850 to 2377 m a.s.l. Lake catchment areas are in general covered by sparse vegetation (alpine meadows, shrubs), except for the forested (timber, pine) area surrounding the southern side of Lake Ritóm. The lakes sampled differed for orographical and geochemical characteristics (tab. 1). The basins are mostly located on metamorphic and igneous crystalline rocks (e.g. amphibolitic and granatiferous gneiss, mica—schist, hornblende-schist) but four of them (Ritóm, Tom, Cadagno, Campanitt) are partially lying on a large lenticle of calcareous rocks (schists, gypsum and dolomia) which is enclosed between the crystalline rocks forming the northern and southern slopes of the Piora Valley. The lakes entirely lying on the crystalline rocks are likely to be potentially affected by acidification processes. This seems to be confirmed for Pécian, Taneda and di Dentro lakes by pH values < 7 measured during the open water season (Boggero *et al.*, 1996; Peduzzi, personal communication). On the contrary, the release of calcium, sulphur and magnesium salts from the gypsum-dolomite layer increases the buffer capacity of the lakes in contact with the calcareous rocks and determines the meromictic stratification of lake waters. While Lake Cadagno is still meromictic, Lake Ritóm and Tom lost this feature following human induced hydrodinamic modifications.

Lake Ritóm is the most heavily human impacted (dammed for power plant exploitation) but anthropogenic activities in the area (tourism, pasture, fish introduction, water abstraction for hydroelectric power plant and drinking water supply) more or less affect most of the lakes sampled. If on the one hand a low to moderate degree of human disturbance is expected to affect Giubin and Segna lakes, on the other hand they probably represent natural examples of ecosystem extremes due to their temporary character.

Along a trophic gradient the Taneda, Pécian, di Dentro and (probably) Campanitt lakes can be assigned to the ultra-oligotrophic category, while a moderately higher nutrient availability is expected in the remaining lakes as a result of either geochemical (Tom, Ritóm, Cadagno) or morphometric (della Segna, Giubin) characteristics. Unfortunately, limnological data are lacking for these lakes, except for L. Cadagno.

Tab. 1 – Inventory of sampled lakes and their characteristics

Lake	altitude	Surface area (km²)	Maximum depth (m)	Type of lake	Presence of fish	pH
Ritóm	1850	1.49	69	dam lake	yes	≥ 7
Cadagno	1923	0.26	21.5	meromictic	yes	≥ 7
Tom	2021	0.13	8	meromictic (?)	yes	≥ 7
Giubin	2097	0.003	8	temporary	yes	≥ 7
della Segna	2191	0.0025	< 1	marsh	no	≥ 7
di Dentro	2298	0.060	28.4		yes	< 7
Taneda 1	2248	0.0059	48 (?)		no (newts)	< 7
Taneda 2	2305				no	< 7
Pecian	2323	0.010			no	≥ 7
Campanit	2377	0.0075			no (?)	≥ 7

Samplings were carried out on July 23th and 24th in 2010. Both phyto- and zooplankton were collected using a 75 µm mesh plankton net. Vertical tows were taken from the deepest part of Lake Cadagno to the surface; in the other lakes, due to the lack of a boat, horizontal tows were taken by retrieving plankton nets thrown by hand from the shore. Vertical and horizontal tows were taken in Lake Ritóm from the dam. Samples were concentrated and preserved in a 5 % neutralized (CaCO3) formaldehyde solution.
Phytoplankton taxonomic composition was determined using inverted microscope following the Utermöhl technique (Utermöhl, 1958). Samples were observed for species identification, drawing on the following references: Huber-Pestalozzi (1938, 1941, 1942, 1955, 1961, 1968, 1982, 1983); Bourelly (1972, 1981); Komàrek & Anagnostidis, (1999, 2005), Ettl & Gärtner, (1988) and Kadlubowska (1984). The Bacillariophyta were identified according to Krammer & Lange-Bertalot (1986, 1988, 1991a, b, 2000).
Zooplankton organisms were sorted from the samples for qualitative analysis in the laboratory and taxa were identified to a species (or genus) level. The identification of copepods followed Dussart (1967, 1969), Kiefer (1978) and Einsle (1993), the identification of cladocerans followed Margaritora (1985) and Alonso (1996), and that of rotifers followed Ruttner-Kolisko (1974) and Koste (1978).
Zooplankton beta diversity was calculated according to Wilson & Shmida (1984).
Zooplankton samples collected in previous years during the same season were also re-analyzed (tab. 4).

RESULTS AND DISCUSSION

Phytoplankton

The total number of phytoplankton taxonomic units recorded in Piora lakes during the July 2010 survey was 106 (fig. 1). The complete taxa list is reported in tab. 2. Bacillariophyta and Chlorophyta were the most common phyla, with 33 and 56 taxonomic units respectively. As shown in fig. 1, the total number of *taxa* found per lake was close to 40 units, with a minimum of 34 in Lake Tom and a maximum of 49 in Lake Campanitt. Bacillariophyta and Chlorophyta amounted to around 20 taxonomic units each in lakes Segna and Cadagno, whereas in Lake Campanitt the number of chlorophytes taxa was higher than the number of diatoms taxa (27 vs. 12) and the opposite was recorded in Lake Tom (7 vs. 20).
Most of the *taxa* were found in a single lake: only 8 *taxa* were common to the four lakes (*Achnantes minutissima, Fragilaria cfr. pinnata, Fragilaria construens, Navicula* sp., *Chlamydocapsa cfr. planctonica, Mougeotia* sp., *Planktothrix agardhii, Sphaerocystis schroeterii*), 10 were recorded in three lakes and 23 in two lakes. However, considering the genus level, the phytoplankton populations are much more homogeneous, as clear from tab. 2. From the functional point of view, the assemblages are typically characterised at genus level (see Reynolds *et al.*, 2002), therefore our data seem to indicate similar habitat conditions in the lakes investigated.
We can assume the number of *taxa* found in each lake as a measure of α diversity, whereas the total number of taxonomic units found in the Piora lakes can be considered as a rough estimation of γ diversity, assuming the region as homogeneous from the limnological point of view. The γ/α ratio gives the β diversity, an estimation of the contribution of each single lake to the total biodiversity in the Piora area. The values of the β diversity are shown in fig. 2: higher the value of this parameter, lower the contribution to biodiversity. As concerns the whole phytoplankton assemblage, the four lakes give a similar contribution, although, some differences can be pointed out for single phyla. We already mentioned the surprisingly low value of chlorophytes taxa in Lake Tom; Lake Campanitt contributes less than the other lakes to diatoms (Bacillariophyta) and Cadagno shows a slightly lower number of Cyanoprokaryota taxa. Dinoflagellata were not found in Lake Segna. Of course, we are aware that our results cannot be taken as a reliable measure of the phytoplankton biodiversity in Piora lakes, at least because of two main reasons: the first

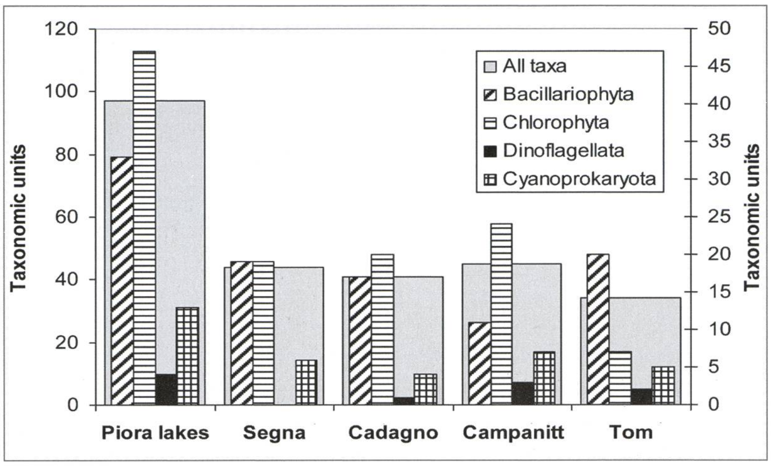
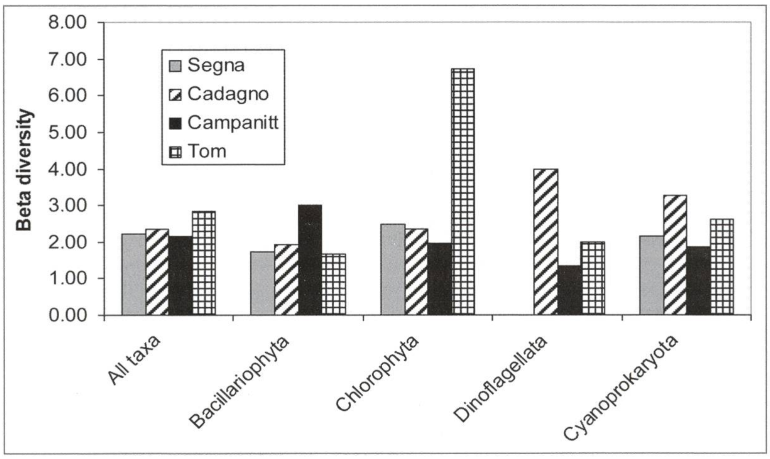


Fig. 1 – Number of phytoplankton taxa found in July 2010 in four lakes of the Piora Valley. Large grey bars in the background are the total number of taxa (left scale), whereas the small bars indicate the contribution of single phyla (right scale). The data for "Piora lakes" are the sum of the four lakes.

Fig. 2 – Values of ß diversity for the whole phytoplankton assemblage and for single phyla in the lakes sampled in July 2010.



Tab. 2 – Phytoplankton taxa recorded in Piora lakes in July 2010.

Phylum	Class	Order	Family	Genus/Species	Segna	Cadagno	Campanitt	Tom
Bacillariophyta	Bacillariophyceae	Achnanthales	Achnanthaceae	*Achnantes minutissima*	•	•	•	•
Bacillariophyta	Bacillariophyceae	Achnanthales	Achnanthaceae	*Achnantes sp.*	•		•	
Bacillariophyta	Bacillariophyceae	Achnanthales	Achnanthaceae	*Achnanthes cfr. taeniata*	•			
Chlorophyta	Chlorophyceae	Zygnematales	Zygnemataceae	*Actinotaenium sp.*		•		
Bacillariophyta	Bacillariophyceae	Thalassiophysales	Catenulaceae	*Amphora ovata*	•		•	•
Cyanophyta	Cyanophyceae	Nostocales	Oscillatoriaceae	*Arthrospira cfr. platensis*	•		•	•
Bacillariophyta	Bacillariophyceae	Fragilariales	Fragilariaceae	*Asterionella formosa*		•		•
Dinoflagellata	Dinophyceae	Gonyaulacales	Ceratiaceae	*Ceratium hirundinella*		•	•	•
Chlorophyta	Chlorophyceae	Tetrasporales	Palmellopsidaceae	*Chlamydocapsa cfr. ampla*			•	
Chlorophyta	Chlorophyceae	Tetrasporales	Palmellopsidaceae	*Chlamydocapsa cfr. planctonica*	•	•	•	•
Chlorophyta	Chlorophyceae	Tetrasporales	Palmellopsidaceae	*Chlamydocapsa sp.*			•	
Chlorophyta	Chlorophyceae	Zygnematales	Zygnemataceae	*Closterium acicularis*		•		
Bacillariophyta	Bacillariophyceae	Achnanthales	Cocconeidaceae	*Cocconeis cfr. placentula*		•	•	•
Chlorophyta	Chlorophyceae	Chlorococcales	Coelastraceae	*Coelastrum astroideum*	•			
Chlorophyta	Chlorophyceae	Zygnematales	Zygnemataceae	*Cosmarium abbreviatum*		•		
Chlorophyta	Chlorophyceae	Zygnematales	Zygnemataceae	*Cosmarium depressum*		•		
Chlorophyta	Chlorophyceae	Zygnematales	Zygnemataceae	*Cosmarium margaritatum*		•		
Chlorophyta	Chlorophyceae	Zygnematales	Zygnemataceae	*Cosmarium punctulatum*	•			
Chlorophyta	Chlorophyceae	Zygnematales	Zygnemataceae	*Cosmarium subgranatum*	•	•		
Chlorophyta	Chlorophyceae	Zygnematales	Zygnemataceae	*Cosmarium vexatum*		•		
Chlorophyta	Chlorophyceae	Zygnematales	Zygnemataceae	*Cosmarium cfr. phaseolus*		•		
Chlorophyta	Chlorophyceae	Zygnematales	Zygnemataceae	*Cosmarium cfr. reniforme*	•		•	
Chlorophyta	Chlorophyceae	Zygnematales	Zygnemataceae	*Cosmarium cfr. subgranatum*			•	•
Chlorophyta	Chlorophyceae	Zygnematales	Zygnemataceae	*Cosmarium sp.*	•	•	•	
Bacillariophyta	Coscinodiscophyceae	Thalassiosirales	Stephanodiscaceae	*Cyclotella cfr. radiosa*				•
Bacillariophyta	Coscinodiscophyceae	Thalassiosirales	Stephanodiscaceae	*Cyclotella comensis*				•
Bacillariophyta	Coscinodiscophyceae	Thalassiosirales	Stephanodiscaceae	*Cyclotella sp.*		•		
Bacillariophyta	Bacillariophyceae	Cymbellales	Cymbellaceae	*Cymbella cfr. cymbiformis*	•	•		
Bacillariophyta	Bacillariophyceae	Cymbellales	Cymbellaceae	*Cymbella minuta (Encyonema ventricosum)*		•		•
Bacillariophyta	Bacillariophyceae	Cymbellales	Cymbellaceae	*Cymbella sp.*	•	•	•	
Bacillariophyta	Bacillariophyceae	Bacillariales	Bacillariaceae	*Denticula cfr. tenuis*		•		•
Bacillariophyta	Bacillariophyceae	Fragilariales	Fragilariaceae	*Diatoma mesodon*				•
Chlorophyta	Trebouxiophyceae	Chlorellales	Chlorellaceae	*Dictyosphaerium cfr. pulchellum*			•	
Bacillariophyta	Bacillariophyceae	Rhopalodiales	Rhopalodiaceae	*Epithemia adnata*				•
Chlorophyta	Zygnematophyceae	Zygnematales	Desmidiaceae	*Euastrum binale.*			•	
Chlorophyta	Zygnematophyceae	Zygnematales	Desmidiaceae	*Euastrum verrucosum*	•			
Chlorophyta	Chlorophyceae	Euglenales	Euglenaceae	*Euglena sp.*		•		
Bacillariophyta	Bacillariophyceae	Eunotiales	Eunotiaceae	*Eunotia pectinalis var. undulata*	•			•
Bacillariophyta	Bacillariophyceae	Fragilariales	Fragilariaceae	*Fragilaria cfr. pinnata*	•	•	•	•
Bacillariophyta	Bacillariophyceae	Fragilariales	Fragilariaceae	*Fragilaria construens*	•	•	•	•
Bacillariophyta	Bacillariophyceae	Fragilariales	Fragilariaceae	*Fragilaria crotonensis*		•		•
Bacillariophyta	Bacillariophyceae	Fragilariales	Fragilariaceae	*Fragilaria sp.*	•			

Phylum	Class	Order	Family	Genus/Species	Segna	Cadagno	Campanitt	Tom
Chlorophyta	Chlorophyceae	Chlorococcales	Radiococcaceae	*Gloeocapsa sp.*	•			
Chlorophyta	Chlorophyceae	Chlorococcales	Radiococcaceae	*Gloeocystis sp.*		•	•	
Bacillariophyta	Bacillariophyceae	Cymbellales	Gomphonemataceae	*Gomphonema truncatum*		•		•
Chlorophyta	Chlorophyceae	Zygnematales	Zygnemataceae	*Gonatozygon monotaenium*		•	•	
Dinoflagellata	Dinophyceae	Gymnodiniales	Gymnodiniaceae	*Gymnodinium elveticum*				•
Chlorophyta	Chlorophyceae	Chlorellales	Chlorellaceae	*Kirchneriella cfr. microscopica*	•			
Cyanophyta	Cyanophyceae	Chroococcales	Merismopediaceae	*Merismopedia cfr. trolleri*			•	
Cyanophyta	Cyanophyceae	Chroococcales	Merismopediaceae	*Merismopedia glauca*			•	
Chlorophyta	Zygnematophyceae	Zygnematales	Desmidiaceae	*Micrasterias rotata*	•			
Cyanophyta	Cyanophyceae	Chroococcales	Chroococcaceae	*Microcystis cfr. flos-aquae*				•
Cyanophyta	Cyanophyceae	Chroococcales	Chroococcaceae	*Microcystis flos-aquae*	•			
Cyanophyta	Cyanophyceae	Chroococcales	Chroococcaceae	*Microcystis sp.*	•		•	
Cyanophyta	Cyanophyceae	Chroococcales	Chroococcaceae	*Microcystis wesembergii*	•			
Chlorophyta	Chlorophyceae	Zygnematales	Zygnemataceae	*Mougeotia sp.*	•	•	•	•
Bacillariophyta	Bacillariophyceae	Naviculales	Naviculaceae	*Navicula radiosa*		•	•	•
Bacillariophyta	Bacillariophyceae	Naviculales	Naviculaceae	*Navicula sp.*	•	•	•	•
Bacillariophyta	Bacillariophyceae	Bacillariales	Bacillariaceae	*Nitzschia cfr. acicularis*				•
Chlorophyta	Chlorophyceae	Oedogoniales	Oedogoniaceae	*Oedogonium sp.*				•
Chlorophyta	Trebouxiophyceae	Oocystales	Oocystaceae	*Oocystis lacustris*			•	
Chlorophyta	Trebouxiophyceae	Oocystales	Oocystaceae	*Oocystis sp.*			•	
Cyanophyta	Cyanophyceae	Nostocales	Oscillatoriaceae	*Oscillatoria cfr. limosa*		•		•
Chlorophyta	Chlorophyceae	Chlorococcales	Hydrodictyaceae	*Pediastrum boryanum*	•	•	•	
Chlorophyta	Chlorophyceae	Chlorococcales	Hydrodictyaceae	*Pediastrum duplex*			•	
Chlorophyta	Chlorophyceae	Chlorococcales	Hydrodictyaceae	*Pediastrum tetras*	•			
Dinoflagellata	Dinophyceae	Peridiniales	Peridiniaceae	*Peridiunium sp.*			•	
Dinoflagellata	Dinophyceae	Peridiniales	Peridiniaceae	*Peridiunium umbonatum*			•	
Bacillariophyta	Bacillariophyceae	Naviculales	Pinnulariaceae	*Pinnularia sp.*	•	•		
Chlorophyta	Chlorophyceae	Sphaeropleales	Neochloridaceae	*Planktosphaeria gelatinosa*	•	•		
Cyanophyta	Cyanophyceae	Nostocales	Oscillatoriaceae	*Planktothrix agardhii*	•	•	•	•
Cyanophyta	Cyanophyceae	Nostocales	Nostocaceae	*Pseudoanabaena cfr. catenata*	•	•	•	
Cyanophyta	Cyanophyceae	Nostocales	Nostocaceae	*Pseudoanabaena cfr. limnetica*				•
Cyanophyta	Cyanophyceae	Nostocales	Nostocaceae	*Pseudoanabaena sp.*		•		
Chlorophyta	Chlorophyceae	Chlorococcales	Scenedesmaceae	*Scenedesmus aculeolatus*	•			
Chlorophyta	Chlorophyceae	Chlorococcales	Scenedesmaceae	*Scenedesmus costato-granulatus*	•			
Chlorophyta	Chlorophyceae	Chlorococcales	Scenedesmaceae	*Scenedesmus disciformis*		•	•	
Chlorophyta	Chlorophyceae	Chlorococcales	Scenedesmaceae	*Scenedesmus quadrispina*	•	•		
Chlorophyta	Chlorophyceae	Chlorococcales	Scenedesmaceae	*Scenedesmus smithii*				•
Chlorophyta	Chlorophyceae	Chlorococcales	Scenedesmaceae	*Scenedesmus sp.*	•			
Chlorophyta	Chlorophyceae	Tetrasporales	Palmellopsidaceae	*Sphaerocystis schroeterii*	•	•	•	•
Chlorophyta	Chlorophyceae	Zygnematales	Zygnemataceae	*Spondylosium planum*			•	
Chlorophyta	Chlorophyceae	Zygnematales	Zygnemataceae	*Spyrogira sp.*		•		
Chlorophyta	Chlorophyceae	Zygnematales	Desmidiaceae	*Staurastrum cfr. bieneanum*			•	

Phylum	Class	Order	Family	Genus/Species	Segna	Cadagno	Campanitt	Tom
Chlorophyta	Chlorophyceae	Zygnematales	Desmidiaceae	*Staurastrum cfr. brebissonii*			•	
Chlorophyta	Chlorophyceae	Zygnematales	Desmidiaceae	*Staurastrum cfr. paradoxum*		•		
Chlorophyta	Chlorophyceae	Zygnematales	Desmidiaceae	*Staurastrum alternans*			•	
Chlorophyta	Chlorophyceae	Zygnematales	Desmidiaceae	*Staurastrum furciferum.*		•		
Chlorophyta	Chlorophyceae	Zygnematales	Desmidiaceae	*Staurastrum pingue*		•		•
Chlorophyta	Chlorophyceae	Zygnematales	Desmidiaceae	*Staurastrum punctulatum*			•	•
Chlorophyta	Chlorophyceae	Zygnematales	Desmidiaceae	*Staurastrum setigerume*			•	•
Chlorophyta	Chlorophyceae	Zygnematales	Desmidiaceae	*Staurastrum teliferum*			•	
Chlorophyta	Chlorophyceae	Zygnematales	Desmidiaceae	*Staurastrum sp.*		•	•	
Bacillariophyta	Bacillariophyceae	Bacillariales	Naviculales	*Stauroneis anceps*	•		•	
Bacillariophyta	Bacillariophyceae	Bacillariales	Naviculales	*Stauroneis sp.*	•			
Bacillariophyta	Bacillariophyceae	Surirellales	Surirellaceae	*Surirella sp.*	•			
Bacillariophyta	Bacillariophyceae	Surirellales	Surirellaceae	*Surirella spiralis*	•			
Bacillariophyta	Bacillariophyceae	Fragilariales	Fragilariaceae	*Synedra acus*		•	•	
Bacillariophyta	Bacillariophyceae	Fragilariales	Fragilariaceae	*Synedra ulna*	•	•		•
Bacillariophyta	Bacillariophyceae	Tabellariales	Tabellariaceae	*Tabellaria fenestrata*	•			•
Bacillariophyta	Bacillariophyceae	Tabellariales	Tabellariaceae	*Tabellaria flocculosa*	•			
Chlorophyta	Chlorophyceae	Zygnematales	Zygnemataceae	*Teilingia granulata*	•		•	
Chlorophyta	Chlorophyceae	Chlorococcales	Scenedesmaceae	*Willea irregularis*			•	
Cyanophyta	Cyanophyceae	Chroococcales	Chroococcaceae	*Woronichinia naegeliana*			•	
Chlorophyta	Chlorophyceae	Zygnematales	Zygnemataceae	*Xanthidium armatum*		•		
Chlorophyta	Chlorophyceae	Zygnematales	Zygnemataceae	*Zygnema sp.*	•			

one is that the taxonomic composition of the phytoplankton assemblages is extremely variable across the seasons, therefore a single sampling cannot be representative for the whole species structure; the second reason is that sampling phytoplankton with a net would exclude most of the small species from the sample. This could probably explain why we did not record Chrysophyceae, usually common in alpine lakes (Tolotti *et al.*, 2006), or Cryptophyta, found in previous studies in lakes Cadagno (Schanz *et al.*, 1988; Bertoni *et al.*, 1998; Camacho *et al.*, 2001) and Tom (Schanz *et al.*, 1988). As already mentioned in the introduction, the planktonic assemblages in Piora lakes are almost completely unknown, with the only exception of Lake Cadagno. However, the different sampling strategies followed in this and previous phytoplankton studies in Cadagno do not allow a reliable comparison of the data, although a raw estimation of the evolution of assemblages' structure across the time could be given (tab. 3). The comparison with past phytoplankton records show an unchanged importance of the Bacillariophyceae, among which species belonging to the genera *Cyclotella*, *Asterionella* and *Fragilaria* were commonly found during the last 20 years. Schanz *et al.* (1988), going back to the beginning of XX century, report that the phytoplankton taxonomic structure they observed in Piora region was not significantly different from that described in 1915-1928 (Bachmann, 1924; 1928), indicating that these lakes were not affected by pressures modifying their ecological status. On the other side, it is a bit surprising the lack or the few findings of Chlorophyceae in previous studies, with the only exception of *Sphaerocystis schroeteri*, always found in Cadagno samples. We could hypothesise this class would be rare in plankton, but quite frequent in littoral populations: in fact, chlorophytes are reported as common among littoral algae by Schanz *et al.* (1988), but were virtually absent in studies mainly dealing with open water phytoplankton (Bertoni *et al.*, 1998; Camacho *et al.*, 2001). Using a net sampling we probably collected and concentrated many chlorophytes taxa coming from the littoral zone of Lake Cadagno. The littoral *taxa* list reported in Schanz *et al.* (1988) for the Piora lakes, confirms this hypothesis, including many organisms identified in our net samples.

Zooplankton

In total thirty-three zooplankton species were identified from all samples. Of these, eighteen were Rotifera, ten Cladocera, and five Copepoda (tab. 4). The taxonomic composition varied not only among the lakes, but, as can be expected, also within each lake during the different years. The greatest number of species was recorded in Lake Cadagno (25 taxa for entire sampling period), followed by Lake Tom (16) and Lake Giubin (14) (fig. 3).

Lake Cadagno 2010	**Friedl (1987)**	**Schanz et al (1988)**	**Schanz & Stalder (1998)**	**Güttinger & Straub (1998)**	**Bertoni et al. (1998)**	**Camacho et al. (2001)**
Achnantes minutissima	•			•		
Asterionella formosa	•			•	•	
Cocconeis cfr. placentula				•		
Cyclotella sp.	•	•	•	•	•	•
Cymbella sp.	•			•		
Cymbella cfr. cymbiformis				•		
Cymbella minuta				•		
Denticula cfr. tenuis				•		
Fragilaria construens				•		
Fragilaria crotonensis	•		•	•		
Fragilaria cfr. pinnata				•		
Gomphonema truncatum				•		
Navicula sp.						
Navicula radiosa				•		
Pinnularia sp.						
Synedra acus						
Synedra ulna					•	•
Tabellaria fenestrata						
Oscillatoria cfr. limosa						
Planktothrix agardhii						
Pseudoanabaena cfr. catenata						
Pseudoanabaena sp.						
Actinotaenium sp.						
Chlamydocapsa cfr. planctonica						
Closterium acicularis						
Cosmarium sp.	•					
Cosmarium abbreviatum						
Cosmarium depressumm						
Cosmarium margaritatum						
Cosmarium cfr. phaseolus						
Cosmarium subgranatum						
Euglena sp.						
Gloeocystis sp.	•					
Gonatozygon monotaenium						
Mougeotia sp.	•					
Pediastrum boryanum	•					
Planktosphaeria gelatinosa						
Scenedesmus disciformis						
Scenedesmus quadrispina						
Sphaerocystis schroeterii	•	•	•		•	
Staurastrum furciferume						
Staurastrum pingue						
Staurastrum cfr. paradoxum						
Spyrogira sp.						
Xanthidium armatum						
Ceratium hirundinella						

Tab. 3 – Phytoplankton taxa list of Lake Cadagno, after the 2010 survey, compared with the past phytoplankton records.

Rotifers constituted the largest share of zooplankton diversity (15 species) in Lake Cadagno. On the contrary, Lake Pecian was the least diverse most likely due to the absence of rotifers. *Kellicottia longispina, Polyarthra gr. vulgaris-dolychoptera* (*sensu* Ruttner-Kolisko) and *Keratella cochlearis* were the most widespread, while 5 species occurred only in one lake. In particular, *Polyarthra* gr. *minor-remata* (*sensu* Ruttner-Kolisko), *Synchaeta lakowitziana* and *Testudinella* sp. were found only in Lake Cadagno, *Synchaeta pectinata* only in Lake di Dentro and *Hexarthra fennica* var. *oxyuris* in Lake Giübin. We must consider that the rotifer component was probably underestimated due to the inadequacy of sampling. Indeed, rotifers should be sampled by bottles and/or traps, but if nets are used the mesh size should be much narrower than 75 µm. In spite of this source of bias in rotifer sampling, the number of species found in Lake Cadagno is higher than reported by a previous study

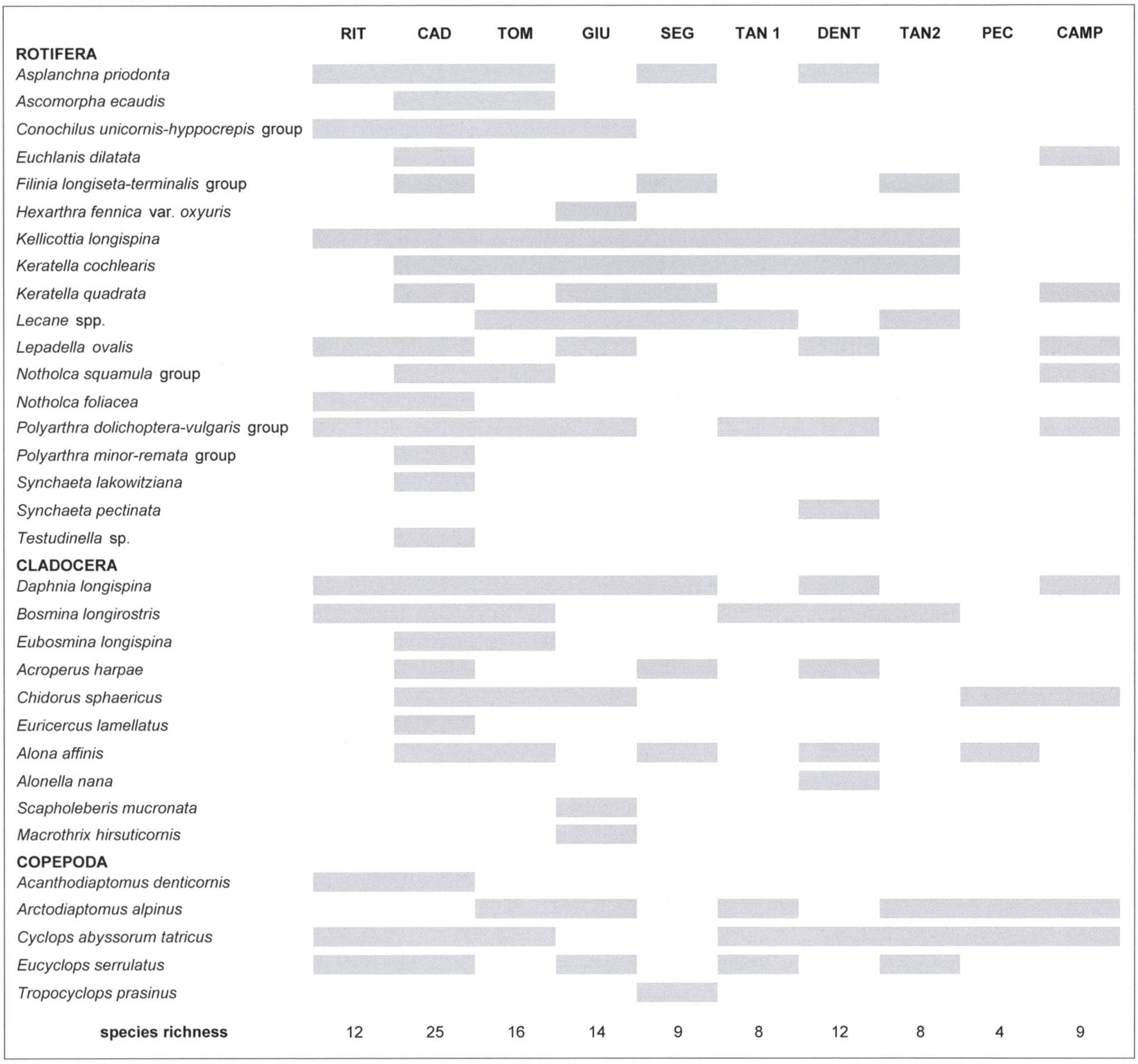


Fig. 3 – Distribution of the zooplankton species at the ten sampled lakes ordered according an altitudinal gradient. **RIT** = Lake Ritóm, **CAD** = Lake Cadagno, **TOM** = Lake Tom, **GIU** = Lake Giübin, **SEG** = Lake della Segna, **TAN1** = Lake Taneda 1, **DENT** = Lake di Dentro, **TAN2** = Lake Taneda 2, **PEC** = Lake Pecian, **CAMP** = Lake Campanit.

which used a 50 μm mesh size net (Winder *et al.*, 2001). This lake also appears to have the highest rotifer richness out of the 10 sampled lakes as can be reasonably expected in a meromictic lake due to the abundant and diversified bacterial assemblage (De Marta *et al.*, 1998; Tonolla *et al.*, 1998).

Most of the species found in this survey are common representatives of rotifer assemblages in high mountain lakes, such as the cosmopolitan eurithermic *Keratella cochlearis* and the cold-stenotermic *Notholca squamula, Synchaeta lakowitziana* and *Polyarthra dolychoptera* (e.g. Ruttner-Kolisko, 1974; Jersabek, 1995). The occurrence of other species seems to be favoured by particular local conditions. For instance, the regular occurrence of abundant populations of *Filinia* gr. *longiseta-terminalis* (*sensu* Ruttner-Kolisko) in Lake Cadagno confirm the affinity of this taxon for waters rich in detritus and bacteria and for its capacity to deal with hypoxic conditions (Kizito & Nauwerk, 1995). Due to taxonomical difficulties within the *Filinia longiseta-terminalis* group (e.g Ruttner-Kolisko, 1989) we are not entrusted with our identification at the species level, but the Lake Cadagno specimens seemed to belong to *F. hofmanni*. This is an oxiclinal species which concentrates just above the hypolimnetic oxic-anoxic interface and, therefore, it can attain high abundances in meromictic lakes (e.g. Miracle & Armengol-Dìaz, 1995) such as Lake Cadagno.

The occurrence in Lake Giubin of *Hexarthra fennica* var. *oxyure*, a species typically occurring in chloride salt waters (e.g. Ruttner-Kolisko,1974; Modenutti, 1998; Moscatello & Belmonte, 2004) is likely indicative of the periodical increase of water conductivity, one of the most important community structuring factors in temporary ponds (e.g. Caramujo & M-J Boavida, 2010).

Cladocerans were quite well represented in all lakes in July with the exception of Taneda lakes where only one species (*Bosmina longirostris*) occurred. *Daphnia longispina* was the most

prevalent cladoceran species, occurring in all of the lakes except for the two Taneda lakes and Pecian. Low productivity could be hypothesized to explain the absence of *Daphnia* in all of these lakes, probably combined in the two Taneda lakes with low pH and/or the predatory pressure of the abundant newt population. Evidences were reported for the role of food limitation as the most relevant discriminant factor for presence/absence of *Daphnia* in alpine lakes (Winder *et al.*, 2001; Tolotti *et al.*, 2006), as well as for the negative influence of acidification (e.g. Hořická *et al.*, 2006) and amphibian predators (e.g. Schabetsberger *et al.*, 2006) on crustacean zooplankton.
Some typically littoral species were occasionally found only in one lake, such as *Macrothrix hirsuticornis* and *Scapholeberis mucronata* occurring in Lake Giubin, *Alonella nana* in Lake di Dentro and *Euricercus lamellatus* in Lake Cadagno.
Copepods were found to be represented by fewer species than cladocerans. As regards cyclopoids, *only Cyclops abyssorum tatricus* was found in most lakes in relatively high numbers, while *Eucyclops serrulatus* was eventually present in Cadagno, Giubin, Ritóm and the two Taneda lakes. *Tropocyclops prasinus*, a small species that predominantly occupy the weedy littoral of lakes and ponds, only occurred in Lake Segna (tab. 4). None of these cyclopoid species may be regarded as being typical for alpine waters, except for C. *abyssorum tatricus* which is the sole euplanktonic cyclopoid in high-altitude lakes (Jersabek *et al.*, 2001). All of the lakes, except for di Dentro and della Segna, hosted calanoid copepods, either *Acanthodiaptomus denticornis* or *Arctodiaptomus alpinus*, which were never found to co-occur in any lake. The occurrence of *A. denticornis* in the lower altitude (Cadagno, Ritóm) and of *A. alpinus* in the higher altitude lakes (tab. 1) matches the hypothesis of an altitudinal repartition of the species. Indeed, *A. alpinus* seems to show strongest preference for high altitudes above 2000 m, while *Acanthodiaptomus denticornis* is most frequently encountered in upper montane and subalpine waters (1500–2000 m) (Jersabek *et al.*, 2001). Although in the altitudinal band between 1800 and 2200 m populations of both species can be found (Tonolli, 1954), they generally do not co-occur in the same lake. The possibility for calanoid copepods to co-occur in lakes is a still debated question and, even though a few examples of coexisting competing species have been documented (e.g. Santer *et al.*, 2000; Torke, 2001) it is a commonly accepted principle that such species do not co-occur unless there are size differences between them, or differences in their spatial or temporal patterns of abundance. Rare examples of coexistence of syntopic diaptomids were documented only under the control of biotic or abiotic factors which may promote coexistence of similar species by changing competitive advantages (e.g Tonolli, 1954; Bossone & Tonolli, 1954; Anderson, 1971, 1974; Jersabek *et al.*, 2001). However, the presence in the Piora lakes of either *Acanthodiaptomus denticornis* or *Arctodiaptomus alpinus* is not necessarily the proof of a mutual exclusion. Indeed, when a single seasonal sampling is performed species overlooking may occur thus leading to erroneous conclusions.
In general, as the sampling locations were visited only in summer, it is likely that additional samples would have added further species which are strictly seasonal. However, at least as regards rotifers, many species are present almost over the whole year being less affected by the seasonal dynamics in alpine than in lowland lakes (Jersabek, 1995). Therefore, according to the same author, in most cases a representative characterization of the whole assemblage can be provided by even one single sampling in the favourable season. The same assumption could be applied to cladocerans and copepods, since both are generally present in high mountain lakes during the whole ice free season (e.g. Manca & Comoli, 1999; Simona *et al.*, 1999). This assumption seems to be only partially matched by the relatively comparable between-year species composition in each lake (tab. 4). However, differences in taxonomic composition were observed which could reflect between-years variations in seasonal conditions and the sampling performance. This latter source of variation expectedly affects more significantly the samples obtained by horizontal than by vertical net tows for (at least) one main reason that is the vertical migration of zooplankton. For this reason it is likely that Lake Cadagno, the only one sampled at the deepest point by vertical tows, was the least affected by sampling error. Lake Cadagno is also less affected by strong between-years variations, for instance in hydrology, temperature and food availability, which are likely to occur in other lakes of this study, such as the ponds that either desiccate (Giubin and Segna) or fill up with ice and snow in winter (Lake Taneda 1 and 2).
Just as the typical pattern of diversity variation with latitude and altitude (Rosenzweig, 1995) a tendency towards a decrease of species richness with increasing lake altitude was observed (fig. 4). Obviously, due to the low number of lakes considered and to the high number of driving factors involved, this relationship cannot be expected to be linear, that is to entirely explain the observed pattern. For instance, the highest species richness was not found in Lake Ritóm (the lowest in altitude) but in Lake Cadagno. The development of a rich zooplankton assemblage in this lake is explained by its particular physico-chemical conditions. Indeed, the meromictic conditions yield a relatively high productivity (e.g. Bertoni *et al.*, 1998) and provide zooplankton with a refuge against fish predation in the hypoxic and turbid water layers at the edge of the chemocline. Taking into account the bias introduced by sampling methodology, the better representativeness of Lake Cadagno

	Lago di Cadagno					Lago Tom					Lago Giubin		
	giu.98	lug.03	lug.04	lug.06	lug.10	lug.02	lug.03	lug.04	lug.06	lug.10	lug.03	lug.04	lug.08
ROTIFERA													
Asplanchna priodonta	•	•		•	•		•	•	•	•			
Ascomorpha ecaudis			•			•							
Conochilus unicornis-hyppocrepis group		•	•	•	•		•	•	•		•	•	
Euchlanis dilatata	•												
Filinia longiseta-terminalis group	•	•	•	•	•								
Hexarthra fennica var. oxyuris											•		•
Kellicottia longispina	•	•	•	•	•	•	•	•	•	•		•	
Keratella cochlearis	•		•	•		•	•		•	•		•	
Keratella quadrata	•		•		•							•	
Lecane spp.									•			•	
Lepadella ovalis	•										•		•
Notholca squamula group	•								•				
Notholca foliacea	•												
Polyarthra dolichoptera-vulgaris group	•	•		•	•	•	•	•	•	•	•	•	
Polyarthra minor-remata group	•	•		•									
Synchaeta lakowitziana	•			•									
Synchaeta pectinata													
Testudinella sp.	•												
number of species (18)	13	6	6	8	6	5	5	4	7	4	4	6	2
CLADOCERA													
Daphnia longispina		•	•	•	•	•		•	•		•	•	•
Bosmina longirostris		•	•	•	•				•				
Eubosmina longispina	•				•	•				•			
Acroperus harpae					•								
Chidorus sphaericus	•				•			•			•	•	•
Euricercus lamellatus					•								
Alona affinis				•		•	•		•				
Alonella nana													
Scapholeberis mucronata													•
Macrothrix hirsuticornis											•		
number of species (10)	2	2	2	3	6	3	1	2	3	1	3	2	3
COPEPODA													
Acanthodiaptomus denticornis	•	•	•	•	•								
Arctodiaptomus alpinus							•		•	•	•	•	•
Cyclops abyssorum tatricus	•	•	•	•	•		•	•					
Eucyclops serrulatus					•						•		
Tropocyclops prasinus													
number of species (5)	2	2	2	2	3		2	1	1	1	2	1	1
number of species per lake					25					16			14

Tab. 4 – Zooplankton taxa recorded in Piora lakes during different sampling periods

samples could theoretically explain by itself the highest richness in this lake.

The degree of differentiation along the altitudinal gradient mirrors the pattern of α diversity variation (fig. 4). The rate of change in species composition across Lake Ritóm, Cadagno, Tom and Giubin is relatively low, but its sharp increase in the passage to Segna points to an altitudinal threshold partitioning the lakes into two groups characterized by different zooplankton assemblages. As pointed out by Jersabek *et al.* (2001) a distinct decrease in species richness with increasing altitude is the obvious result of the reduced probability of colonists introduction in remote high altitude lakes (Starkweather, 1990) of the harshness of the physical environment, and of the reduction of resource diversity along with a decreasing habitat complexity. However, in several cases the effect of altitude on the composition of pelagic crustacean assemblages seems to play a minor role compared to such parameters as acidity, humic content, lake morphometry and fish predation (e.g. Nilssen, 1976; Gliwicz, 1985; Cammarano & Manca, 1997; Cavalli *et al.* 2001; Schabetsberger *et al.*, 1995, 2006; Hořická *et al.*, 2006). For instance, the absence of fish could explain the relatively rich zooplankton assemblage (including the large

Lago Ritóm		Lago di Dentro			Lago Campanitt		Lago della Segna			Lago Taneda 1		Lago Taneda 2		Lago Pecian	Number of lakes where species occurred
lug.01	lug.06	lug.00	lug.03	lug.06	lug.03	lug.10	lug.03	lug.03	lug.10	lug.03	lug.06	lug.03	lug.06	lug.03	
	•			•				•							5
															2
	•														4
						•									2
								•				•	•		3
															1
	•		•					•			•		•		8
		•	•	•							•		•		6
						•			•						4
								•			•		•		5
•		•				•									4
						•									3
•															2
•		•	•	•	•					•	•				7
															1
															1
				•											1
															1
3	3	3	3	4	1	4	0	4	1	1	4	1	4	0	
•	•	•	•		•	•	•	•	•						7
•	•	•	•	•							•	•	•		6
															2
		•						•							3
					•	•								•	5
															1
		•					•		•					•	5
		•													1
															1
															1
2	2	5	2	1	2	2	2	2	2	0	1		1	2	
	•														2
					•	•				•	•	•	•	•	6
•		•		•	•	•				•	•	•	•	•	8
	•										•		•		5
							•	•	•						1
1	2	1	0	1	2	2	1	1	1	2	3	2	3	2	
	12			12		9			9		8		8	4	

pelagic crustaceans, *Daphnia longispina* and *Arctodiaptomus alpinus*) inhabiting Lake Giübin in spite of the particularly harsh conditions related to its ephemeral character. On the contrary, fish introduction likely contributes to the reduction of species richness in Ritóm, Tom, and di Dentro lakes.

CONCLUSIONS

Due to the sampling strategy adopted and because they are not representative of the whole seasonal succession, the phytoplankton samples collected in July 2010 in some of the Piora lakes can provide only a very limited information about taxonomic diversity. A reliable quantification of the contribution of single taxonomic units can not be done from net phytoplankton samples, therefore just a qualitative, though not exhaustive, evaluation is possible. The conclusion we can draw after this survey is that the four lakes sampled share a similar phytoplankton structure: there are some differences in the *taxa* list, but the composition is quite homogeneous at the genus level and all the lakes appear dominated by diatoms. Finally, we want to point out that, in spite of the differences in the sampling protocols among present and past investigations carried out in Lake Cadagno,

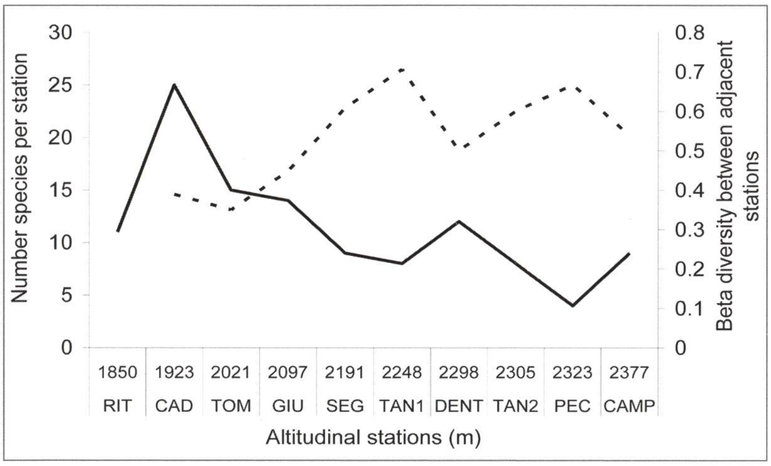


Fig. 4 – Number of zooplankton species (continuous line) and beta diversity values (dashed line, β_T, WILSON & SCHMIDA, 1984) for adjacent stations in the lakes of the Piora valley ordered according an altitudinal gradient.

we found many diatoms *taxa* already recorded in previous studies: the stability of the diatom population probably indicates that this lake was almost unaffected by anthropogenic pressures at least since the beginning of the last century, although the increased records of cyanobacteria in our survey could be regarded as a recent sign of worsening trophic conditions.

In spite of a sampling strategy likely inadequate to account for the whole zooplankton component composition, some conclusions come up from our study. Rotifer assemblages (the highest species richness) in the Piora lakes are presented by cosmopolitan and uncommon species, these last seem to be favoured by particular local conditions in the lakes (e.g. hypoxic conditions, detritus, acidification, periodical increase of water conductivity). The distribution of calanoid copepods matches the hypothesis of altitudinal species reorganization, but the effect of altitude could not explain alone the alteration of taxonomic composition across the altitudinal gradient. Even if the limiting effects of general abiotic conditions likely become increasingly important with altitude, the composition of assemblages is always the result of a complex interaction of abiotic and biotic conditions and of the species ecological requirements. Biotic interactions (competition, predation) are strengthen under the trophic web simplicity of high altitude lakes (ANDERSON, 1974) and their effects amplified when approaching the tolerance limits of the species involved. It is therefore unlikely that altitude alone explain assemblage composition, because this would result in a species distribution reflecting the order of variation of species tolerance limits along the major environmental gradient. Such a regular distribution indicating a strongly predominant limiting factor is very uncommon (perhaps limited to didactical examples), while commonly the distributional patterns of, for instance, planktonic assemblages cannot be explained within the frame of abiotic conditions alone. However, whether is altitude the major structuring factor for zooplankton species composition in the Piora lakes, or (likely) local factors are more effectively acting in each site is a question that cannot be answered by this preliminary study. But what this survey probably put in focus is that such a small study area, with its high morphogeologically and anthropogenically induced habitat diversity, fulfil the requirements of an ideally suited natural laboratory for ecological studies of alpine lakes communities.

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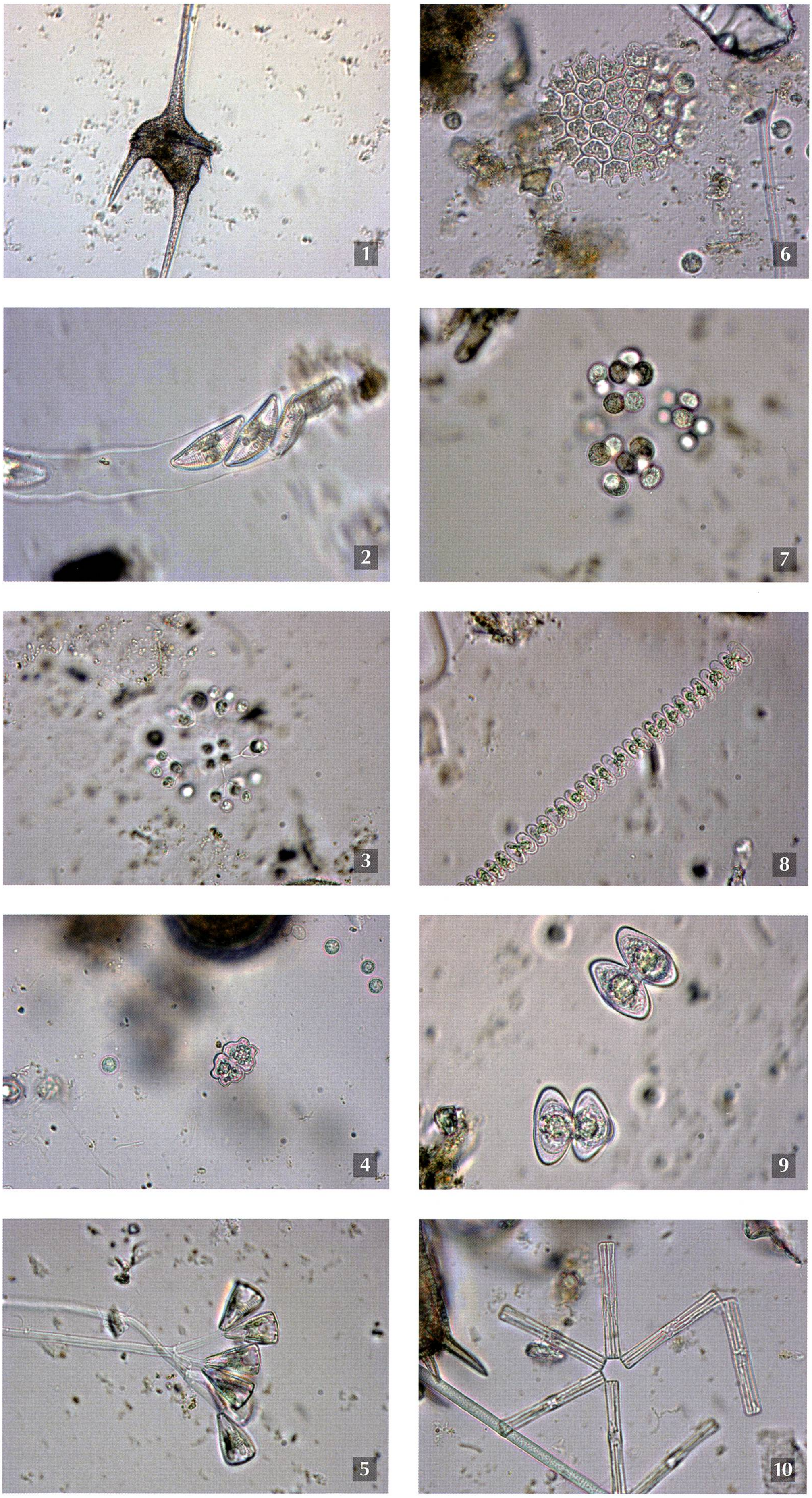

Fig. 5 – Some phytoplankton species found in the lakes of the Piora Valley. 1 *Ceratium hirundinella*, 2 *Cymbella minuta (Encyonema ventricosum)*, 3 *Dictyosphaerium sp.*, 4 *Euastrum sp.*, 5 *Gomphonema truncatum*, 6 *Pediastrum sp.*, 7 *Sphaerocystis schroeterii*, 8 *Spondylosum planum*, 9 *Staurastrum sp.*, 10 *Tabellaria sp.*

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