Invertebrates: zoobenthos

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■ Macrobenthos of high-altitude lakes

Laghi della Valletta (Maritime Alps, Piedmont)

There has been little limnological research carried out in Italy on the zoobenthos of mountain lakes compared with the attention paid to phyto- and zooplankton. It has only been in the last decade that some studies have been conducted on the structure and function of zoobenthic communities in lakes, mainly by CNR-ISE in Pallanza (Lake Maggiore) and the Trento Natural Science Museum. The most thoroughly studied section of zoobenthos in Alpine lakes is that of macro-zoobenthos, which is defined as invertebrates longer than one millimetre that live in water-bodies in close contact with the substrate. Little is known of the even smaller organisms to be found in lake-bed sediments (meiofauna), to which the box on page 93 refers.

In water courses, macrobenthic organisms mainly use food resources carried by the continually flowing current. In lakes, the availability of food is principally through deposit and accumulation of organic materials on the lake-bed, washed off the surrounding land or carried by inlet streams, and dead organisms. Lake benthos thus mainly depends on the decomposition cycle for nutrition. Filtering organisms, typical of flowing waters, are scarce or absent, as are many of the rheophilous groups described in the “Habitat” volume on mountain streams. There are three main categories of lake habitats offered to benthos - littoral, sub-littoral, and deep - each of which hosts a separate community.

The littoral zone comprises three distinct types of environment. The first is the shoreline affected by waves, with aquatic, but no terrestrial, vegetation. In lakes, especially small mountain ones, seiches (oscillations of the water mass caused by atmospheric pressure) are usually insignificant, whereas waves produced by the wind create a rather narrow zone. Organisms that have in

Trichopterans (*Pseudopsilopteryx zimmeri*) during winter mating

Larva of caddis fly (*Rhyacophila torrentium*)

some way solved the problem of subaerial respiration live in this narrow zone, especially molluscs and a few crustaceans. The advantage of living in this transition zone (or ecotone) is easier access to trophic resources of terrestrial origin.
The littoral benthic community that settles among aquatic macrophytes along the shores appears to be entirely separated. This zone offers an abundance of food and refuges for all invertebrate life-stages, and its extent strongly depends on the water transparency and therefore on the light penetration, which is indispensable for chlorophyll processes. Lastly, there is a community of the littoral zone which is entirely bare of vegetation - either because of scarcity of light, or because of the unsuitable shape of the shoreline (e.g., too steep). All these environments are characterised by marked variations, both from one lake to another and between different points in the same lake, but there generally is higher biodiversity in common than that to be found in deeper waters. The sub-littoral zone (2.5-6 m) is a more homogeneous environment, less diversified than the littoral one, with benthic communities which include species of both deep and littoral benthos. The substrate is fine-grained, but may also have larger elements like sand and gravel.
Lastly, deep benthos is the one which is generally more comparable in different lakes, as the environmental conditions are very similar: the substrate is dominated by silt, the temperature is low, light is scarce or absent, and there is little oxygen for most of the year. The deep benthos of lakes (below 10 m) is less diverse than that of the more superficial zones, because few organisms have overcome the difficulties of surviving in such a severe environment.
In mountain lakes, the sub-littoral environment hosts the most abundant and diversified macrobenthos. Insects that use atmospheric oxygen to breathe (e.g., aquatic beetles) are confined to the littoral and sub-littoral strips. Those with an aquatic larval stage with gill respiration also frequent deeper waters. However, the maximum depth reached depends on the length of the journey which they must make to reach the surface when they emerge from their pupal cases. The most favoured in this sense are the larvae of several species of chironomid dipterans, whereas, for example, ephemeropteran nymphs are limited to depths of 10-15 metres.

Principal benthic invertebrates

Crenobia alpina

Triclads. The triclads, or planarians, include both rheophilous species and others exclusive to lakes and pools. *Crenobia alpina*, frequently found in cold fast-flowing mountain streams and springs, sometimes lives in the littoral environment of mountain lakes, as long as the water is fresh and well oxygenated. It preys on smaller aquatic invertebrates.

Oligochaetes. Together with chironomids, oligochaetes include the most important taxa of the deep zones of mountain lakes, in terms of both number of individuals and species. Their appearance is generally worm-like, with length ranging from a few millimetres in naidids to approximately 30 cm in some lumbricids. They are generally associated with sandy or silty lake-beds in which they bury themselves, feeding on decomposing organic matter and associated bacteria. The lumbriculid family includes small species with a transparent integument. *Stylodrilus heringianus* is found also in lakes at altitudes above 2000 m. The haplotaxids are decidedly larger, with a thin white body up to 25 cm long, such as *Haplotaxis gordioides*, a predator present in streams, subterranean waters, and lakes of medium to high altitude. A family of special interest is that of the tubificids, which build mucous tubes (hence their name) in which they live, buried in the silt on lake-beds, with the posterior end open to permit respiration and the release of faeces. In general, they are also able to live in poor-quality waters with little oxygen. The species living in high-altitude lakes include *Spirosperma ferox*, *Potamothrix hammoniensis*, *Aulodrilus limniobius*, *A. pluriseta* and *Tubifex tubifex*. The latter is very widespread and with a high capacity for adaptation, being able to live both in highly polluted lake environments and in high-altitude oligotrophic lakes.
The oligochaetes which appear to be best adapted to aquatic life are the naidids. These tiny, transparent animals are generally able to swim, and reproduce by scission, forming “chains” of individuals. *Nais bretscheri*, *N. communis* and *N. elinguis* are certainly present in high-altitude waters.
The last family is that of the enchytraeids, which include both terrestrial and aquatic species, the latter also found in streams and high-altitude lakes. *Cernosvitoviella atrata* and *Cognettia* sp. have been recorded from Alpine lakes.

Lago d'Aver Soprano (Piedmont)

Hirudineans. The hirudineans, better known as leeches, are mostly freshwater anellids, with few marine or terrestrial species. The general shape of the body is like that of a flattened worm, with suckers at either end. Size varies between 1 and approximately 30 cm, but the same animal may assume very different lengths by elongating or shortening its body during displacements.

Contrary to popular belief, very few leeches suck the body fluids of vertebrates: most freshwater species are predators on other benthic invertebrates, which they can swallow whole.

In mountain lakes, colonisation by hirudineans is limited by low temperature and scarcity of suitable preies. A few species are found on the hard substrates near the shores, whereas there are very few which also manage to colonise deeper zones. The species reaching greatest depths in mountain lakes is *Glossiphonia complanata* s.l. (see drawing), which prefers moderately cold waters.

Helobdella stagnalis colonises weakly flowing or standing waters from the plains up to 2500 m in the Alps. The larger *Haemopis sanguisuga* (which may reach 16 cm in length) also may live in some Alpine lakes.

Molluscs. Molluscs are very common in mid- and low-altitude lakes, whereas few species can tolerate the low temperatures in mountain lakes, preferring those on a limestone substrate or in any case with the "hard" calcium-rich waters necessary for shell formation. Pulmonate gastropods include *Physa* spp., *Radix peregra* and *Galba truncatula* Among the bivalves there are *Pisidium amnicum* and *P. casertanum*, which are both frequent in Alpine lakes, having presumably been transported to them by birds. *Galba truncatula* has been found in small lakes up to 2800 m a.s.l. in the Dolomites.

Gastropod of the genus *Physa*, moving with foot fully extended

Amphipods. Amphipod crustaceans are very important constituents of the macro-zoobenthos of some high-altitude lakes, where they are sporadically represented by *Niphargus foreli*, a blind species frequenting the surrounding springs and lake-bed sediments. An element of important biogeographical interest is *Gammarus lacustris*, an Ice Age relict to be found in only a few lakes in the Alps and Apennines. This boreo-montane species is considered endangered and at risk of extinction in Italian high-altitude lakes, due to the over-stocking of fish.

Hydrachnids. Hydrachnids, or freshwater mites, are generally present and at times abundant in the littoral and sub-littoral zones of lakes. Species recorded in Alpine lakes above the treeline include *Atractides loricatus*, *Feltria minuta*, *Gnaphiscus setosus*, and many representatives of the genus *Lebertia*.

Ephemeropterans. These are an order of insects with aquatic larvae, widespread in Italian inland waters, although the majority of species are to be found in running water. Along the shores of small mountain lakes, the large numbers of nymphs sometimes produce mass emergences of adults with a very brief lifespan (hence the name of the order) and no functioning mouth parts. A peculiarity of ephemeropterans, or mayflies (unique among insects), is that of performing a moult after reaching the winged stage: from the nymph, a

Niphargus foreli, an unpigmented blind species, found in the deep waters of some small Alpine lakes

subimago emerges which, after a new moult, finally assumes the definitive adult form (imago). During their nymphal stage, the mayflies of Alpine lakes feed on organic detritus and plant material, and are the prey of other aquatic invertebrates (mainly plecopterans and odonates) and fish.
The mayfly best adapted to life in mountain lake environments is *Siphlonurus lacustris*, a species widespread throughout Europe, in both slow-moving watercourses and littoral and sub-littoral lake environments at altitudes up to 2300 m a.s.l., especially if there is aquatic vegetation. *Baetis alpinus* is a typical species of streams, associated with high-altitude watercourses with fast-flowing and relatively cold waters. However, it has also been occasionally found on the shoreline of high-altitude lakes, probably transported by inlet streams, and has succeeded in adapting to the new conditions.

Odonates. The odonates comprise damselflies (or zygopterans: adults and nymphs with a conical, elongated abdomen) and dragonflies (or anisopterans: nymphs with an oval-shaped body and a generally more stumpy appearance). These insects have an aquatic larval stage, and the adults are generally skilful fliers which live a relatively long time, catching other insects on the wing. The nymphs prefer slow-flowing or standing waters, and the great dispersal capacity of the adults has allowed this order to colonise many lake environments, even at high altitude. Temperature and the availability of prey limit their presence at high

Somatochlora alpestris

Aeshna juncea

altitudes. The nymphs are also formidable predators of any type of animal of the right size: from benthic organisms and amphibian larvae to small fish.
Various species of zygopterans are particularly well adapted to life in mountain lakes, including *Lestes dryas*, which also colonises high-altitude lakes in the Apennines. Among the damselflies which are more easily found at high-altitude lakes are *Enallagma cyathigerum* and *Coenagrion hastulatum*, which are present throughout Italy in lakes with little vegetation and silty beds.
The best known anisopterans include the aeshnid family, large dragonflies with powerful wings, which are unlikely to go unnoticed by hikers walking around a mountain lake. *Aeshna grandis,* and its congeners *A. juncea* and *A. caerulea* are limited to the Alps, especially the central-eastern parts. High-altitude specialists are *Somatochlora alpestris* and *S. arctica* of the corduliid family. Last but not least are the libellulids - *Sympetrum danae*, *S. flaveolum* and *Leucorrhinia dubia*, the first confined to the western and central Alps, the second also to be found in the central Apennines, but always at high altitudes.

Plecopterans. In Italy, this order comprises seven families, with that of the nemourids being the most diversified, with 49 species, including the few which are occasionally found in high-altitude lake environments.
All plecopterans have aquatic nymphs which generally frequent cool, well-oxygenated flowing waters.
Their preference for high-altitude environments poses particular problems of adaptation: for example, the brevity of summer has favoured recourse to diapause in various species, at both egg and nymph stages, so that the animal can survive the adverse seasons, often finding refuge in the hyporheic environment. Species with spring emergence (e.g., *Capnia vidua*) often find themselves in an environment still covered in snow and with temperatures close to freezing, to avoid which they are able to produce glycols with an anti-freeze function. Only the flying adults of a few species feed on mosses or plant matter during their lives, which last from a few days to some weeks. Stonefly nymphs have different feeding habits: those of the nemourids are herbivorous. In mountain lakes, nemourids are generally restricted to the habitat near the shore-line: *Nemoura cinerea*, *Nemurella pictetii*, and various species of the genus *Protonemura* are relatively common.

Adult plecopteran (*Perlodes* sp.)

Lago di Lillet (Gran Paradiso Massif, Val d'Aosta)

Meiofauna

Fabio Stoch

Whereas the zooplankton and, to a lesser extent, the macrobenthos of small high-altitude lakes have been the subject of many research projects, there is almost no work on the meiobenthos, which presumably includes the largest number of organisms on and in lake-beds. Most of these animals are less than one millimetre long, are known as "meiofauna". They are mainly turbellarian worms, nematodes, tiny oligochaetes, mites, micro-crustaceans (cladocerans, copepods, ostracods) and tardigrades, which live in close contact with or in the substrate, among grains of gravel and sand (interstitial fauna) or in silty sediments. The most abundant organisms in the meiofauna of small mountain lakes are copepods (see chapter on zooplankton). The most frequent species, particularly in the littoral zone, belong to the order of the harpacticoids (genera *Bryocamptus*, *Maraenobiotus*, *Hypocamptus*).
Some species are very rare and localised only on the Alps, like *Hypocamptus paradoxus* and *Hypocamptus* sp., the latter not yet fully described, which is exclusive to glacial tarns above 2500 m. Other species are typically boreo-alpine - i.e., they are found in northern Europe and the Alps, like *Maraenobiotus insignipes.* Others are widespread in central and northern Europe (and sometimes, as well as being present in the Alps, they live in Apennine sites as glacial relicts): examples are *Bryocamptus (Arcticocamptus) rhaeticus* and *Maraenobiotus vejdovskyi*. Ostracods and tardigrades are also often found in small mountain lakes. Ostracods are amongst the oldest known crustaceans. Covered with a bivalve carapace, in general spherical, bean-shaped or elongated, they exclusively frequent small lakes on limestone. They are almost always missing from the "soft" waters of small lakes on metamorphic or crystalline rocks. Tardigrades are unusually shaped organisms: they resemble minute sloths moving slowly around the lake-bed, and are able to survive adverse environmental conditions in a dormant state (cryptobiosis). During these periods, all movement is suspended and the metabolism is reduced to the minimum.

Bryocamptus (*Arcticocamptus*) *rhaeticus*

Helophorid beetle (3 mm) walking on the bed of a lake

Coleopterans. Water beetles, with few exceptions, conduct an aquatic life also (or only) at the adult stage, either swimming with specially adapted legs or marching around in the detritus on the lake-bed. They frequent the calm littoral waters of high-altitude lakes, where they may also be locally abundant if there are no fish. The species found in small high-altitude lakes are mainly hydroadephagans and hydrophilids; the most widespread family is that of the dytiscids. Dytiscids are extremely capable aquatic predators, both as larvae and adults. The larvae have robust canaliculate mandibles for the capture and pre-oral digestion of a wide variety of prey, including tadpoles and fish fry. The adults are the water beetles best adapted for swimming and are also very good flyers, a characteristic which also allows easy colonising of remotely sited small lakes at very high altitudes. *Agabus (Gaurodytes) congener*, *A. (G.) solieri* and various smaller species of the genus *Hydroporus*, such as *H. (Hydroporus) foveolatus* and *H. (H.) nivalis*, are common in small high-altitude lakes, even above 2500 m.

A tiny dytiscid beetle (4 mm)

Among the hydroadephagans, the hydraenids and helophorids are not infrequent in the littoral areas of small high-altitude lakes and nearby springs, in particular *Helephorus nivalis*, the tiny adults of which rove around on the lake-bed feeding on the aquatic vegetation.

Dipterans. The benthic fauna of the shores of Alpine lakes is usually dominated by dipterans. Various families are present, among which the chironomids, or non-biting midges, (mostly orthocladiines and chironomines) prevail, in terms of both number of individual and of species. Other frequent dipterans are the limoniids (*Dicranota*), culicids, ceratopogonids, empidids and anthomyids. Chironomids are often the most abundant family of insects in freshwater ecosystems. The capacity of these animals to tolerate wide ranges of pH, salinity, depth, oxygen concentrations, temperature and productivity allow them to potentially occupy all the ecological niches in freshwater environments.

Chironomids occupy all trophic levels and are characterised by large numbers of species (around 15,000 in the world, and more than 400 in Italy), which are extremely diversified from an ecological point of view. Because of their ubiquity and richness of stenoecious and stenotopic species,

Chironomids as indicators of the trophic status of lakes

The use of chironomids as indicators of the trophic level of lakes is now normal practice, as is their use as indicators of chemical, radioactive and acid rain pollution. Between the 1950s and 1970s, classification systems were formulated of the trophic level of lakes, starting from an analysis of the benthic community. Basing his work on previous studies by Thienemann, Brundin was the first to demonstrate that deep communities can be utilised for characterising the trophic level of lakes. Attention then focussed on biological indexes which describe the status of lakes, thanks to the use of the benthic community as an indicator of environmental quality. In particular, the Benthic Quality Index (BQI), proposed by Wiederhom in 1976, is based on the chironomid community:

$$B.Q.I.=\sum_{i=0}^{5}\frac{n_i}{N}\left(K_i-1+C_i\right)$$

where:
K_i has values close to 5 for the association with *Heterotrissocladius subpilosus*, close to 1 for that with *Chironomus plumosus*, and 0 when no indicator species is present; n_i is the number of individuals present in the n-th indicator species of the sample, and C_i is the total number of individuals. However, the BQI did not put enough emphasis on the necessity for differentiating stenotopic organisms, i.e., typical of oligotrophic environments like Alpine lakes, from those which adapt to a wide food range. The need therefore arose for a more accurate revision of the system while, at the same time, the inadequacy of single lacustrine parameters became increasingly evident: for example, primary production alone cannot represent the exclusive key to understanding the entire ecosystem of a lake. Research has therefore attempted to find new analogies between data from various types of analytical approaches, in order to yield an exhaustive, integrated and clear perspective of lacustrine systems. Saether therefore revised the BQI, leaving the idea of an index and subdividing the ambits of the chironomids into deep, littoral, and sub-littoral communities. Fifteen types of chironomid communities were defined, indicated by Greek letters starting with α. Six of these are typical of oligotrophic lakes, three of mesotrophic lakes and six of eutrophic lakes. Data from the chironomid communities were again related to the phosphorus and chlorophyll levels in lakes, yielding good correlations between these parameters, even in widely varying lacustrine systems. It was demonstrated that identification of the typical communities of ultra-oligotrophic lakes is simple, whereas the limits between oligotrophy, mesotrophy and eutrophy are clear, although less immediate.
Thanks to these and other studies (e.g., those of Warwich in the 1970s), it has been demonstrated that availability of food is the controlling factor governing the succession of chironomid communities. It had previously been thought that hypolimnetic oxygen was the controlling factor, but this is probably mainly true in the case of eutrophic lakes, ones with particular basin morphology (lake surface - volume - depth ratios) which affects the re-oxygenation rate, or humic lakes.
In ultra-oligotrophic lakes, the Orthocladiines (e.g., *Heterotrissocladius*, *Orthocladius*) generally prevail, whereas chironomids dominate in all other conditions.
In more detail, *Micropsectra* and *Tanytarsus* (tanytarsine tribe) are abundant in oligotrophic lakes; *Sergentia*, *Endochironomous*, *Microtendipes* and *Stictochironomus* (chironomine tribe) predominate in mesotrophic environments; *Chironomus anthracinus* and *C. plumosus* (chironomine tribe) in eutrophic environments, and *Chironomus plumosus* alone in highly eutrophic lakes.

Sampling in a small Alpine lake

Chironomus plumosus: the bright red colour is due to haemoglobin in the haemolymph, which enables these dipteran larvae to live in oxygen-poor lake sediments

Larva of limoniid dipteran, with the typical five-lobed spiracle disc

chironomids are optimal bioindicators, and have been used for many years as indicators of the trophic and acidification status of lakes. The cephalic capsules of chironomids are also used in palaeo-limnological studies to reconstruct the natural and man induced changes occurring in lake basins, particularly following air pollution and eutrophication.

The various taxa have evolved specific physiological, morphological and behavioural adaptations in order to survive in lentic environments. For example, some species, like *Chironomus plumosus*, can regulate their haemoglobin production in order to survive even prolonged periods of anoxia. The individuals belonging to taxa which live in deep water are usually larger than those living on the shore, they are mainly tubicolous, and their survival depends on ventilation efficiency, through vigorous waving of the body to and fro. Tubicolous species with haemoglobin are frequent and abundant in eutrophic lakes, whereas free-living taxa which frequently move in search of food prevail in oligotrophic lakes.

High altitude lakes are generally in remote and potentially isolated areas, but endemisms or particular biogeographical gradients within the Alpine area are unknown among the chironomids. Moreover, the occurrence of rare species may be explained by hypothesising that these taxa are stenoecious, associated with particular combinations of morphometric and ecological factors, often still unknown. *Paratanytarsus austriacus*, *Zavrelimyia* spp., *Corynoneura scutellata*, *Heterotrissocladius marcidus*, *Macropelopia nebulosa* and *Micropsectra* spp. are the most frequent and abundant, being distributed in lakes throughout the Alpine area.

Some species are associated with specific environmental conditions, where they may reach high numbers, such as *Paracladius alpicola*, *Acamptocladius reissi*, *Pseudokiefferiella parva* and *Pseudodiamesa nivosa*. For example, *Paracladius nivosa* emerges immediately after the ice has melted in spring, and *P. alpicola* is known only in high-altitude lakes with a low trophic level. *A. reissi* is restricted to the littoral zone of shallow lakes with abundant macrophytes, or to peat bogs, and appears to be able to tolerate pH values as low as 3. Among the rare taxa present along the shores of small mountain lakes there are *Krenosmittia* sp., *Zavrelimyia berberi*, *Paraphaenocladius irritus* and *Pagastiella* sp., which are particularly demanding from an ecological point of view.

Trichopterans. Trichopterans, or caddis flies, are an extremely heterogeneous order of insects with aquatic larvae which undergo complete metamorphosis. They have colonised most inland waters: torrents, springs, large rivers, ponds and lakes. A peculiar characteristic of many trichopterans is the case or “house” that the larvae construct around their body, with a silky secretion, to which material from the environment is glued. These cases have a double function: as protection and as an anchor to fix them to the substrate. The cases are made of the most disparate materials - plant materials, tiny pebbles, grains of sand, or empty mollusc shells. Shape also varies from species to species, from cylindrical to conical, to the shape of a bag or a hut, etc. Other species do not have larval cases, but construct “nets”, with methods and purposes similar to the webs woven by spiders in terrestrial environments; lastly, the larvae of the rhyacophilid family have no cases, and are carnivores. After dipterans, trichopterans are the best represented group in mountain lakes. In high-altitude Alpine lakes, the available literature lists: *Rhyacophila italica*, *Plectrocnemia conspersa*, *P. geniculata*, *Polycentropus flavomaculatus*, *Oligotricha striata*, *Limnephilus coenosus*, *Halesus radiatus*, *Melampophylax mucoreus*, *Phacopteryx brevipennis*, *Allogamus antennatus*, *A. auricollis*, *A. uncatus* and *Odontocerum albicorne*. These species are not usually exclusive to lake environments, but also frequent inlet streams and, even more especially, outlets. They are generally found in littoral or sub-littoral zones.

Larva of a limnephilid trichopteran

Vertebrates

LUCA LAPINI · SERGIO PARADISI

Fish

Lago di Tovel (Trentino)

There is only one fish in Italy which may be said to be truly exclusive to mountain lakes, including those at high altitude: it is the arctic char (*Salvelinus alpinus*), a markedly oligostenothermal salmonid, originally limited to a few small water-bodies in the Trento area, belonging to the basins of the rivers Sarca and Brenta, together with the Adige and its tributaries Avisio and Noce, the lakes of San Giuliano, Bocche, Stellune, and few others. That the char is native to these waters is given as a certainty, although we cannot entirely rule out its introduction by man in historycal times, perhaps due to the fact that the territories on both sides of the Alpine barrier came under the same Hapsburg rule.

Salvelinus alpinus is a holarctic species with a wide circumpolar distribution, and its largest populations are concentrated in the coastal sea waters of the sub-arctic zones of Europe, Asia and North America, as well as in tributary river basins, where the arctic char is an anadromous migrant. In these areas, the species, because of its tasty flesh and the reasonable size of its populations, is still of some importance commercially. It is also present in sedentary populations with extremely irregular distributions in the clear cold waters of many lakes in northern Russia, Siberia, Europe, North America and Greenland. European lakes hosting these resident forms are found in the British Isles, Norway, Sweden, Finland and Iceland. At lower latitudes, arctic char can be found in a few lakes in the Pyrenees, the French Massif Central, and the Alps. In these more southerly regions the species is considered to be a glacial relict,

Male alpine newt (*Triturus alpestris*)

restricted to the deep oxygenated waters of some high-altitude lakes by its requirement for low temperatures (from 4 to 8 °C, with peaks of 12 °C tolerated for brief periods).

In Italy, the original distribution of the char has been modified over the last two centuries through repeated introductions from lakes in the Trentino and abroad. The first documented attempts to extend the distribution of the species were made by the ichthyologist Filippo De Filippi in 1862, who divided 70,000 embryonate eggs, acquired in Munich, between the lakes of Avigliana and Mergozzo in Piedmont and Montorfano in Lombardy. The 50,000 eggs released in Lago d'Idro in 1885 were again from Bavaria. A further 150,000 eggs were introduced into the same lake three years later, this time coming from Lake Tovel in the Trentino. These operations were not successful and were never repeated. The outcome of introductions attempted in 1895 in Lake Lugano were very different, where fry (rather than fertilised eggs) from Lake Zug in Switzerland were released: the result was total and immediate, and tons of arctic char appeared in the catches of the lake's commercial fishermen just a few years later. After Ceresio, in 1910, it was the turn of Lake Maggiore and then, in 1930, Lake Como, always with excellent results. Instead, the species was unable to colonise Lake Garda, and there have never been more than sporadic catches of single specimens, almost always in the deeper part of the lake. The arctic char populations in the large Italian lakes are currently all in

Arctic char (*Salvelinus alpinus*)

serious decline. In these sub-alpine basins, the low temperatures required by the fish are not always guaranteed by altitude, but by depth of water, and the fish remain close to the lake bed.

Extending the Italian distribution area of this species has also, on more than one occasion, involved high-altitude lakes, mainly in Piedmont, Val d'Aosta and Lombardy, using not only specimens from the Trentino but also non-indigenous stock. The original populations in the lakes of Fusine and Raibl (Julian Alps), considered by some to be native and by others to be of Trentino origin, have been supplemented by other arrivals in relatively recent times, to the extent that today's arctic char in Lake Fusine probably all originate from Lake Bohinj in Slovenia.

Lago di Fusine (Julian Alps, Friuli Venezia Giulia)

The arctic char is very similar to trout, but identification is always simple, without any need to examine internal characteristics: however, it should be remembered that, as the char belongs to the genus *Salvelinus*, unlike *Salmo*, the ploughshare bone - the bone forming the roof of the mouth - bears no teeth. As in all salmonids, there is a second small dorsal fin with a fleshy appearance, but the scales covering the body are much smaller than those of trout, whereas the mouth, well equipped with teeth, is bigger and extends past the eye. The background colour is greyish-olive or brown in sedentary populations, paler and silvery during the marine trophic stage of migratory populations; there are many small round marks on the flanks, pale or sometimes pinkish, but these are not very visible in animals living in the sea. There may also be pinkish tinges on the white underbelly. The fronts of the yellowish pelvic and anal fins are edged in white. The flanks of the young, as in other salmonids, bear dark traverse bands, known as parr marks. On the whole, the arctic char is an attractive fish, but not particularly conspicuous. The story is very different when the males are in nuptial livery: their colours become much more contrasting, the back and sides show bluish reflections, the markings become more obvious, all the lower part of the body - including the fins - takes on a bright red colour, and the mandible assumes the characteristic hooked shape: they look magnificent.

The reproductive biology of this fish differs according to whether the population is sedentary or migratory. In the latter, mature adults begin migrating from the sea to the lakes at the end of summer, losing their silvery colour and gradually assuming nuptial coloration. Spawning takes place in rivers and lakes in late autumn or winter. At the end of the following spring, the adults return to the sea, while the young pass the summer in the lower stretches of rivers and in brackish waters. They subsequently move out to sea, to waters with low salinity, where they pass through a growing stage leading them, after 3-6 years, to sexual maturity. During this stage, their food of choice is small fish, especially young cod. At Italian latitudes, the breeding season is the same, although anticipated spawning in early autumn has been observed (but not habitually) in the large sub-alpine lakes. Each female produces from a few hundred up to approximately 5000 eggs, each with a diameter of 4-5 mm. The eggs are laid deep in the lakes (sometimes even deeper than 100 m), on stony or rocky bottoms, in small natural depressions or in ones dug by the female and tidied by flicks of her tail. There is no tendency of breeding fish to move to flowing waters, as trout usually do. Hatching is in late spring.

In sedentary arctic char, growth varies in relation to the temperature and trophic conditions in the hosting water-body, but is generally rather slow, lengths of 13-18 cm being reached after 3-4 years on average, and 30-35 cm after 10 years in populations living further north. At Italian latitudes, although precise data are lacking, it is possible that the growth rate is higher. After re-absorption of the yolk sac, the fry at first feed exclusively on plankton, and then pass mainly to benthic invertebrates. Specimens which reach more than 20 cm in length begin to include small fish in their diet, also preying on conspecifics.

The oligotrophic environments in which arctic char live often lead them to diet specialisation: one study conducted in high-altitude sites in the western Alps demonstrated an arctic char diet composed of almost 98% chironomid larvae and pupae. For these fish, the trophic spectra in relation to altitude and the size of the lake translate into ecological polymorphism, which allows available resources to be exploited to the full and which is expressed in local forms differing in size, diet, livery, and also biological cycle.

In the Alps, at least four different forms are known: common arctic char (the typical lake form, which feeds on plankton and benthos), predatory arctic char (fast-growing, typical of large deep lakes, with a diet based on fish), dwarf arctic char (a small plankton-eating form), and deep-water arctic char (a dwarf form found on large lake-beds which feeds on benthic organisms). Populations thus exist in which the maximum length is no more than 15 cm, compared with predatory arctic char which may reach 80 cm in length and more than 8 kg in weight, although the more normal length is around 50 cm and weights between 1.5 and 3 kg.

In the Bavarian and Austrian Alps, two of these forms often live in sympatry, and not only differ in size but also have different breeding times and sites. In some lakes in the Trentino, arctic char are present in dwarf form, but no cases of cohabitation between the different forms are known in Italy. The variability of these fish has led in the past to the description of more than one species and numerous subspecies. Nowadays, the existence of a single species, *Salvelinus alpinus*, is recognised, after reconsideration of the nomenclature in the light of the very minor genetic differences which appear to accompany polymorphism. For the Italian populations, the name *Salvelinus alpinus salmarinus*, now abandoned, used to be adopted by some Authors. The biogeographical interest of the Alpine populations - isolated within the vast distribution area of the species - deserves further taxonomical study.

For some years now, following introductions, another species of the genus *Salvelinus* has been found in some lakes in the Italian Alps: the brown char (*Salvelinus fontinalis*). This species is native to the north-eastern regions of North America, where it is known as brook trout, and populates rivers from North Georgia to Labrador, flowing into the Atlantic Ocean and Hudson Bay.

Brown char (*Salvelinus fontinalis*)

From the last decades of the 19th century onwards, it was introduced and acclimatised not only in many other areas of the United States and Canada, but also in South America (including the Falkland Islands), South Africa, and various regions of Asia and New Zealand. In Europe, where it has been present since 1884, the species is irregularly distributed and adapted in many areas, but is especially common in Scandinavia.

Its first introduction in Italy would appear to have been into Lago d'Idro in 1891. In many cases, the brown char appears to have difficulty in competing with the native salmonids in the areas of release, particularly with brown trout. This prevents it from forming stable populations and often causes its disappearance from the watercourses into which it has been introduced within a brief period, so that - with the exception of some flowing waters in the upper reaches of the rivers Isarco and Rienza in Alto Adige (South Tyrol) - finding it in free waters is in general sporadic and linked to the restocking policies of local administrations. Better results have been obtained from releases in lakes, where char would seem to settle at greater depths than trout. The species appears to be particularly well-suited to populating natural and artificial mountain lakes where there are no other salmonids: it seems to find these environments suitable and can also create viable populations at high altitudes. However, in particularly severe conditions of low temperatures and marked oligotrophy, the species demonstrates slowed growth: in sites of

Lago di Avostanis (Carnic Alps, Friuli Venezia Giulia)

the Piedmont Alps situated around 2700 m a.s.l., specimens of 6-7 years old, but still sexually immature, and only about 25 cm long have been observed. In normal conditions, this size would be reached in the second-third year, the age at which males usually attain sexual maturity (females normally reach this stage the following year).

In Italy, acclimatised populations now exist in various lakes on the Alps (e.g., lakes Combal and Laures in Val d'Aosta, Lago Nero in Val di Viù, various small high-altitude lakes in the Gran Paradiso area, Laghetto di Avostanis in the Carnic Alps) and in the northern Apennines (e.g., Lago Santo Parmense).

In their native lands, examples of this species may exceptionally reach 80 cm in length and more than 5 kg in weight; in Italy, they are rarely longer than 45 cm, with a maximum weight of around 1 kg. From the aesthetic point of view, for many the brown char is the most attractive fish to be found in Italian freshwaters. Morphologically, it is very similar to *Salvelinus alpinus*, but the livery - particularly striking - allows immediate identification. The background colour is green-brown-violet, decorated along the flanks by profuse round yellowish markings and sparser red or pink dots, surrounded by a pale blue halo. An irregular pattern on the back originates vermiculate characteristics, which extend to the dorsal fins and part of the caudal fin; the overall effect is of variegated gilding. The underbelly is white, with pinkish-orange tints. The orange pelvic and anal fins have a white front edge, duplicated by a black line. As in arctic char, colours become bolder in the breeding season, especially in the males, when the lower body, including fins, assumes a magnificent red colour; in larger males, the hooked deformation of the mandible also becomes evident.

Spawning is between October and December, on deep gravelly bottoms. Each female lays between 2000 and 3500 eggs per kilo in weight. The eggs, which the female covers with gravel by beating her tail, are large (from 3.5 to 5 mm in diameter), with rich yolks, and hatching time of 500 degree-days: temperatures of around 5 °C entail an incubation period of more than three months.

The brown char is usually also able to reproduce in standing waters, as long as they are cold and well oxygenated. For trout, this is much rarer, and the need to move to flowing waters for reproduction is certainly a factor limiting the presence of these fish in high-mountain lakes. The altitudinal limit of reproduction ascertained for the brown trout (*Salmo* [*trutta*] *trutta*) in streams of the Italian Alps is around 2400 m, but in favourable climatic periods specimens may arrive higher up, reaching lakes located at higher altitudes through their outlets. However, it would appear that favourable conditions of temperature, oxygenation, depth and particle-size of the bed exceptionally allow brown trout to breed in lakes, at even higher altitudes than that given above. As happens in the large Pre-alpine basins, also Alpine lakes of sufficient depth and size occasionally host resident populations of so-called "lacustrine" trout: these are ecotypes of *Salmo trutta* characterised by "pelagic" colouring - metallic grey on the back and silvery on the sides - which generally grow quite large, due to the higher trophic level in these waters compared with the inlet and outlet streams.

According to some scientists, the trout populations in small Alpine lakes are not indigenous. In effect, unrestricted trout stocking for angling has led to these fish being introduced almost everywhere in Italy, even in water bodies that had never hosted them, often with negative impacts on resident species. The brown trout is the usual protagonist of these introductions, but - although less frequently than in the recent past - rainbow trout (*Oncorhynchus mykiss*) is also used for stocking, due to widespread fish-farming and its lower market price, thanks to the fact that its growth rate is faster that of the European trout. Indeed, the rainbow trout is the fish we are all used to seeing for sale in the fishmongers. The species, originally distributed with both sedentary and anadromous migratory populations in the rivers of the Pacific board of North America and north-east Asia, was imported into Europe for the first time around 1880, and immediately began to spread very rapidly. Although in some lakes its release has led to the formation of wild populations, the

Minnow (*Phoxinus phoxinus*)

acclimatisation of this trout in European waters has been problematical, and cases of breeding in free waters are also few and local in Italy. Its presence in high-altitude lakes is therefore usually temporary, and linked to the stocking policies of the local administrations and bodies involved in the management of angling.

As previously mentioned, the very low productivity in these environments accentuates phenomena of competition. The salmonids cited so far have greatly overlapping ecological niches - when they do not entirely coincide - and their presence in just one small high-altitude lake is often limited to a single species. This is occasionally accompanied by one or two small-sized species, which inevitably assume the role of forage-fish.

The most common of these is the minnow (*Phoxinus phoxinus*), which gained fame by being used by Karl von Frisch in his studies on the hearing capabilities of fish. This small, highly gregarious cyprinid, has a wide Eurasian distribution area and is indigenous to northern Italy, where its irregular distribution is due to its requirement for good environmental quality. It needs cool water with good oxygenation, preferring the mid-upper reaches of watercourses and springs.

In mountain and high-mountain lakes, where it is often visible in large shoals, according to many authors, the presence of the minnow is also due to accidental releases (mixed with other introduced fish species - chiefly salmonids - or else as a consequence of their being used by fishermen as live bait). High altitudes are reached: for example, minnow is recorded in the lakes of Gran San Bernardo (Val d'Aosta, 2472 m) and Cima d'Asta (Trentino, 2457 m), but there are numerous lakes throughout the Alps that host this species. In these particular environments, the possibility of constituting stable populations is linked, amongst other things, to the temperature which, at least in some shallow inlets next to the shore, must reach the necessary threshold value of 12 °C for reproduction. Breeding takes place in July-August on beds of gravel or pebbles. Although the season is later and shorter than in waters on the plain, repeated spawnings are still possible. Each female produces between 200 and 1500 eggs, 1.5 mm in diameter, per breeding season and, in these cold waters, they hatch in 8-10 days.

Growth is slow, despite an opportunistic non-specialist diet which may include zooplankton, insect larvae and adults, benthic crustaceans and also fish eggs and fry; the food spectrum may also widen to include plant material, mainly composed of filamentous algae and detritus. The low trophic capacities of the environment translate into small-sized fish compared with waters on the plain, with maximum lengths that rarely exceed 8 cm. Larger dimensions are the prerogative of females, which also live longer, quite frequently exceeding 4 years of age. The sex ratio is normally 2 to 1 in favour of females.

The minnow also displays clear sexual dimorphism in the breeding season: the yellowish or brownish tones in the male are replaced by a metallic bluish-green covering back and flanks; on the latter, crossed lengthwise by a narrow golden band, is a clearcut series of dark transversal marks, while the jugular area and the base of the pelvic and anal fins become a vivid blood red. Only a reddening of the underbelly appears in the female, whereas both sexes have the so-called “nuptial tubercles” on the head.

Another species forming part of the salmonid retinue is the Miller’s thumb, or sculpin (*Cottus gobio*), which is widespread in Europe, with the exclusion of the far south. In Italy, it is found in the Alpine tributaries of the river Po, to an altitude of 1200 m, but it is missing from the Apennine tributaries, with the exception of the Orba (tributary of the Bormida), Scrivia, and some lesser watercourses of the upper stretch of the Panaro. It also lives in the Alpine tributaries of the northern Adriatic and is present in the area of the Veneto and Friuli Plain, especially in the watercourses immediately downstream from the springs.

In the central Apennines, there are isolated populations distributed as far south as the Marche on the Adriatic side and the upper reaches of the Tiber in the west. None are found further south. Miller’s thumb is also found in the large

Miller’s thumb (*Cottus gobio*)

lakes of northern Italy and in various high-mountain lacustrine basins. In these environments, where it usually remains in shallow waters close to shore, it reaches much higher altitudinal limits than in flowing waters. Two records, although very much out of date, may be cited, relating to localities situated well above 2000 m: Lake Fallere (2415 m) in Val d’Aosta and Lake Bombasel (2267 m) in the Trentino. Miller’s thumb has also been reported in many locations of the Alps at altitudes between 1200 and 2000 m.

Brown trout (*Salmo* [*trutta*] *trutta*)

Its penetration into Italy appears to be relatively recent, as no significant morphological differences are found in comparative analyses between specimens of Italian and Danubian origin. Like the other cold-loving species already mentioned (*Salmo trutta*, *Phoxinus phoxinus*), Miller’s thumb probably arrived through the meeting of the headwaters of the Cisalpine and Transalpine basins. During the peak glaciations (and consequent extension of the Po basin) in the Ice Ages, the species then expanded to all the basins of the Po valley, later penetrating into Tuscany and Latium (Serchio, Arno and Tiber basins), probably once again due to phenomena of river capture between courses of the opposite sides of the Apennines during the Pleistocene.

Miller’s thumb has strictly benthic habits: it lives almost permanently resting on the bottom. It is active at dusk and during the night, but remains hidden during the day amongst the stones on the bed. It feeds on benthic macro-invertebrates (particularly crustaceans, insect larvae and annelids) as well as eggs and fry of both its own and other species of fish, especially trout and char. It is, in its turn, the habitual prey of adult trout, forming a characteristic association, particularly in mountain streams, where trout and Miller’s thumb are often the only two species present. In high-mountain waters, growth is slow and sexual maturity late but, to compensate for this, Miller’s thumb reaches larger dimensions here (up to 16 cm, and exceptionally, 18 cm in length) and has a longer life-cycle than conspecifics living in the more productive watercourses in the lowlands. In high-altitude lakes breeding takes place at 3-4 years of age. In these waters, there is a single spawning per breeding season in late spring. Each female lays up to 600 eggs, reddish-yellow in colour and 2-2.5

mm in diameter, glued to the lower surface of a pebble, which acts as a roof for a sort of lair dug by the male in the lake bed. The male, which displays territorial behaviour, may induce more than one female to lay eggs in his shelter, and thereafter guards and actively defends them until they hatch, approximately 4 weeks later. There is dimorphism between the two sexes, although not marked: the males have a bigger head and longer pelvic fins, and are more intensely coloured than the females during the breeding season.

The species quoted until now (apart from rainbow trout, the non-acclimatisation of which has been discussed) may pass their whole life-cycle in the limiting conditions of the high-altitude environments examined here. However, other species may also be found in these basins - like bleak (*Alburnus alburnus*), tench (*Tinca tinca*), roach (*Rutilus erythrophthalmus*) and chub (*Leuciscus cephalus*) - which are occasionally introduced because someone considers them “lake” species. If they do not quickly succumb to thermal stress, predation, or lack of suitable food, these fish merely survive without any possibility of breeding, which is generally precluded by the failure to reach threshold temperatures.

These cyprinid components of the fish community - always the result of introductions - may have better opportunities in the high-altitude lakes of central-southern Italy, where mountain climatic and trophic conditions are relatively less severe.

Tench (*Tinca tinca*)

Amphibians and reptiles

Amphibians. The most frequent amphibians in high-altitude environments are the common toad (*Bufo bufo*), Alpine newt (*Triturus alpestris*) and European frog (*Rana temporanea*). They all use these areas for breeding and are widespread up to the highest altitudes, both in small Alpine lakes where there are no fish and in mountain basins in the Apennines.

Whereas the common toad is found all over Italy, the European frog arrives as far south as the Monti della Laga, and the Alpine newt reaches the Calabrian coastal chain, although with extremely fragmentary distribution. This urodele is differentiated into various subspecies in Italy: the nominal form lives on the Alpine range, the colourful subspecies *Triturus alpestris apuanus* on the Apuan Alps, and a subspecies described only a short time ago, called *Triturus alpestris inexpectatus*, lives in the Calabrian coastal chain, and is endemic to these mountains.

On the Eastern Alps, the Alpine newt may cohabit with the common newt (*Triturus vulgaris vulgaris*) and Italian crested newt (*Triturus carnifex*) in some small lakes. The latter reaches high altitudes, sometimes well above 1500 m, in various parts of the Alps and Apennines.

The yellow-bellied toad (*Bombina variegata*) is present in some high-altitude lakes of the Alps, and may sometimes even be found above 1800 m in the

Italian crested newt (*Triturus carnifex*)

Eastern Alps. It is not particularly common, and indeed all populations of yellow-bellied toad living above 1000 m are considered of special conservation value in Europe.

In the Apennines, the species is substituted by the kin *Bombina pachypus*, an Italian endemic, which displays similar ecological propensities and breeds in some marshy areas at moderate altitude. The green toad (*Bufo viridis*) also tends to become rarer with increasing altitude, but in some areas of the Alps it may exceed 1500 m, at times forming quite dense, but almost always very isolated, populations - as at Piani di Erera-Brendol in the province of Belluno.

The agile frog (*Rana dalmatina*) and Italian frog (*R. italica*) also sometimes reach quite high altitudes on the Apennine chain, but it is unusual if they use these areas for breeding. The agile frog prefers broadleaved woodlands, whereas the Italian frog prefers cool valleys cut by Apennine streams.

The green frogs of the L-E system (*Rana* synklepton *esculenta*) do not reach the small high-altitude lakes on the Alps, generally remaining at lower altitudes and rarely reaching 1000 m a.s.l., but the situation is different on the Apennines. Green frogs of the genetic hybrid system B-H (*R.* synklepton *hispanica*) live here, as endemics, and may also be found above 1000 m a.s.l., colonising very different mountain basins. These animals are characterised by particularly variable coloration, between green, brown and yellow, with white vocal sacs.

European frog (*Rana temporaria*)

Reptiles. The reptiles which frequent the shores of the highest lakes in the Alps include the grass snake (*Natrix natrix*), which in these habitats turns its predatory attentions towards tadpoles of the European frog and common toad and the larvae of various urodele species.

On the shores of these often marshy basins, the viviparous lizard (*Zootoca vivipara*) also finds an ideal habitat. This small hygrophilous lizard, which lives on the Alpine range and in some areas overlooking the Po Valley, has a vast distribution area which stretches from western Europe to the Pacific coasts of Russia, at least as far as the Sakhalin Peninsula in Siberia. To the north, the distribution area of the species touches the 70th parallel; to the south, it reaches the mountain ranges of central-southern Europe and central Asia, also covering part of north-eastern China. In the southern part of its range, it has an obvious Alpine bent, and its distribution is very fragmented. The species is ovoviviparous over much of its distribution area. However, populations in many areas of southern Europe are oviparous (Pyrenees and south-eastern Alps), and those living in parts of Slovenia, Austria and Italy are particularly archaic. They have been ascribed to the newly described subspecies *carniolica* (viviparous lizard of the Carniola) which, with its peculiar genetic traits, may indeed merit species status. This oviparous form is present from sea level up to 1900 m a.s.l. in northern Italy, and is common on the mountains of north-eastern Italy. Instead, in the Italian Alps, the

Viviparous lizard of the Carniola (*Zootoca vivipara carniolica*)

Adder (*Vipera berus*)

ovoviviparous form is found in areas which were heavily glaciated during the Pleistocene.

Despite the fact that the two subspecies may cohabit on the same mountain, no cases are known of natural hybridisation between them, and this supports the hypothesis that they are two distinct species. In any case, ovoviviparity is a recent acquisition. This mode of reproduction probably appeared and was propagated between the early and second half of the Pleistocene, in an area situated between southern Russia and the Balkan Peninsula. During the successive cold phases of the Quaternary, the ovoviviparous populations of this lizard invaded much of the European subcontinent, remaining separate from the more archaic oviparous populations of the Balkans and northern Italy. At the end of the Ice Ages, the latter followed the retreat of the glaciers, invading most of the Friuli Venezia Giulia region, Eastern Austria, Slovenia, and some areas of Alpine and Pre-alpine Piedmont. This distributive tension between the two forms is still evident today in wide areas of the Alps, with an unclear distribution pattern. The viviparous lizard displays a decided predilection for the marshy areas on the shores of Alpine lakes - to the extent that, in these habitats, it is possible to find both oviparous and ovoviviparous forms, occasionally up to highest locally accessible altitudes.

In these mountain habitats, the viviparous lizard cohabits with the adder (*Vipera berus*), which constantly preys on it. This snake is widely distributed in central-northern Europe. To the north, the species almost reaches the Arctic Circle; to the east, it reaches the Pacific coasts as far as the Sakhalin Peninsula and North Korea. At Italian latitudes, it shows a clear preference for high altitudes, and on the Alps it may be found from 600 m to the summits. This eclectic snake has extremely variable colouring. In the breeding season, the males are more or less black and white, with a highly contrasting zig-zag design along the back, whereas the females tend towards brown. Melanic (black) specimens are very common, at times making up 30% of the high-altitude populations.

■ Birds

Only a few brief notes are devoted here to birds, as there are very few species strictly associated with high-altitude aquatic environments. Those few include the dipper (*Cinclus cinclus*) and grey wagtail (*Motacilla cinerea*). However, the former requires the fast-flowing waters of brooks and streams, so that its presence on lake shores is limited to the mouths of any feeder-streams or emissaries. The eggs and juvenile stages of fish appear regularly in its diet, which mostly comprises aquatic macro-invertebrates. This bird is extremely territorial, migrating only in particularly severe winters by making wandering erratically down towards lower altitudes. The species is not especially constrained to a fixed altitudinal belt: it is most common between 500 and 1700 m, but - especially in the Western Alps - nests have been recorded as high as 2200 m a.s.l..

The distribution of the grey wagtail is also not particularly affected by altitude: it may even nest above 2000 m and, if anything, its presence becomes more sporadic descending towards the plains. It nests near water, in cool shady nooks on the banks of streams and lakes. The shores of water bodies are also frequented by the congener white wagtail (*Motacilla alba*): however, this is a practically ubiquitous species, to be seen in a wide variety of environments - even in towns and cities.

Dipper (*Cinclus cinclus*)

Tree pipit (*Anthus trivialis*)

The presence of other bird species on the shores of high-altitude lakes is, in final analysis, determined mainly by the surrounding habitat.

Thus, in environments with cool steep banks, marshes and shrubs, the wren (*Troglodytes troglodytes*), robin (*Erithacus rubecula*) and garden warbler (*Sylvia borin*) may appear, and sometimes also build their nests.

Grey wagtail (*Motacilla cinerea*)

Wood sandpiper (*Tringa glareola*)

The garden warbler is even more frequent in the belt of contorted shrubs and scattered larch at the treeline. In these areas, the following birds may also put in an appearance on the shores in summer - especially in the early morning to drink and perhaps take a quick bathe - the chaffinch (*Fringilla coelebs*), redpoll (*Carduelis flammea*), citril finch (*Serinus citrinella*), siskin (*Carduelus spinus*), bullfinch (*Pyrrhula pyrrhula*), linnet (*Carduelis cannabina*), common crossbill (*Loxia curvirostra*), hedgesparrow or dunnock (*Prunella modularis*), fieldfare (*Turdus pilaris*) and mistle thrush (*T. viscivorus*), just to mention some of the most common species.

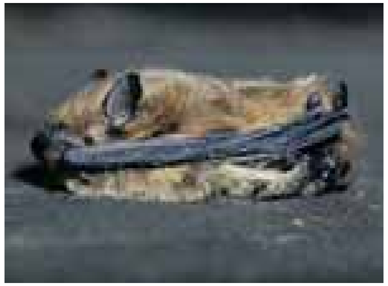
Areas of open grassland attract the water pipit (*Anthus spinoletta*) and rocky south-facing pastures are frequented by the rock bunting (*Emberiza cia*), wheatear (*Oenanthe oenanthe*), black redstart (*Phoenicurus ochruros*) and rock thrush (*Monticola saxatilis*). Areas of peat bog with shrubs and trees bring the tree pipit (*Anthus trivialis*), yellowhammer (*Emberizia citrinella*) and whinchat (*Saxicola rubetra*) to the shores of open waters. At higher altitudes, the debris-strewn shores of the cirque lakes - inserted among crags, screes and rocky cliffs - are witness to the flights of the alpine accentor (*Prunella collaris*) and snow finch (*Montifringilla nivalis*).

Finally these environments, like all water bodies (even small ones) may reserve pleasant surprises during periods of migration. Solitary waders may occasionally be observed resting on the shoreline. These may include the common sandpiper (*Actitis hypoleucos*), wood sandpiper (*Tringa glareola*) and green sandpiper (*T. ochropus*).

■ Mammals

High-altitude lakes are also the haunt of numerous small mammals, which drive the second and third trophic levels of the food-chain. Among those closely associated with mountain lakes, occasionally even at high altitudes, are water shrews. These tiny semi-aquatic insectivores produce a salivary enzyme which paralyzes small prey. The shrews weigh slightly more than 10 grams, are covered by a dense water-repellent coat, and divide up the habitat in a very characteristic way. The water shrew (*Neomys fodiens*) prefers flowing waters in the Alps and Apennines (to the south at least as far as Abruzzo). Strongly territorial, it is capable of reaching food sources anchored to the bottom, actively swimming and diving as deep as half a metre. On the beds of mountain streams and brooks, it searches for various species of benthic invertebrates, but is also capable of attacking small fish and amphibians, which it kills with its poisonous bite. Miller's water shrew (*Neomys anomalus*) is a less active swimmer, and mainly preys on the invertebrates that it seeks out in shallow pools, or in the puddles of water which form on the margins of the major basins, areas often also covered by a film of water. The species has gregarious tendencies, tolerates the presence of conspecifics, and supports reasonable concentrations of animals. It becomes notably rarer with rising altitude, but may cohabit with the water shrew up to considerable heights in both the Alps and Apennines. Miller's water shrew reaches the extreme south of Italy, but the animals living in the Serre Calabre are larger and particularly dichromatic, reminiscent of many typical characters of water shrews.

Water shrew (*Neomys fodiens*)



Common pipistrelle (*Pipistrellus pipistrellus*)

Among the rodents living in the marshy areas which often surround small Alpine lakes, the field vole (*Microtus agrestis*) prefers ungrazed meadows at high altitudes. In the central-eastern Italian Alps, this species is common on the muddy banks of small lakes, where it can occasionally be observed swimming across small stretches of water. However, this rodent mainly inhabits the tall grasses growing on the banks, in which it digs systems of tunnels that often become submerged by water.

Another vole of these areas is the northern water vole (*Arvicola terrestris*). At higher altitudes in the south-eastern Alps, the subspecies *A. terrestris scherman* can be found. This is a nocturnal fossorial species living in meadows, which visits water only exceptionally, but the small high-altitude lakes of the Apennines are regularly frequented by the southern form of the northern water vole. In the Alps, the western polecat (*Mustela putorius*) frequents forested valley bottoms, whereas the high-altitude marshlands of the Apennines are an attraction to this animal, as it searches for amphibians and rodents. Bats recorded near high lakes include the common pipistrelle (*Pipistrellus pipistrellus*), parti-coloured bat (*Vespertilio murinus*) and Nilsson's bat (*Amblyotus nilssonii*), the latter two being cold-loving species of northern European distribution, which live at quite high altitudes in the Alps. The small mountain lakes of the Apennines are frequented by other species. The most abundant are those of the genus *Myotis*, amongst which perhaps the most common is Daubenton's bat (*Myotis daubentonii*), a small bat frequently hunting over water.

Ungulates visiting mountain lakes to drink are wild boar (*Sus scrofa*), found up to the highest altitudes in the Alps, and various species of deer (red and roe deer) and goats (chamois and Alpine ibex). In high-altitude environments, lakes play an important role as regards the water and energy balance of numerous species of wild ungulates. This translates both into the provision of food and drinking-water, and the possibility of taking mud baths, which are much appreciated by both deer and wild boar. It is easy to identify the tracks of these large animals in the peat bogs and water meadows that form around the lake shores, as well as the characteristic depressions they use for rolling in the mud.

Conservation and management

MARCO CANTONATI · LUCA LAPINI · SERGIO PARADISI · FABIO STOCH

■ Degradation of high-altitude lakes

Artificial lake of Venerocolo (Adamello) exploits a lateral moraine as a bank

It is commonly imagined that high altitude lakes are remote environments, and thus almost entirely natural and intact, as they are far removed from the influence of the presence and actions of man. Indeed, compared with the majority of water-bodies in valleys or on the plains, although these lakes are less affected by human activities, they are still subjected to a whole series of direct and indirect impacts which alter their physical, chemical, biological and, at times, morphological characteristics. The most important of these include leisure pursuits, changes made to the landscape for hydro-electric purposes (i.e., the construction of dams and power stations) and to provide drinking water, introduction of alien species of fish, release of organic matter from mountain shepherds' huts or mountain refuges (eutrophication), distribution of acid substances (acidification) and other pollutants (heavy metals, organic compounds) with precipitation, and even increased ultraviolet radiation, caused by the thinning of the ozone layer, and the altered temperature and water regime because of global climate change.

■ Modifications to lake morphology

Many small high-altitude lakes have been modified by "structural" works for hydro-electric purposes. In extreme cases, this has involved the transformation of the lakes from natural to semi-artificial by the building of dams, with drastic variations in water level which prevent the biological communities from populating the shores. Water fluxes due to these modifications generate an environmental situation far from the original lacustrine one, creating an artificial system with characteristics that may be defined as intermediate between those of rivers and lakes.

Lago dei Colli di Ancoccia (Cottian Alps, Piedmont)

Hazards arising from high-altitude lakes

Alberto Carton

Hazards arising from high-altitude lakes occour to either natural or artificial basins. In both cases, danger comes from the sudden release of large volumes of water or to surges. High-altitude lakes which are of the ice-scar, glacier-dammed type, or ones located at the edges of glacier snouts, may unexpectedly and very rapidly empty. Other lakes may also discharge their waters, but over longer periods of time, so that the risk to humans is less. In all cases, the cause of sudden lake emptying is the more or less rapid removal or collapse of an obstruction. Another risk is the flooding which may occur in all basins, if large sections of ice from a glacier or rocks fall into them. The emptying of an ice-scar, glacier-dammed or ice-marginal lake is due to physical-dynamic variations of the nearby glacier, modification of the topographical surface that supports the basin, opening of englacial run-off routes (crevasses), or thawing of transient ice masses, which can temporarily obstruct natural drainage points (crevasses, sink holes, etc.). Water can flow from the surface or inside the glacier. A spectacular example of risk due to the formation of an englacial lake occurred during the summer months of 2001 and 2002 on the ridge of the Belvedere glacier (Monte Rosa group), threatening the village of Macugnaga, in the upper Anzasca valley. Other high-altitude lakes which create, or have created, problems of risk are the ice-marginal lakes of Rocciamelone and Miage, in Val d'Aosta. On August 9 1996, an enormous block broke off the ice cliff that forms one of the edges of Lake Miage (see photo) and fell into it, causing a huge flood. Prevention of damage caused by the sudden emptying of high-altitude lakes lying in depressions between ice and rock, between ice and moraine ridges, between ice and ice, or created by glacial snout damming, must be undertaken in good time, when the accumulated volume of water is not excessive, and must involve continuous monitoring. When monitoring is not possible, the water level must either be artificially lowered or a retaining wall built.
An interesting example of such man-made constructions can be seen in the upper Val Martello (South Tyrol), where, to mitigate the terrible floods which struck the villages of Ganda and Martello towards the end of the 19th century, a stone dam was built to create an overspill area against the repeated emptying of the lake higher up the mountainside, which is naturally dammed by the snout of the Vedretta del Cevedale.

Apart from these modifications of large-scale environmental impact, there have been numerous other "minor" projects which cause a significant rise, although only limited to a few metres, of the level of the lake, by the building of an artificial reinforced-concrete weir at the emissary and installing a conduit for discharging variable amounts of water. It can easily be imagined that, during the building stage, these projects involve traumatic events - intentionally or accidentally - in a small Alpine lake, particularly the sinking or submersion of the original shores.

Man-made basin for supplying artificial snow-cannons (Ciampac, Alba di Canazei)

Alterations to morphology profoundly affect the plant and animal populations of a lake ecosystem. Plants no longer find the shore suitable for colonisation, as fine sediment and organic debris gradually accumulate, typically more frequently and extensively close to the emissary. Aquatic or semi-aquatic lichens must re-colonise the strips of shoreline that they typically occupy in relation to the water level: this is a process that requires many decades, because of the millimetric growth of lichen thalli. The re-conquest of the new shoreline by microalgae and benthic cyanobacteria is more rapid, as they have brief life-cycles and are adapted to the natural variability of water levels in small high-altitude lakes. Obviously, phytoplankton populations are also affected when these interventions include a conduit to draw water from the lake. The level of disturbance greatly depends on the depth at which the overspill pipe is placed, because planktonic microalgae colonise various preferential positions in the water column over time. However, planktonic algae generally appear to be much less affected by these impacts, and this is doubtless due to their very brief reproductive cycles and the fact that the majority of species produce forms of resistance (for example, cysts), which facilitate re-colonisation of the environment after traumatic events such as the accidental emptying of the basin.
The possibility of moving into inlet and outlet streams to gain access to breeding grounds is also important for the survival of fish populations, particularly salmonids: if continuity of the lakes with their inlets and outlets has been interrupted, breeding migrations for breeding purposes are still possible by creating bypasses to the weirs or equipping them with suitable "fish ladders".

■ Introduction of alien fish species

In mountain lakes, so-called “fish genetic practices” have been frequent for some time. Despite the declarations and stated good intentions of the managing bodies, these actions often translate into the indiscriminate stocking of miscellaneous species of salmonids. In Italy, the phenomenon became particularly evident from the 1960s onwards when, with the economic boom, fishing became a popular sport, managed by organisations specialising in the administration of fishing resources and angling. Almost every permanent lake, even at high altitude, was “filled” with fish, even if it had previously lacked any, with the intention of creating populations of fish which could afterwards be caught. Paradoxically, fish are one of the main hazards for the delicate ecology of these aquatic habitats, since they are capable of disturbing the equilibrium and drastically reducing the already modest biotic diversity.
The introduction of brown trout (*Salmo* [*trutta*] *trutta*) or species from across the Atlantic Ocean, such as the rainbow trout (*Oncorhyncus mykiss*) and brown char (*Salvelinus fontinalis*) trigger competition for food resources and predation of invertebrates and the juvenile or larval stages of local species of fish and amphibians - particularly in small water-bodies with a reduced food-chain. Restocking with arctic char (*Salvelinus alpinus*), whose status as an indigenous species in Italy has given rise to serious doubts, should also be evaluated with caution, ascertaining the source of stocks in order to limit risks of genetic pollution and completely avoiding their introduction into lakes where their presence has never previously been recorded. The ban on the release of alien species is also sanctioned by Italian law (DPR no. 120 of 12 March 2003), which implemented the Habitat Directive.
Many fish prey on sight and juveniles, in particular, mainly attack larger-sized zooplankton species, including filterers like cladocerans of the genus *Daphnia* and calanoid copepods, which play a key role in the food-chain of lake waters. By filtering the water in order to feed, these organisms control phytoplankton growth, but when their abundance is reduced through selective predation by introduced fish, algal populations rapidly multiply and the lake waters consequently begin a process of eutrophication.
The introduction of alien fish species and transfaunations (i.e., the transfer of faunal elements from one environment to another within national boundaries) also constitute the most important threat to the few species of indigenous fish living in high-altitude lakes. The indigenous populations, or those acclimatised a long time ago, of arctic char, a stenoecious species with limited vagility, are most severely threatened. Massive restocking with salmonids also obviously pose serious predation problems for minnow and miller’s thumb, if present. Lastly, the possibility is far from remote that these

Mandron lakes (Adamello Group, Trentino)

Brown trout (*Salmo* [*trutta*] *trutta*)

Small lake in Valle Aurina (South Tyrol)

practices may cause health problems in the resident fish populations.

The introduction of salmonids or cyprinids into the waters of mountain lakes also disrupts the reproduction of amphibians which, in the cold, well-drained, summit environments, often find their only possibility for breeding. The disruption of breeding translates into a drastic interruption in the energy transfer along the food-chain of small Alpine lakes. Amphibian breeding strategy involves an enormous production of eggs and tadpoles; the latter are herbivores and live on the patina of unicellular algae covering the rocks on the lake-bed and the meagre vegetation of the shores. Tadpoles grow very rapidly and, during their progression towards metamorphosis, face a high mortality rate, essentially due to predation. The role of amphibians in the energy transfer of high-altitude aquatic ecosystems is important in particular because of the large biomass of their larval stages, which can make the solar energy fixed by the unicellular algae of these basins - otherwise practically oligotrophic - available to a whole array of aquatic predators, detritivores and decomposers.

Tadpoles teem on the bed of a small Alpine lake

After the introduction of fish into high-altitude lakes, the only alternative places for amphibian reproduction are often livestock watering-holes constructed by herdsmen. However, recent developments in rural economy and drastic changes to agro-pastoral systems have sealed the fate of the traditional livestock migration to high-altitude summer pastures, so that the watering-holes have lost (or are rapidly losing) their primary function (economic and logistic). Without maintenance and the trampling of livestock on their summer pastures, watering-holes rapidly dry up, and are therefore not available for amphibian courtship in many mountain areas. Thus, due to an unexpected outcome of economic policy, the ecological damage caused by the release of fish in mountain basins is no longer efficiently mitigated by livestock watering-holes. They are tending to disappear everywhere, and the contradictory work of man has decreed the rapid decline of a delicate ecological equilibrium. In the Alps, it is mainly the arid and drained Prealps overlooking the plains that have suffered the drastic rarefaction of amphibian populations, whereas in the Apennines the situation has merely aggravated a previous chronic shortage of surface water, so that the phenomenon is apparent everywhere.

■ Eutrophication of waters

Shepherds' huts and pastures are quite frequently found near high-mountain lakes. The presence of livestock gives rise to natural fertilisation of part of the lacustrine basin and therefore of the lake itself. This effect is greatly accentuated if management operations (for example, mucking out cattle-sheds) are done using methods that directly involve feeder-streams.

A rise in the nutrient content of the waters of a mountain lake not only causes an increase in the quantities of phytoplankton, but also a change in the groups of dominant algae. The typical dominance of chrysophytes, dinoflagellates and diatoms (in the case of non-acid waters) may change to green algae and cyanobacteria. Some genera of the latter group may also produce toxins, which must be kept under strict control if the lake acts as a reservoir for drinking water. Algal blooms also confer colour and an unpleasant smell to the waters, abd cause anoxia. However, it should be stressed that these are extreme cases and, luckily, rare. Instead, the mild influence of diffuse grazing activities is very common (although it has been in regression everywhere for decades), without relevant damage to small lakes.

Sewage discharges from mountain refuges, which are another potential cause of eutrophication of high-altitude lakes, are now also the subject of campaigns for surveillance.

High-altitude lake rich in aquatic vascular plants

Mild eutrophication may reduce the number and variety of lichens in the submerged zone, probably because of competition with littoral algae (for example, some green filamentous algae) which grow more luxuriantly in the presence of nutrients.

Higher phytoplankton growth may also subtract light from algae which live at greater depths on the lake-bed, thus altering the structure of communities, which often include rare species.

Nutrients do not necessarily reach high-altitude lakes through direct release of organic matter in the basins. For some decades now, values of nitric nitrogen have been recorded in lakes free of direct impacts which, while they cannot really be called high, are above average. It has now been demonstrated that these values are due to the increased nitrogen load distributed by precipitation. Nitrogen oxides are generated by a series of human activities, the most important of which is vehicular traffic. These oxides are transported by the air currents, converted into nitrates, and fall in this form with precipitation, reaching even the most remote localities. A similar thing occurs with sulphates. However, in this case, the main source of sulphur oxide emissions is smoke and fumes from industry.

Thanks to international agreements, the atmospheric content of sulphur oxide has been drastically reduced in recent years, and efforts are under way to limit nitrogen oxides.

Small lake tinted green by a proliferation of microalgae

■ Acidification of waters

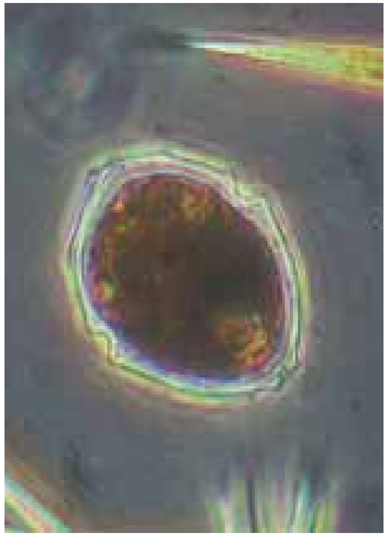
By the early 1980s, sulphates and nitrates had become very well-known in central Europe and the Alpine countries in connection with another environmental problem, that of acidification: both sulphates and nitrates notoriously behave as strong acids in water.

In aquatic environments, where the composition of the rocks of the substrate favours a sufficient supply of substances that can buffer the acidity of these compounds (carbonate rocks, such as limestone and dolomite), the effect of sulphates and nitrates is felt only as regards their role as algal nutrients. Other problems may arise in water lying on crystalline rocks (granite, porphyry, etc.), which are practically insoluble in the short term and yield only very modest amounts of mineral substances to the water.

This effect is accentuated in Alpine lakes lying in rocky basins and therefore with underdeveloped soils and steep sides, which do not favour prolonged contact between rock and run-off waters. As a consequence, there are fewer compounds able to lower the acidity level, and the arrival in the lake of even relatively modest amounts of acid contaminants is sufficient to cause acidification.

The first negative effects are registered on the more susceptible organisms when the pH descends to values below 6; true acidification occurs when pH is lower than 5.3 and there are no substances that can raise the value. In Italy, precipitations are markedly acid near major urban areas on the plains, where emissions, because of the action of air currents, also affect vast sectors of the Alps.

Diatom of the genus *Epithemia*



The dinoflagellate *Peridinium umbonatum*

Diatom of the genus *Pinnularia*

Microalgae are extremely sensitive to the variables linked to mineralization level and therefore also to acidification.

As regards phytoplankton, acidification leads to the disappearance of the more typically planktonic diatoms. Dinoflagellates and chrysophytes begin to dominate, with the presence of some species known to be indicators of acid waters - in particular, the dinoflagellates *Peridinium inconspicuum* and *P. umbonatum*.

Good indicators of waters with extremely low alkalinity are also to be found among the littoral diatoms of Alpine lakes: in particular, the diatoms *Achnanthes acidoclinata* and *Eunotia exigua*. More pronounced growth of some genera of littoral filamentous green algae has also frequently been observed where there is acidification. A rise in acid levels generally also involves a drastic reduction in the number of species of lichens on the shores.

Low pH in waters also has negative effects on invertebrates, leading to the disappearance of the more sensitive species and a net reduction in biodiversity. The box on the following page is devoted to this problem.

Macroinvertebrates and acidification

Valeria Lencioni

Following studies by various European research institutes on the benthic communities of acidic lakes or ones susceptible to acidification, data have been gathered on the tolerance of various zoobenthic species to low pH values. An index (Raddum's index) has been compiled for the zoobenthos, based on the greater or lesser sensitivity to low pH values. A high score (0.5-1) goes to sensitive species, which cannot tolerate pH <5.5; low score (0) goes to those less sensitive, which can tolerate pH <4.7, and intermediate score (0-0.5) to the so-called "indifferent" species. Among the macro-invertebrates, scores have so far been derived for a few genera and species of turbellarians, hirudineans, gastropods, amphipods, plecopterans, ephemeropterans, trichopterans and chironomid dipterans.

Data are available on species common in Nordic countries, generally absent or rare in the communities of Italian Alpine lakes, apart from a few exceptions like *Nemoura cinerea* and *Plectrocnemia conspersa*, tolerating pH between 4.5 and 7.0, *Siphlonurus lacustris*, (5.0-7.0), and *Baetis rhodani* (5.5-7.0).

The genus *Baetis* appears to be highly sensitive to variations in pH and is used as an indicator of incipient acidification. Enchytraeid oligochaetes, nemourid plecopterans, limnephilid trichopterans, sialid megalopterans and dytiscid beetles are known to be tolerant to even unexpected variations in pH. Among oligochaetes, naidids are the family least tolerant to falls in pH (they are normally absent from lakes with alkalinity <20 $\mu eq\ l^{-1}$ and pH <6). Other oligochaetes, the lumbricids, are to be found in lakes with alkalinity of >20 $\mu eq\ l^{-1}$ and pH >6.5. Molluscs are generally absent from acidic lakes, being particularly sensitive to low pH values, but also to calcium and alkalinity.

The Raddum's index must be applied with extreme caution to the macro-invertebrates of Italian Alpine lakes, because a reliable sensitivity value to variations in pH is not yet available for most of the species living in them. One of the taxa of major importance for the biodiversity of small lakes, but little understood from this point of view, is that of the chironomid - by and large among the insects most tolerant to variations in acidity. Recent studies have indeed revealed that some chironomids are definitely tolerant towards low pH values (such as the genera *Ablabesmyia* and *Procladius*, the species *Heterotrissocladius marcidus*, and some species of *Parakiefferiella*, *Paratanytarsus* and *Tanytarsus*), whereas others are frequent in non-acidic environments (like *Conchapelopia* sp., *Orthocladius* s. str., *Psectrocladius sordidellus*, *Thienemannimyia* sp. and *Zavrelimyia* sp.).

Nymph of *Baetis alpinus*

■ Other contaminants and global change

Small ice-covered lake in Val Ridanna (South Tyrol)

Acid contaminants are, unfortunately, only one of many categories of atmospheric pollution that may reach high-altitude lakes. For example, heavy metals and persistent organic pollutants (the notorious POPs) have already been recorded in mountain basins. The degradation of the latter is prolonged and difficult, and they therefore persist for a long time in lacustrine systems, especially in sediments.

These pollutants include compounds with a structure very similar to that of DDT, which are still widely used in many equatorial and tropical countries. A mechanism on a vast scale, known as "global distillation", can lead to their presence even in high-altitude lakes. These toxic organic compounds are mainly released in the atmosphere from the hot areas of the planet. Masses of hot air can move long distances and then the water vapour they contain condenses and falls as rain when they reach in the cold circumpolar areas, or above the major mountain ranges.

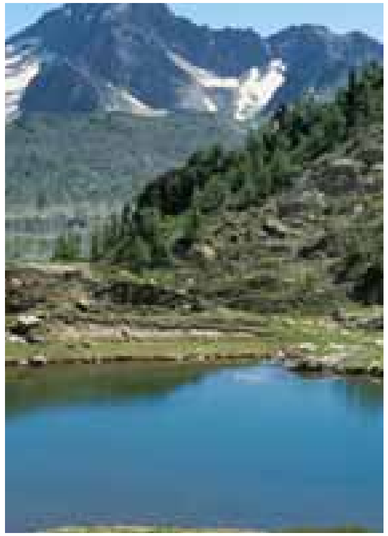
The rapid climate changes under way may also have important consequences on high-mountain lakes. For example, because of global warming, the shortening period in which the waters of these small basins are covered by a thick layer of ice is becoming shorter, a fact which may lead to a marked increase in the production of algae and, consequently, alter the delicate lacustrine food-chain.

The progressive rise in ultra-violet (UV) radiation, caused by the rapid thinning of the atmospheric ozone layer in recent years, may also lead to an alteration in the structure of animal communities, particularly those of zooplankton. It is thought that UV radiation is approximately 50% higher at an altitude of 3000 m than at sea level, and that it has risen by a further 10% since 1970. In relation to the varying tolerance of different species to UV radiation, this increase may well have a negative impact on more susceptible species.

Suggestions for teaching

MARGHERITA SOLARI

■ Small lake of glacial origin: a geomorphological study



Lago del Colle di Sant'Angela (Piedmont)

● Aims: to stimulate awareness of a mountain environment and encourage respect for the environment and a responsible attitude when visiting the mountains; to increase capacity for observation, analysis and comparison of data; to understand the concept of geomorphological evolution of the territory, with special reference to the changes caused by the action of ice.

● Level: secondary-school pupils 14 to 16 years of age.

● Equipment: literature; topographical maps (preferably scale 1:5,000 or 1:10,000, perhaps 1:25,000) of one or more areas for comparisons, including the area chosen for the excursion; geography or earth sciences textbook; proper clothing for excursion; reflex camera (or digital, but with suitable lenses); air and water thermometers.

● Possible collaborators: nature guide, CAI guide, or expert for the excursion.

PRELIMINARY STAGE

1. Identify an area with a small mountain lake of glacial origin (with the help of a geologist or expert nature guide) suitable for the field excursion: easily accessible itinerary, route lacking difficulties; the best times are May-June or September. Prepare cartographic materials: trekking map, topographical map, geological map, etc.
2. Introduce the work in class, study the modelling effects of glaciers during the Quaternary: forms of erosion and accumulation typical of high altitudes

Visitors to the small lake at Avostanis, above Pramosio (Carnic Alps, Friuli Venezia Giulia) (cirques, moraines, etc.), and map reading: the pupils should learn to identify contour lines, cross-hatching, symbols indicating erratic masses and screes, hydro-geographical symbols, etc.

3. Research by students on place names from historical and literature sources.

4. Divide the class into groups of four-five students each, to study topographical maps. Identify the itinerary for reaching the lake on the trekking map; highlight elements of interest for geomorphological study on a photocopy of the topographical map: lake perimeter, glacial cirque faces, morainic ridges, sills, detritus cones, artificial elements (weirs, dams, conduits), any water springs, feeder streams, snowfields or glaciers.

5. Each group should prepare a survey card (location, date, altitude, air and water temperatures, presence of man-made constructions, type of vegetation cover on lake shores, detritus deposits close to the lake, any accumulated materials filling it, degree of naturalness and human impact). Compare the cards of the various groups and compile a single chart.

FIELD EXCURSION

6. Divide the class into groups different from those previously made up (for a better exchange of proficiency), observe the geomorphological elements of the chosen environment, and compile survey charts.

7. Guided observations of the environment (perhaps with the aid of the nature guide): species of local flora and fauna; analysis of visible (waste, constructions and, particularly in the Alpine area of Italy, relicts dating to the Foirst World War and, occasionally, also the Second) and invisible human impact (pollution, acid rain, introduction of fish).

8. Summarise the essentials of good photography: exposure, time, framing, UV filters, 24- and 28-mm lenses, use of green-enhancing film, preference for diffuse light at dawn and sunset. Students should then take photographs of the landscape.

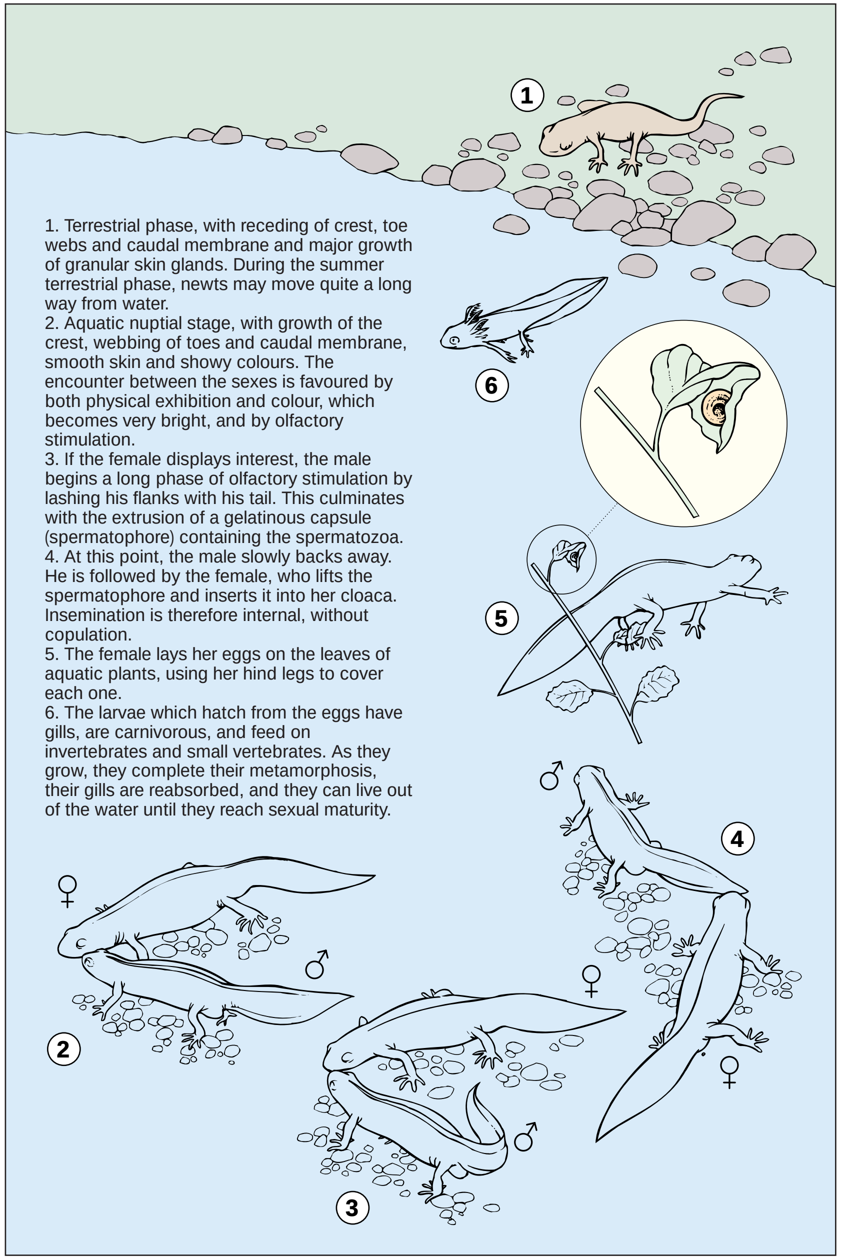
CONCLUSION OF CLASSWORK

9. Explain the geomorphological evolution of the environment and the importance of small Alpine lakes, both for the conservation of plants and animals living there, and from the viewpoint of the landscape for recreation and leisure. Discuss the need to preserve these habitats.

10. Develop or computer process photographs; ask students to write individual reports on the excursion, with a summary of the concepts learned.

Small glacial basin lake in the Carnic Alps (Friuli Venezia Giulia)

Small lake in Val Gesso (Maritime Alps Nature Park, Piedmont)



Life-cycle of the alpine newt

■ The newt and the char

- Aims: to discover the main characteristics of the fish and amphibians living in small mountain lakes; to learn about the concept of environmental adaptation; to develop the capacity for observation, analysis and comparison.
- Level: primary school pupils 8 - 10 years old.
- Equipment: literature; biology textbook; documentaries; materials for drawing up a poster; proper clothing for the excursion.
- Possible collaborators: nature guide, CAI guide, or expert for the excursion.

PRELIMINARY STAGE

1. Discuss in class the characteristics of small alpine lakes, and the factors restricting animal life (presence of snow and ice for many months in the year, short season with a mild climate suitable for growth and breeding, scarcity of food, high intensity of UV radiations).
2. Identify the vertebrates (fish and amphibians) living in mountain lakes.
3. Analyse the characteristics of the classes of fish and amphibians, using various types of bibliographical material: illustrate respiration, breeding, and feeding habits. Watch documentary films on the fauna of alpine lakes.
4. Further study on the arctic char. Prepare illustrated charts summarising the main characteristics (similarity to trout, small scales, two dorsal fins; bluish, greyish-brown colour with red belly during the breeding season; dark bands on flanks; thousands of eggs laid in small hollows on the lake-bed in late

Arctic char

autumn; hatching of fry in late spring; initial diet of plankton, then benthic invertebrates, and lastly small fish; competition with brown char; fish often released in small high-altitude lakes for sports fishing purposes).

5. Further study of the alpine newt. Students should prepare illustrated cards summarising the main characteristics (eggs laid in water, development of aquatic larvae, complete metamorphosis and development of adults, which continue to pass part of their lives in water; typical appearance of adults, with flattened tail and dorsal crest; characteristic courting rituals, in which the male, recognisable by his showy nuptial livery, curls his tail and vibrates it unceasingly).

FIELD EXCURSION

6. An excursion could be made with a nature guide, preferably in June, to observe nature in an alpine environment, and the species to be found in a small lake. The trip should be organised together with the guide. Choose a short itinerary without obstacles.

CONCLUDING CLASSWORK

7. Draw up illustrated posters on the environment of small mountain lakes.

8. Give a brief talk to verify progress made following direct observations on the morphology, ecology and adaptations of the alpine newt and arctic char.

9. Final debate on the importance of preserving these habitats and maintaining responsible behaviour during excursions in the mountains.

Alpine newt

■ Microcrustacean colours and sizes

- Aims: to stimulate capacity for observation, data analysis and comparison; to improve understanding of the concept of adaptation to the environment in animal species; to reflect on the factors influencing the size and morphology of some species.
- Level: secondary school pupils 14 - 16 years old.
- Equipment: literature; biology textbook; net for sampling zooplankton; thermos for transportation; microscope slides for observations; equipment and proper clothing for field trip.
- Possible collaborators: guide for the excursion, with experience in sampling and microscopic observation of living things.

PRELIMINARY STAGE

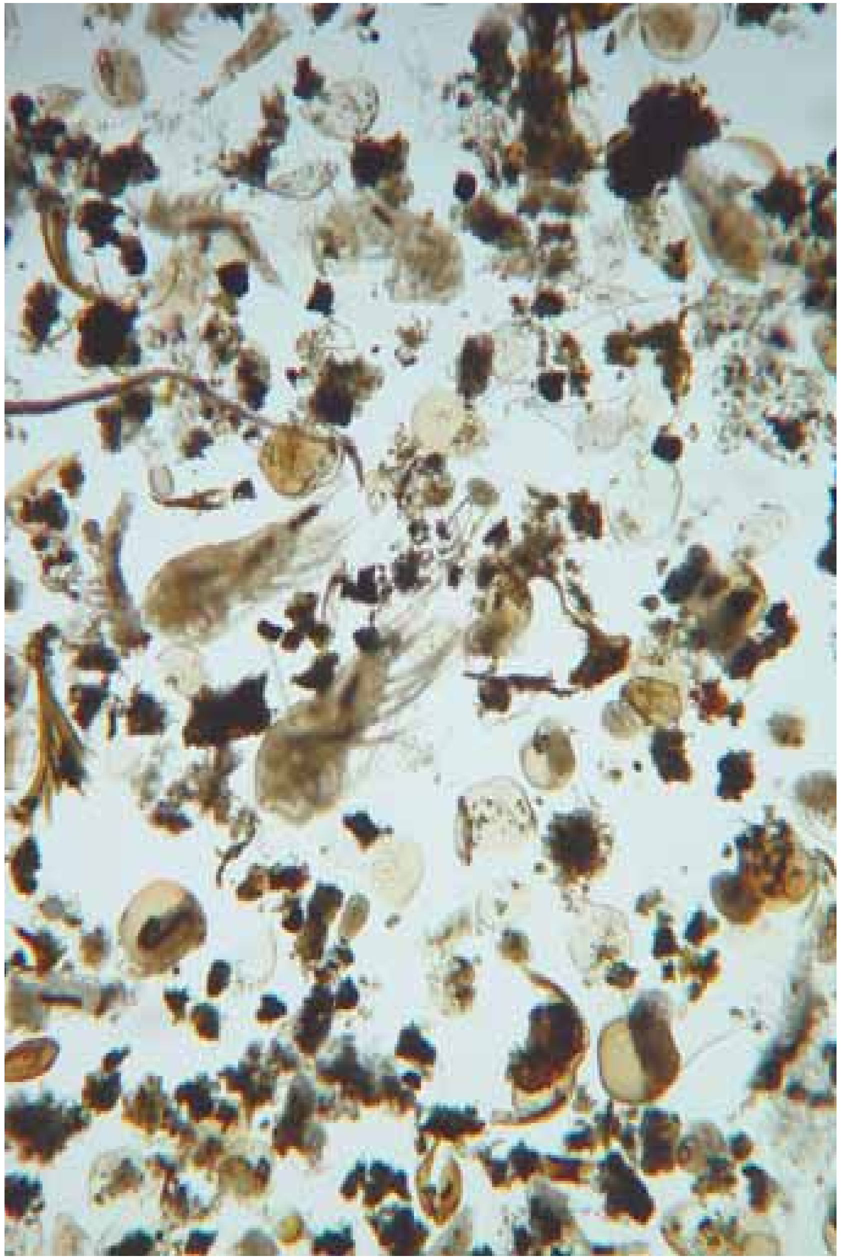
1. With the aid of the textbook and specialist literature, study the morphology, ecology, and role in the food-chain of typical micro-crustaceans (cladocerans, copepods) of small high-altitude lakes.

2. Identify the factors limiting growth: low temperatures, short summer, scarcity of nutrients, predation, water acidification and UV radiation.

3. Carefully analyse the adaptations of micro-crustaceans to predation and UV radiation: reduction in size of individuals, colour changes (see chapter on zooplankton).

4. Consult the literature to identify two small high-altitude lakes, one without

Lake in Rot Tal (South Tyrol)



Zooplankton in a small mountain lake (Sella Group, South Tyrol)

fish, the other with an abundance of fish species. Itineraries must be easily accessible and short. The best periods are May-June or September.

FIELD EXCURSION AND OBSERVATION OF LIVING ORGANISMS

5. With the help of an expert, take samples of the zooplankton in both lakes using a suitable net (max mesh 100 µm). The collected material should be placed in appropriate containers (thermos) for transport to the laboratory.
6. Observe the organisms in the two samples under the microscope, arranging them on suitable slides.
7. Identify the difference in size of the micro-crustaceans from the two environments: larger in the one without fish, smaller where there are fish.
8. Observe the intense colours of some species (from bright red to brown), as an adaptation to UV radiation.

CONCLUDING CLASSWORK

9. Consider the observed adaptations, from the viewpoint of maximum efficiency for the survival of populations living in extremely harsh environments.
10. Ask students to write a brief report summarising the studied concepts.

One of the lakes at Lusia (Trentino)

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Glossary

> Alien: species or populations introduced by man and not belonging to local flora or fauna.
> Alluvial cone/fan: the fanlike deposit of a stream where it issues from a gorge upon a plain or of a tributary stream near or at its junction with its main stream.
> Amphigony: sexual reproduction.
> Anadromous: used to describe sea fish which ascend rivers to breed.
> Cyanobacterium: bacterium containing chlorophyll a - like algae, mosses and vascular plants - and the additional pigments provided by the blue phycobilin (phycocyanin) and red phycoerythrin proteins. Also called blue-green alga.
> Drainage basin: the catchment area from which the waters of a stream or stream system are drawn.
> Ecotone: transition zone between two different communities. These are often species-rich, with higher biodiversity than either of the two communities they separate.
> Endemic: exclusive to a restricted geographical area.
> Frigostenothermal: adapted to living exclusively at low temperatures.
> Macrophyte: a member of macroscopic plant life, especially of a body of water.
> Moraine: an accumulation of earth and stones carried and finally deposited by a glacier, usually along its flanks or behind it.
> Oligostenothermal: adapted to a restricted range of temperature.
> Omnivorous: an organism feeding on both animal and plant substances.
> Ovoviviparous: method of reproduction in which young develop from eggs retained within the mother's body until they are born.
> Parthenogenesis: reproduction by females without intervention by males.
> Phycobiont: an alga - usually a green alga - or a cyanobacterium that participates, together with a fungus, to lichen symbiosis.
> Planktivorous: feeding on plankton.
> Rheophilous: applied to an organism which thrives in running water.
> Seiche: periodic oscillation of a lake surface, due to wind and variations in air pressure.
> Stenotopic: tolerant of only a narrow range of environmental factors.
> Syncline: a basin or trough-shaped fold of stratified rock in which the beds dip towards each other from either side.
> Taxon (pl. taxa): any formal group in the classification, corresponding to a taxonomic category (e.g., class, order, family, genus, species, subspecies, etc.).
> Trophism: fundamental nutrition involving the actual metabolic exchanges of tissues; in lakes, trophism depends on the amount of dissolved salts.
> Yolk sac: the sac containing nutrients which is attached to the embryo in an egg.

List of species

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