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# On ten high-mountain lakes of Corse island – a delayed report of an investigation in summer 1970.

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Abstract
During August 1970, ten mountain lakes on Corse island have been investigated. Temperatures and oxygen concentrations were measured as depth profiles, the shading effects of surrounding topographic elevations as skyline values compared with according diurnal sun elevations. Using Secchi-disks of six colours, turbidity and approximate underwater light spectra were achieved. Values of water hardness and electrical conductivities showed extremely soft waters of the lakes. The effect of altitude on the lake surface temperatures was analysed, compared with lakes of the Caucasus region and could be separated from the effect of topographical sun shading. In zooplankton samples six copepod species were found and compared with meta-communities in other mountain regions.

## 1 Introduction

High-Mountain lakes are usually small, succeeding former glaciations as kar lakes or moraine dams. The first effects of atmospheric acidification were observed in mountain lakes in regions of crystalline bedrock of North-America (Dillon et al. 1998), in Scandinavia (Muniz 1990, Almer and Dickson 2021) and in the Alps (Wögrath and Psenner 1995), with a European survey by Curtis et al. (2005). They also appear as good sentinels for the ongoing climate change (Catalan et al. 2006, Adrian et al. 2009, Moser et al. 2019) and became objects of interest in international and interdisciplinary projects. In European countries the scope of common investigations resulted in comparative limnological research of the mountain regions in Sweden, Norway, Northern Finland, Scotland, the alpine regions of Switzerland, Austria, France, Italy and Slovenia, the Tatra mountains, and the Pyrenees (Catalan et al. 2006, 2009). Some areas, however, were not included into those international projects as the high-mountain lakes of Great Caucasus, which were presented by Efremov (1984, 1988), and the lakes of the high-mountains of Corse island, which are considered in the present paper.

Forty „mountain lakes“ are mentioned for the island of Corse, fifteen of these lakes are larger than 0,5 ha and more than 3 m deep (Gauthier and Quilici 1997). Thirtynine of these are high-mountain lakes situated above the tree line at 1500 m a.s.l. and only one, the forest lake, Lac de Creno, below the tree line (Arnberger 1960, PNCR 2010). There are many descriptions of the landscape around the peculiar lakes for mountain hikers (e.g. Gauthier and Quilici 1997) with general information, especially from the geoscientific or vegetational view (Arnberger 1959, ONF 2011). Limnological investigations, however, till now appear as restricted to singular visits (Huber-Pestalozzi 1925, Angelier 1959), on work on single lakes (Roche and Loye-Pilot (1989), as academical études (Cazaubon 2010), which are not publicly accessible, or on ichthyological studies for fishery (Rivier and Dumont 1987, 1988, Rivier 1996, 1988). The here presented data on ten of Corse island’s mountain lakes have been collected more than fifty years ago, but might fill a still existing gap of comparative limnological knowledge.

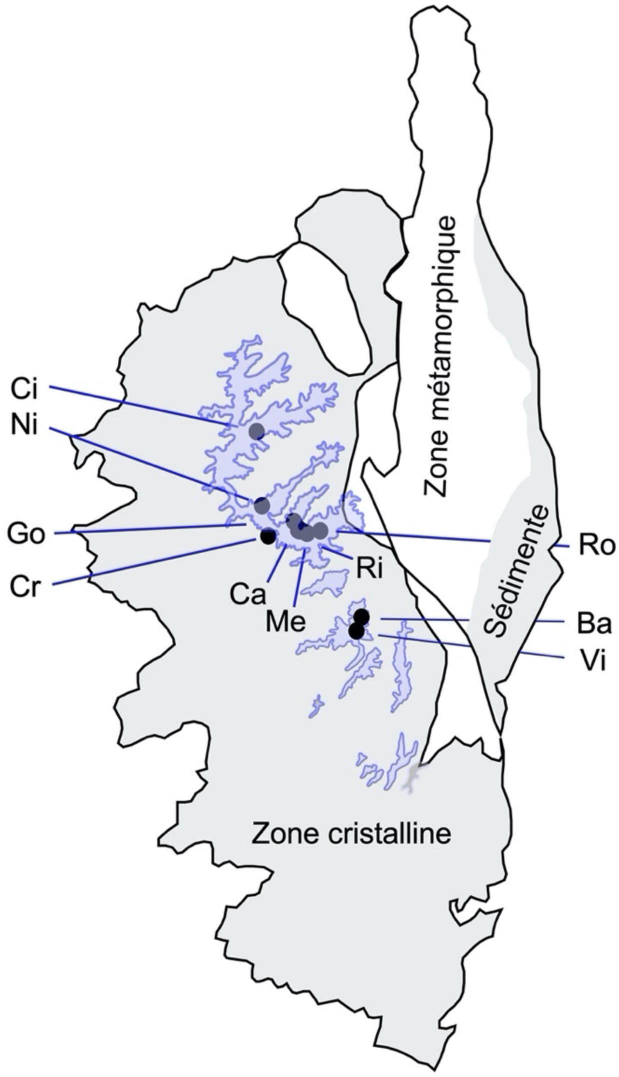



Figure 1: Corse island, simplified map of geological formations and positions of 10 investigated mountain lakes, blue: granitic areas >1600 m above sea level (combined data from Gauthier in ONF 2011 and Arnberger 1960).

| Table 1: Basic data of investigated lakes (Rivier 1996, Gauthier et al. 1984) | | | | | |
|---|---|---|---|---|---|
| Lake | Position | Altitude | Area | $z_{max}$ | $z_{mean}$ |
| | | m a.s.l. | ha | m | m |
| Rotondo | 42° 12‘N, 9° 03‘E | 2321 | 7,4 | 35 | |
| Cinto | 42° 22‘N, 8° 56‘E | 2289 | 1 | 15 | |
| Bastani | 42° 04‘N, 9° 08‘E | 2092 | 4,38 | 24 | 10,1 |
| Rinoso | 42° 12‘N, 9° 02‘E | 2065 | 1 | 12 | |
| Capitello | 42° 13‘N, 9° 01‘E | 1930 | 5,5 | 42 | 16,2 |
| Goria | 42° 13‘N, 9° 00‘E | 1852 | 3,5 | 7 | |
| Vitalaca | 42° 03‘N, 9° 07‘E | 1777 | 0,7 | 2,3 | |
| Nino | 42° 15‘N, 8° 56‘E | 1743 | 6,5 | 12 | 4 |
| Mèlo | 42° 12‘N, 9° 01‘E | 1711 | 6,2 | 20 | 6,5 |
| Creno | 42° 12‘N, 8° 57‘E | 1310 | 2,4 | 6,5 | 1,8 |

## 2 Sites and methods

Ten of the existing forty mountain lakes on Corse island have been investigated during three weeks in August 1970. Lac de Vitalaca as a shallow lake (2,3 m) was included, and also Lac de Creno as a forest lake below the tree limit. The map of Figure 1 shows the lake locations in the geological formation of the crystalline zone of the island, in the mountain areas above 1600 m above sea level. Geographical positions and morphological basic data are given in Table 1. Elevation values of the sun as presented in Figure 2 refer to the position of Ajaccio according to: [https://www.timeanddate.com/sun.](https://www.timeanddate.com/sun.)

The lakes were investigated using a simple, light-weight equipment of „rucksack-limnology". A small, inflatable rubber boat enabled sampling and use of Secchi-disks at the centre of lakes. A self-made montage of a simple theodolite was used to measure the topographic sky-lines around the lakes. The underwater light was approached by measurements with six Secchi-disks of different colours, blue, green, yellow, orange, red and white, as introduced by M. Stepanek (Elster and Stepanek (1967) and approved by Richter (1985). A plastic bottle was used as water sampler ("Schöpfflasche" according to Schwoerbel 1966), in which temperatures were measured immediately after pulling the bottle to the surface. Electric conductivities were determined with a hand-held WTW-device, oxygen by the Winkler-method, water hardness by titration with Titriplex solution (Merck 1975). Zooplankton samples were taken by pulling the plankton net vertically from bottom to surface.

## 3 Results and discussion

### 3.1 Lake surface temperatures in different altitudes

The thermal regime of mountain lakes is depending on latitudes and altitudes as factors of first order (Tab. 1). The Corse mountains can be considered as a small region extending to only 40 km north of 42° N latitude, and therefore, the differences in latitude among the lakes might be neglected. The altitude above 1700 m a.s.l., which corresponds to the tree line, might be used to define „high-altitude mountain lakes", separating these from „forest-mountain lakes" in lower altitude as Lac de Creno at 1310 m above sea level. The tree line is considered to be generally limited by the 10°C summer isotherm of air temperature (Grace 1989).

The lake surface temperatures (LST) are shown in Figure 2, as depending on altitudes and compared with data from Caucasus mountain lakes (Efremov, 1984, 1988), a region at the same latitude in the Mediterranean climate zone. The measurements of the LST on Corse were made in August, those of Caucasus lakes are mean values from June to October and are about 4 °K lower than Corse LST in August. The slopes of the regression lines appear as near identical, indicating a LST-lapse ratio of 7,5° and 8,4 °K $km^{-1}$ of altitude. This values largely agree with findings in other regions as the Alps with 5,2° to 8,1 °K $km^{-1}$ from July to September (Livingstone et al. 1999, 2005) and southern Andes with ca. 5° to 6 °K $km^{-1}$ in mid-summer (Geller 1992, Geller et al. 1997).

The dependence of LST on altitude are usually taken as linear, but show deviations from this simple function. Livingstone et al. (2005) consider factors beyond altitudes as topographic shading, wind exposure, lake morphology, hydrology, stratification and ice cover affecting the thermal regime of lakes. Extrapolations of the linear function to sea level would result in in 28,6 °C at sea level of Corse island and in 27,1 °C at the Black Sea, which are high estimates. Surface temperatures were measured with 27,0 °C, 25,7 °C and 20,6 °C in three étangs of the shore of Corse, and 20,5 °C and 21,2 °C at about 100 m a.s.l. in the Caucasus. Therefore, the lakes might be better aggregated separately as high- and low-mountain lakes below and above the treeline, since lakes surrounded by forest are usually more protected against wind exposition and are more shaded.

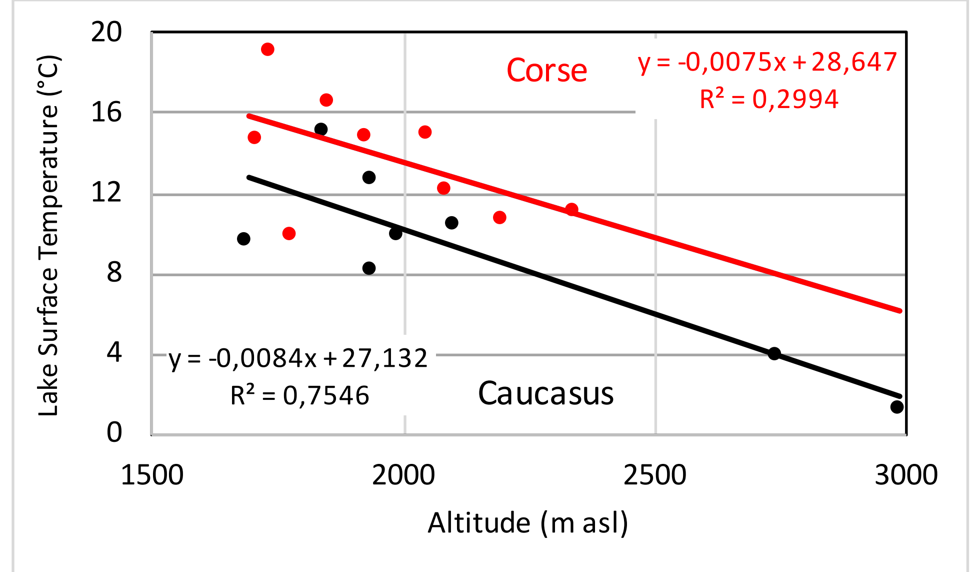



Figure 2: Lake surface temperatures of 9 high-mountain lakes of Corse island compared with lakes in the Great Caucasus mountains with linear approximation in altitudes 1000 – 3000 m: LST decrease by 8,4 to 7,5°K km$^{-1}$ (Caucasus data from Efremov 1984).

3.2 Topographic shading and exposition to solar radiation

The exposition to indirect and direct sun radiation appear as second order variables. The shading effect of the surrounding topography was approached in two ways. The indirect radiation of the open sky was proxy-quantified by subtracting the topographically shaded area from a full horizon area in azimuthal projection at nine of the Corse mountain lakes (Tab. 2, Lakes Cinto and Nino as examples in Fig. 2a). The daily duration of direct sun radiation can be derived from the topographical skylines in cylindrical projection (Fig. 2b). From the characteristic sun elevations of the seasons, the values for summer and winter solstice and for the equinox days are shown with the skylines. The lake-specific potential duration of direct sun radiation was graphically derived (Tab. 2). The most shaded lakes receive no direct sun in winter, as lakes Cinto, Mèlo and Capitello. The annual total of potential sun duration (TPDSR), assuming cloudless sky around the year, was estimated from the mean daily sun-hours at summer and winter solstices and spring and fall equinox days. The sun exposition of Lac de Nino shows the highest value of 4070 potential sun-hours per year, most shaded is the forest-lake Lac de Creno with 1628 potential sun-hours per year. Comparable values were derived for 18 mountain lakes in the Slovakian Tatra at altitudes of 1762 to 2056 m a.s.l. from a GIS-model as Total Duration of Direct Solar Radiation (TDDSR): 1436 to 3418 hours per year (Novikmec et al. 2013).

Table 2: Conductivity, Secchi-depth (white disk), hardness (German degrees in equivalents of CaO mg $L^{-1}$), and annual total of potential direct sun radiation (TPDSR), area partition of open sky as proxy of indirect radiation, Secchi depth[(a)]for Lake Bastani in August 1986 from Roche and Loye-Pilot 1989.

| Lake | Potential direct sun radiation (h/d) | | | TPDSR | Open Sky | Cond. | Hard -ness | Secchi-depth white | Date |
|---|---|---|---|---|---|---|---|---|---|
| | Solstice June | Equi-nox | Solstice Sept. | (h/a) | 0 - 1 | µS/cm | °dt | m | 1970 |
| Rotondo | 13,9 | 10,1 | 6,87 | 3745 | 0,64 | 13 | 0,39 | 12,5 | 03.08. |
| Cinto | 13,7 | 4,2 | 0 | 2018 | 0,48 | 14 | 0,17 | 12 | 17.08. |
| Vitalaca | 12,1 | 7,7 | 4,3 | 2894 | 0,54 | 22 | 0,45 | bot-tom | 22.08. |
| Rinoso | 14,1 | 8,8 | 2,0 | 3077 | 0,63 | 13 | 0,22 | 8,5 | 02.08. |
| Capitello | 13,5 | 9,7 | 5,0 | 3453 | 0,57 | 17,5 | 0,22 | 17,5 | 06.08. |
| Goria | 13,5 | 8,7 | 3,4 | 3124 | 0,61 | 11 | 0,22 | bot-tom | 07.08. |
| Bastani | | | | | | 21,5 | 0,34 | 1,8[a] | 21.08. |
| Nino | 15,5 | 11,2 | 6,7 | 4070 | 0,81 | 31 | 0,9 | 2,1 | 13.08. |
| Mèlo | 13,2 | 8,5 | 0 | 2748 | 0,54 | 15 | 0,56 | 13 | 01.08. |
| Creno | 10,5 | 3,7 | 0 | 1628 | | 45 | 0,56 | 3,4 | 09.08. |

The effects on the surface temperatures were compared for altitudes and the respective daily sun-hours, using the temperatures in August versus the sun elevations at summer solstice (Tab. 2, Fig. 3b). After elimination of the factor altitude the remaining residuals of temperature deviations result in +2,5 °K higher lake surface temperatures with each additional sun-hour. The shading effect as derived from the partial areas of non-shaded, open sky (Tab. 2, Fig. 3a) is estimated as +1,8°K with each additional 10% of open sky area.

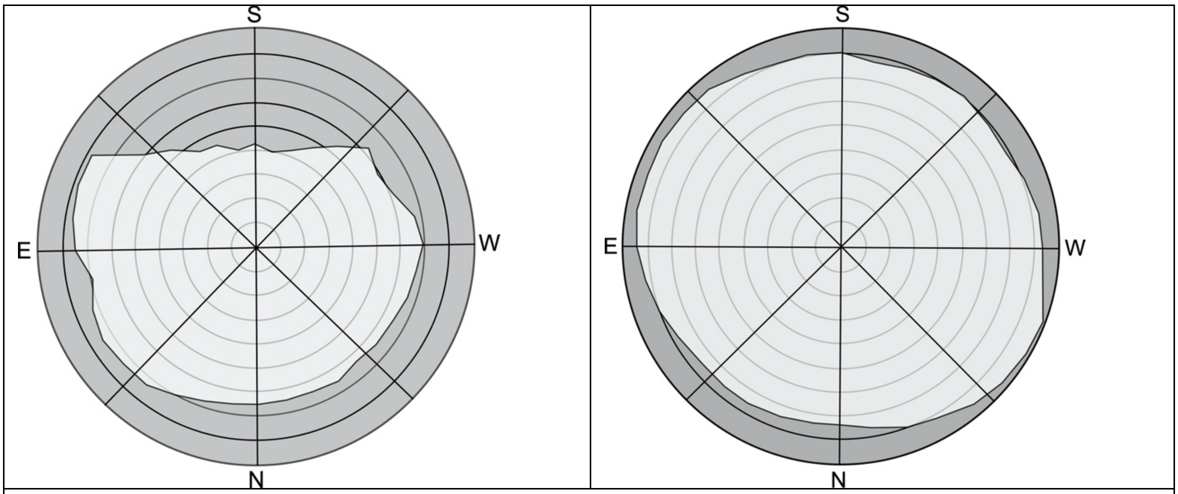
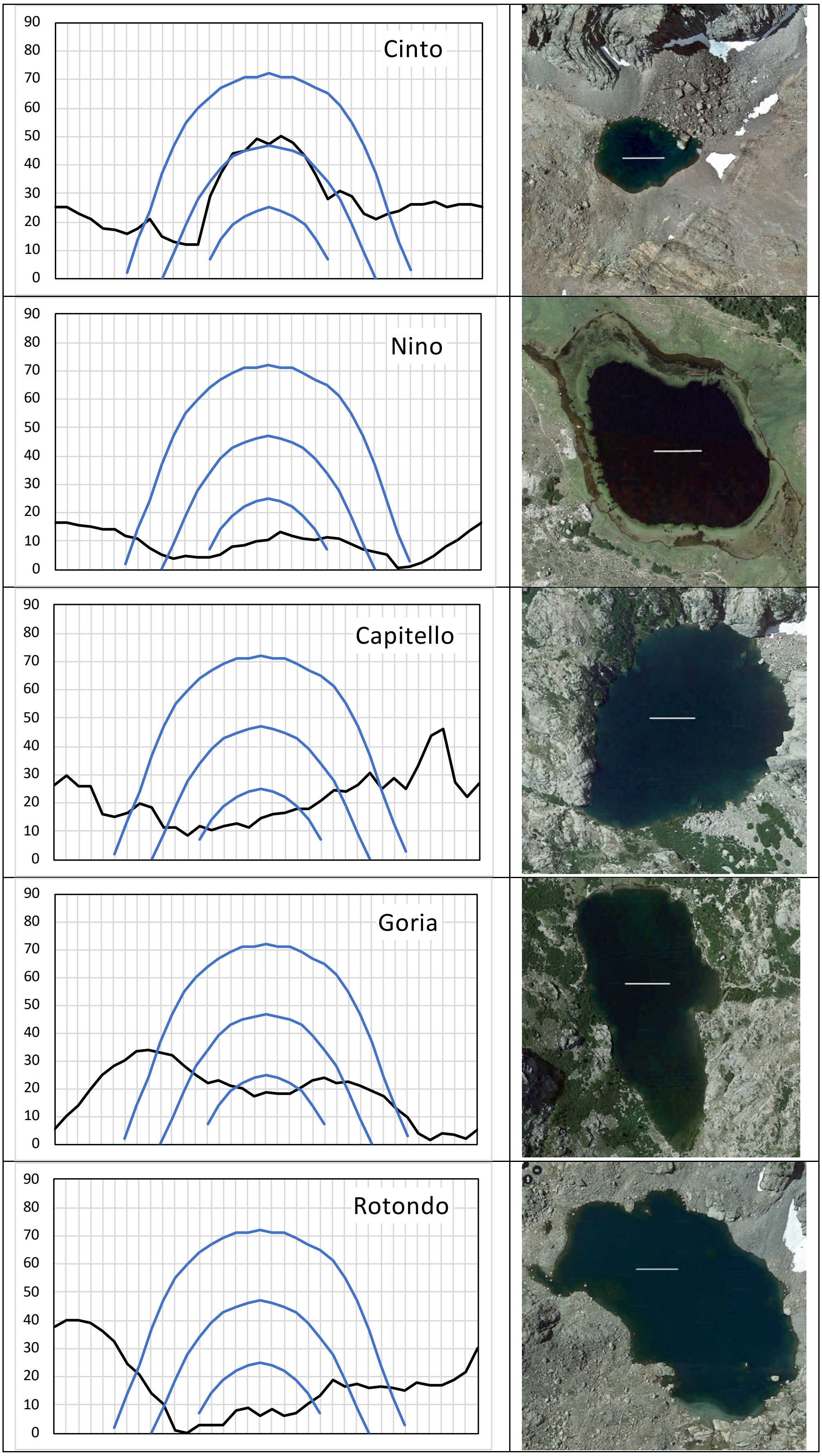



Figure 3a: Topographic skylines of Lakes Cinto and Nino in azimuthal projection.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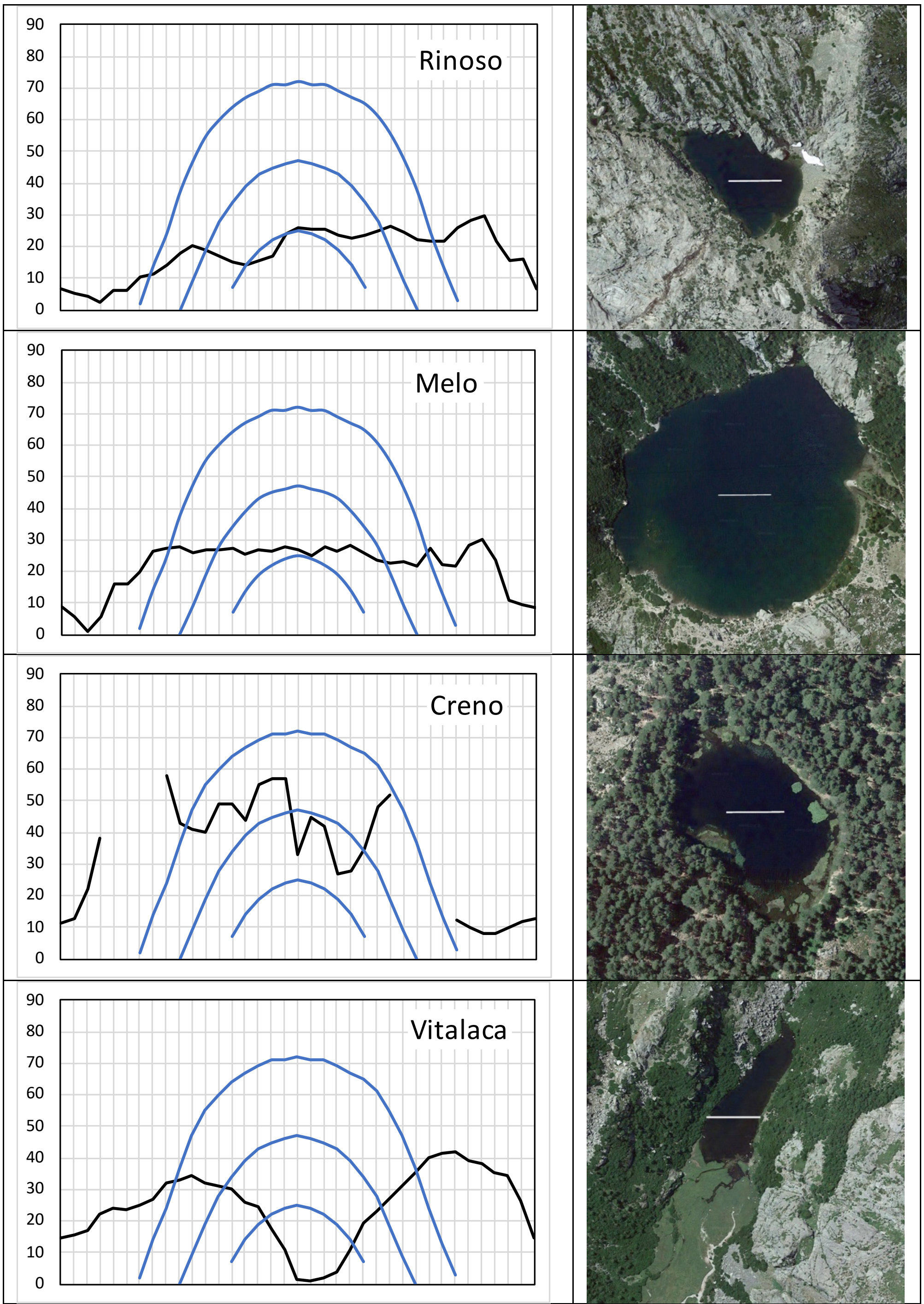



Figure 3b: Topographical skylines in cylindrical projection, with diurnal course of sun elevations for solstice of summer, of winter and of equinox in March and September. Photos of Google-Earth, East-to the left, West-to the right, South-above, North-below, Scale bars = 60 m

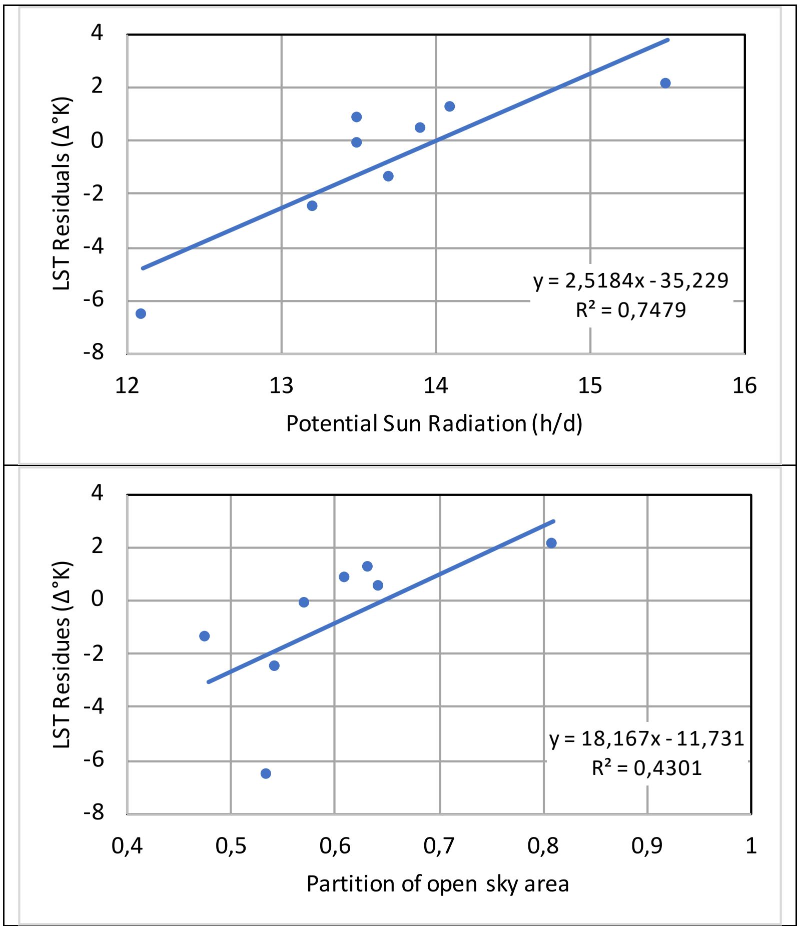



Figure 4 a, b: LST-Residuals after elimination of altitude factor, (a) duration of topographic sun exposition in hours per day at summer solstice: LST are increased by 2,5°K per additional sun-hour, (b) partition of unshaded open sky area as measured in diagrams of azimuthal projection (Fig. 2a): LST are increased by 1,8°K by additional 10% of open sky area.

### 3.3 Increasing specific conductivity with lower altitudes

Dissolved inorganic substances of the lake water were measured by the proxy-variable of electric conductivity, which are increasing linearly along the altitude gradient by about 27 µS $cm^{-1}$ with 1000 m lower altitude (Fig. 5). Similar findings refer to lakes in Northern Ireland between 500 m a.s.l. and sea-level (Gibson et al. 1995), in Switzerland for dissolved $Ca^{2+}$ and $Mg^{2+}$ between 2400 to 400 m a.s.l. (Müller et al. 1998), in Austria (Kamenik et al. 2001), along lake chains in Wisconsin highlands (Riera et al. 2000), in Alaska (Kling et al. 2001), the Adirondacks and the Rocky Mountains (Soranno et al. 1999). The ultimate causes of increasing conductance with decreasing altitude might be found in the order position of the lakes in the respective landscapes since the lake catchment areas (Kratz et al. 2006), and also the weathering rates (Psenner and Catalan 1994) are increasing with lower altitudes.

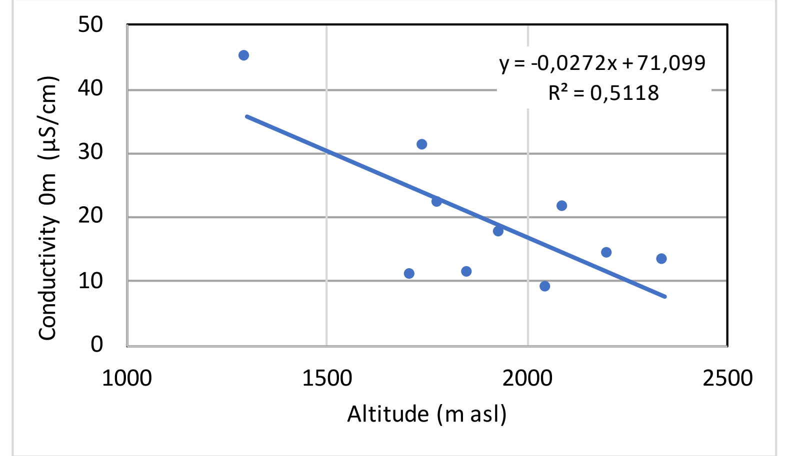



Figure 5: Electrical conductivity of surface water in mountain lakes of the granitic bedrock zone of Corse island: conductivities are increasing linearly with lower altitudes.

3.4 Vertical profiles of temperature and oxygen concentration

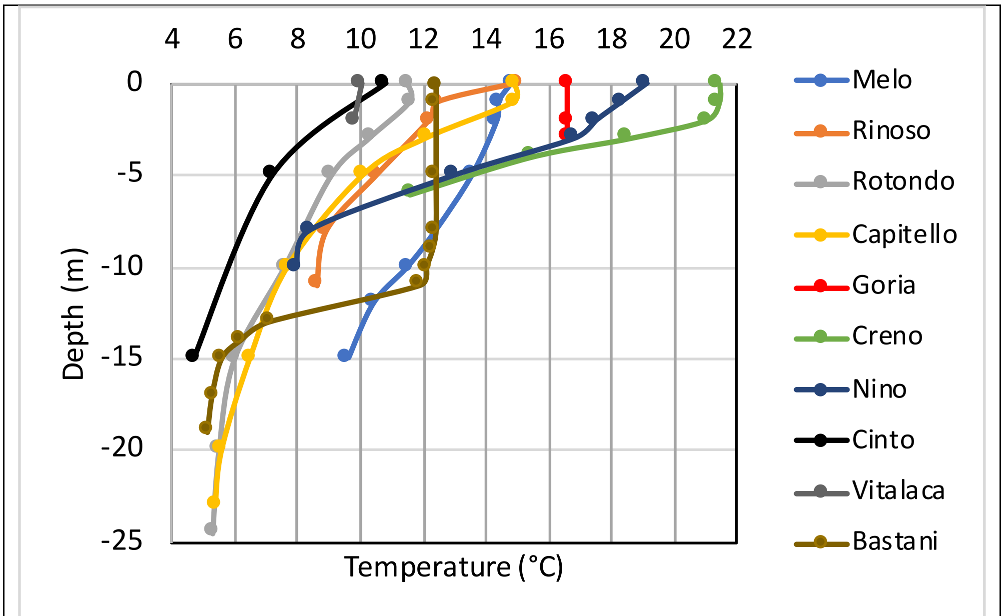
The depth profiles (Fig. 6) divide the ten mountain lakes into three categories:

(1.) two shallow lakes without any stratification, lakes Goria and Vitalaca,

(2.) two markedly stratified lakes of medium depth with a hypoxic bottom layer, lakes Creno and Nino, and

(3.) six deep lakes with high oxygen concentration from the surface to the bottom.

The two lakes Nino and Creno are exceptional ones, lake Creno is a wind-protected forest lake receiving the minimum of sunlight among the considered lakes, and Nino is the lake with the maximum of direct radiation receiving in summer about 50% more sunlight than lake Creno, and 60% more of the potential annual sum of sun-hours. The data for Lake Bastani of Roche and Loye-Pilot (1989) from August 1986 show a sharp stratification with a well mixed epilimnion to 11 m depth with about 12°C and a much colder hypolimnion reaching about 5°C at the bottom. The sharp profile is explained by the free exposition to wind as mentioned by the authors and experienced during my own visit in 1970 when strong winds made it impossible to work on the lake.



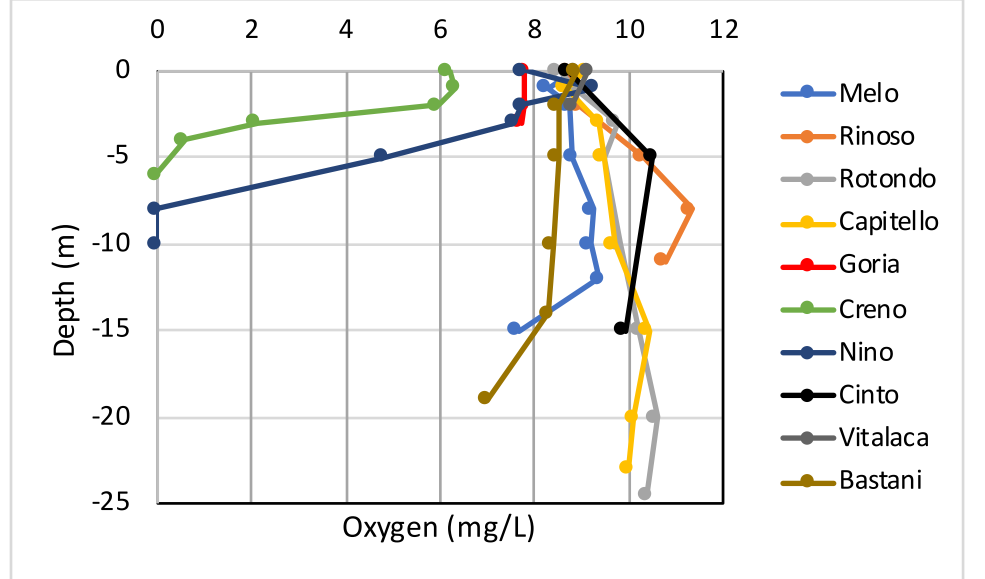



Figure 6 a, b: Depth profiles in 10 mountain lakes of Corse island in August 1970: (a) water temperature, (b) oxygen concentration, (Data for Lake Bastani of 21.08. 1986 from Roche and Loye-Pilot 1989).

3.5 Underwater light spectra and trophic states

In default of sophisticated equipment to measure the underwater light distribution the traditional Secchi-disk might be applied also in different colours to achieve a simple impression of the light spectrum underwater. The results in Figure 7 present characteristic differences among the mountain lakes. The two above mentioned lakes Creno and Nino with hypoxic deep water are the most turbid lakes and present the highest light absorption for the short wave radiation in blue and green. The water colour can be estimated as shifted to brown water in these lakes. In the other lakes light absorption was maximal with the red colour as usual in clear-waters.

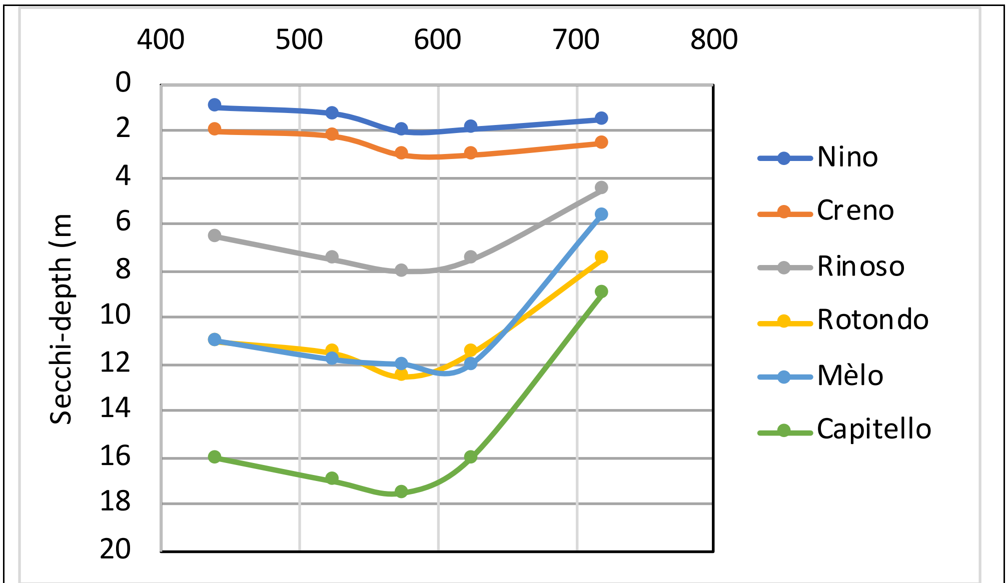



Figure 7: Secchi-depths in 6 mountain lakes of Corse island as measured with 6 disks of different colours; values for white disk are near identical with yellow (Tab. 2); values for lakes Goria (6m) and Vitalaca (2m) not shown, where all disk colours were visible at the bottom. Colours assigned to light wavelengths (nm): blue-440, green-525, yellow-575, orange-625, red-720 (Richter 1985).

The light conditions allow a first estimate of the trophic state. The two lakes with low Secchi-depths might be considered as eutrophic, the surroundings of both lakes are used for cattle pasture. Roche and Loye-Pilot (1989) measured 1,8 m Secchi-depth in August 1986 in Lake Bastani and considered the lake as eutrophic according to chlorophyll values. They explained the high productivity from the open exposition to wind forces and atmospheric input of nutrients, as observed also in the Pyrenees (Camarero and Catalan (2012). The clear-water lakes Melo and Capitello were classified as ultra-oligotrophic by these authors.

### 3.6 Zooplankton species

In the zooplankton samples only copepod species could be found. Rivier (1996) discussed the disappearance of natural species of planktonic crustaceans, as Daphnia, after the introduction of salmonid fish into the considered mountain lakes. Altogether six species were living in the nine investigated lakes (Fig. 8 b), *Cyclops abyssorum* in six lakes, together with *Diaptomus cyaneus* in the four lakes above 1900 m a.s.l. Three species were present in the forest lake Creno, *Mixodiaptomus laciniatus, Megacyclops viridis* and *Thermocyclops hyalinus*, and *Eucyclops serratulus* only in the shallow lake Vitalaca. The cyclopoids were identified by Ulrich Einsle, the calanoids by Friedrich Kiefer. The according meta-communities of high-mountain lake regions in the Pyrenees, the Alps, Tatra, Swedish Lapland and Corse (Fig. 8a) appear as depauperated communities compared with lowland lakes where much more species are living. The most frequent species, *Cyclops abyssorum*, lives in six of nine Corsican lakes, the second frequent species, *Diaptomus cyaneus*, in four lakes, *Eucyclops serratulus* in one lake, only. *Cyclops abyssorum* appears as a characteristic species of mountain lakes in high altitudes above the tree line (Fig. 9). The species of the Pyrenees, the Alps, the Tatra mountains and Corse island live in lakes of similarly high altitudes, but distinctly lower in Scotland where the tree line is at 530 to 640 m a.s.l. (Pears 1967).

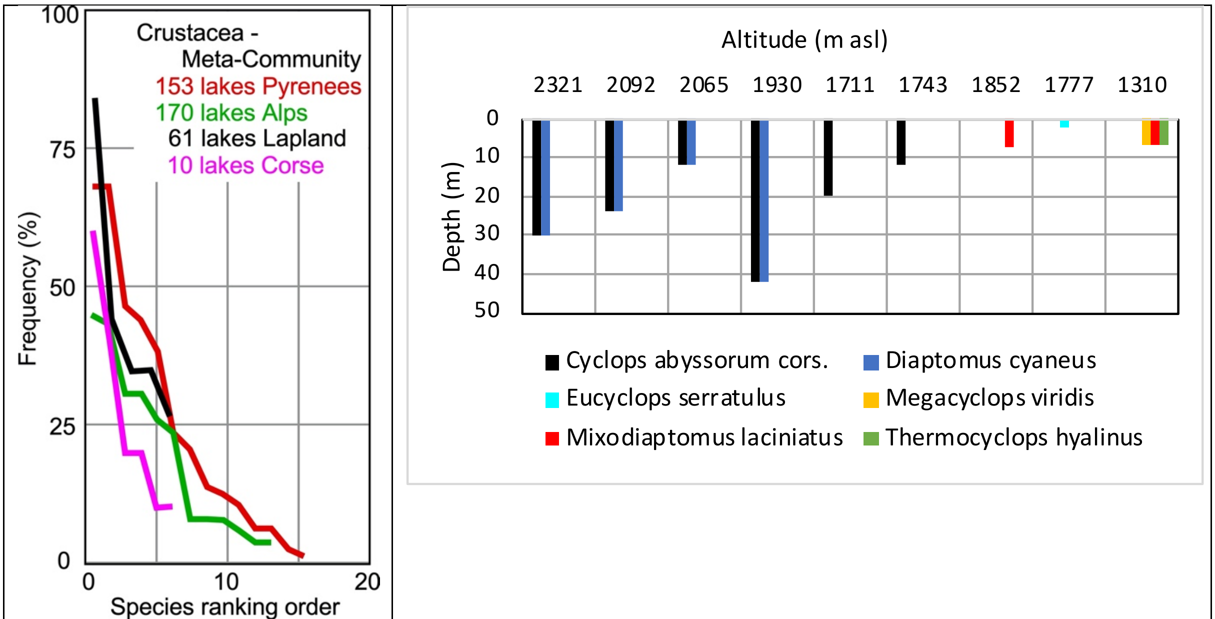



Figure 8 a, b: (a) Frequency of occurrence in metacommunities of pelagic plankton crustaceans in four regions of mountain lakes: Pyrenees, Alps, Swedish Lapland and Corse island (own results compared with data from Miracle 1978, Nauwerck 1994, Catalan 2004, Skala 2015), (b) Co-occurrence of planktonic copepod species versus altitude and depth on Corse island in 8 mountain lakes and Calacuccia reservoir.

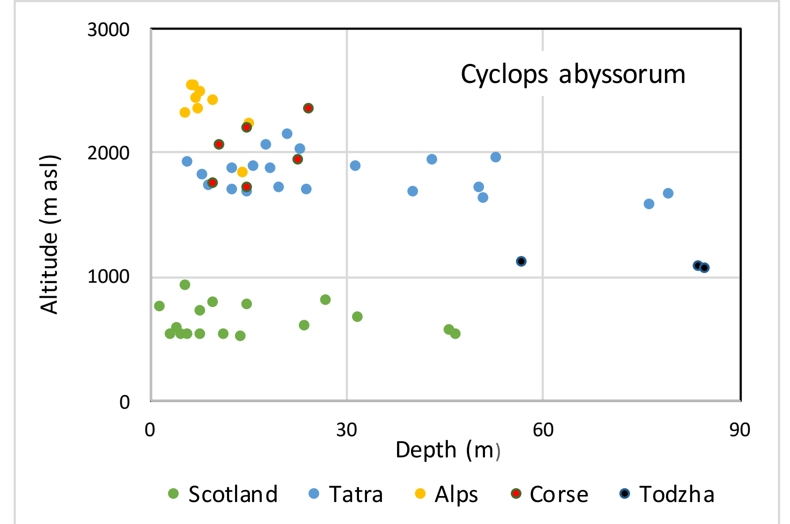


Figure 9: *Cyclops abyssorum* populations in five regions of mountain lakes, altitudes a.s.l. versus lake depths in Scotland, Tatra, Alps, Corse island and in the Todzha region, Siberia; (data from Miracle 1978; Skala 2015; Zuykova und Bocharev 2009).

## 4 Conclusions

The presented results were achieved with a minimum of technical equipment and might show that basic relationships can be identified with simple field methods. The effect of topographic shading on the thermal conditions, and the underwater light spectrum in mountain lakes could be quantified in a first approach more than fifty years ago.


## 5 Acknowledgements

The investigation of the mountain lakes was decisively supported by accompanying friends who worked on ornithological and coleopterological issues, Paul Blum, Walter Sudhaus and Franz Thimm. The copepod species were identified by Ulrich Einsle and Friedrich Kiefer.

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