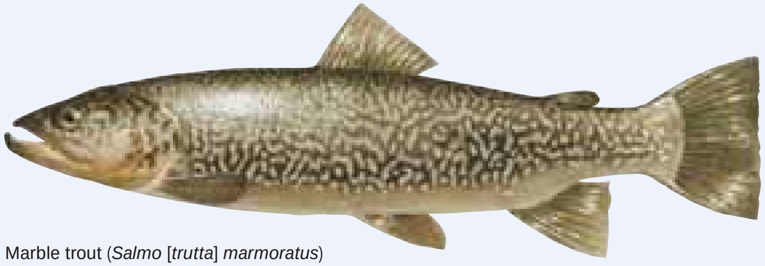
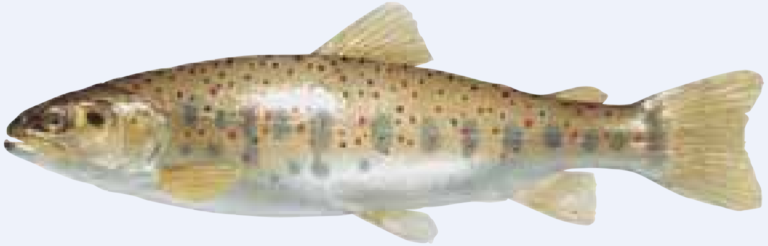


Marble trout (*Salmo* [*trutta*] *marmoratus*)

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

Rainbow trout (*Oncorhynchus mykiss*)



Mediterranean trout (*Salmo* [*trutta*] *macrostigma*)

"superspecies", represented in Italy by three "semispecies" (i.e., populations which have only partially concluded the speciation process): brown trout (*Salmo* [*trutta*] *trutta*), widely distributed in Italy after restocking but, according to the authors, autochthonous to some Alpine streams; Mediterranean trout (*Salmo* [*trutta*] *macrostigma*), found in the Tyrrhenian tributaries of central-southern and insular Italy; and marble trout (*Salmo* [*trutta*] *marmoratus*), endemic to the Po Plain and Veneto areas.

The issue regarding the autochthony of brown trout has not yet been solved.

In 1936, the ichthyologist Edoardo Gridelli wrote about the situation in Friuli, "The *fario* (trout) is not found along the Adriatic coast of Venezia Giulia and Friuli, or, if it is, its presence is due to recent introduction. It is indigenous to waters on the Danubian side"; i.e., only watercourses of the Tarvisio basin, which are tributaries of the Danube through the rivers Gail and Drava. Gridelli's categorical statement on the absence of brown trout in the Alpine tributaries of the Adriatic (Friuli ones at least), was later mitigated by other authors, who even hypothesised that marble trout was typical of downstream and valley watercourses and brown trout was limited to high-altitude streams. This statement was contradicted by the presence of two subspecies in the same basin. Although brown and marble trout change habitats and food, marble trout is often found in high-altitude streams, especially if not particularly small (1 m^3/sec) and characterized by the absence of brown trout.

According to Gridelli, the early introduction of brown trout in the Friuli Venezia Giulia region dated back to 1906, when eggs from the hatchery of Ilidze (near Sarajevo) were released into the river Isonzo. It was in the early 1900s, owing to continual introductions for fishing purposes, that brown trout began to spread and soon became the most widespread salmonid in Italy.

It is worth noting that trout farming and the introduction of fish material are not recent practices: the first industrial farms in European countries date back to the mid 19th century, and the first fish farm in Italy was established in 1860. A few years later, farms were set up in the Friuli and Trentino regions and, in 1885, two state farms were established by the Italian government: the *Regio Stabilimento Ittiogenico* in Brescia, with various branches and hatcheries in northern Italy, and the *Stabilimento* in Rome. Almost all brown trout farmed there and introduced into Italian watercourses were – and still are today – of "Atlantic" breed. The difference between this "Atlantic" trout, and those of Mediterranean tributaries and the Danubian basin is not always morphologically evident, and may result only from biochemical and molecular genetic analyses. In order to consider brown trout autochthonous to the Po Plain basin, "Mediterranean" populations should be found in this area.

Recent morphological and molecular research has revealed that some brown trout presumed indigenous to the Piedmont Alps (Ripa, Chisone, and a few other streams), are phylogenetically more similar to Mediterranean ones than to those deriving from restocking. The same may be said of the trout in small watercourses in the Emilian Appennines, like the Riarbero stream (upper basin of the Secchia), analysis of which was based on morphological characteristics only.

However, these streams are near Alpine and Appennine watersheds, i.e., very close to heads of valleys with Tyrrhenian tributaries, the waters of which belong to the distribution area of the Mediterranean trout. This is why the presence of brown trout may be due to geological events (e.g., fluvial capture through regressive erosion, reversing of stream flow in Alpine valleys during glaciations) or, more simply, to artificial introduction by man.

Under these circumstances, the initial question - which trout is found in Italian streams? - may be answered by summarizing the above. All tributaries of the river Po and Adriatic tributaries of the Veneto and Friuli regions are populated by the autochthonous marble trout, which is absent in tributaries right of the river Po, starting from Belbo. Its absence is probably due to the stream beds, which are rich in fine sediments and not suitable for the reproduction of this fish. In the Emilian and western Piedmont Appennines, there are autochthonous brown trout populations, which are similar to the “macrostygma” type. The latter is distributed in various streams of the Tyrrhenian and Ionian side of central-southern Italy and in some rivers in Sicily, Sardinia and Corsica.

The biology of Italian populations of macrostygma trout has yet to be studied. Marble and brown trout are relatively well-known and their taxa are similar. They share reproductive behaviours. Brown trout females reach sexual maturity at the age of three, and males at two, or three in marble trout. Spawning is determined by factors such as temperature and photoperiod. When the moment for egg-laying approaches, trout stop feeding and swim upstream in search of suitable sites - areas where water is shallow and current speed between 20-60 cm/sec, which gives stream beds the suitable gravel particles. In the spawning site, females use their bellies and caudal fins to dig a hole 20-40 cm deep, where they lay their eggs and cover them with gravel using their caudal fins. Fertilized eggs are protected against environmental dangers under 5-15 cm of gravel. Good interstitial circulation is important to guarantee oxygenation of the laid eggs: gravel packing caused by silt sedimentation destroys spawning areas.

Trout does not grow rapidly: in valleys, farmed offspring of brown trout living in spring waters weigh 25 grams and are 12-15 cm long in autumn. In mountain streams, the situation is completely different. In natural conditions, offspring are smaller and always dependent on the environment: mainly altitude and temperature, which influence metabolic processes directly. The oligotrophic nature of small, high-altitude streams, and the consumption of energy to withstand the speed of the current are important. This is why mountain trout, although very vigorous, are always smaller in size than farmed trout and develop slowly. As regards nutrition, the “hard” waters of limestone areas are more favourable than those flowing on granite, as the former are richer in macrobenthic organisms.


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

The environment does not only determine the development but also the final size of trout. In running waters in Italy, adult brown trout are about 50 cm long and weigh 1.2-1.5 kg. The same applies to macrostygma; marble trout are larger, a few individuals reaching over 1 m and weighing more than 20 kg. In high-altitude streams, these sizes are impossible, and trout are generally less than 30 cm long (at the age of four or five).

Although trout are essentially carnivorous, they do eat various kinds of food, including invertebrates of several taxa, oligochaetes, crustaceans, aquatic insects and terrestrial ones which accidentally fall into the water. As regards vertebrates, food is generally small fish (trout may also prey on fry of its own species), and occasionally amphibians and their larvae. Some trout may feed on specific animals which change the organoleptic character of their meat, as in the "salmon trout", the flesh of which is orange, due to intake of carotenoids (e.g., astaxanthin, found in the bodies of some crustaceans).

Introduced salmonids. Besides trout, Italian streams often host two similar species from North America, which were introduced for fishing reasons. The most well-known is *Onchorhynchus mykiss*, or rainbow trout. Known as *Salmo gairdneri* until recently, this species was imported to Europe from North America in 1880, and today its naturalized populations also live in South America, southern Africa, southern Asia and New Zealand. Although some wild species live in Austria and some areas of former Jugoslavia, the species is not acclimatized to European waters, and generally does not reproduce. In Italy, reproduction in free waters is rare, although documented, and distribution of rainbow trout is therefore unstable and closely linked to restocking, which has decreased considerably in recent years. Rainbow trout is the most frequently marketed and the most frequently farmed in Europe, due to its very high food conversion coefficient (and rapid growth) compared with Italian trout.

Another American salmonid occasionally found in Italian waters is brook trout (*Salvelinus fontinalis*), native to north-eastern North America, where it populates rivers flowing into the Atlantic and Hudson Bay, from northern Georgia to Labrador. Brook trout, like rainbow trout, was introduced in Europe at the end of the 19th century. In its original territory, this trout is a migrating anadromous species (spawning in freshwater but migrating to the sea for feeding and maturation), whereas in Europe it lives in freshwater. In Italian streams, stable populations of brook trout are very difficult to develop: their habitat and food resources are similar to those of indigenous trout, and give rise to competition which results in the disappearance of brook trout from watercourses where it cannot reproduce properly. Its introduction was more successful in high-altitude lakes. Acclimatized populations are randomly distributed in the Alps and northern Appennines.

Salvelinus alpinus, or Arctic char, is autochthonous to Alpine waters, although localized. This species is widely distributed in seas and rivers around the Arctic, where it is an anadromous migrant; in the Alps, it is a glacial relict. In Italy, char is certainly autochthonous only to some Alpine lakes of the Trentino-South Tyrol region. Restocking has given rise to some of today's acclimatized populations in Alpine and northern Appennine lakes. Unlike the situation in northern latitudes, Alpine char is closely associated with lake environments, where reproduction occurs. It is only occasionally found in streams.

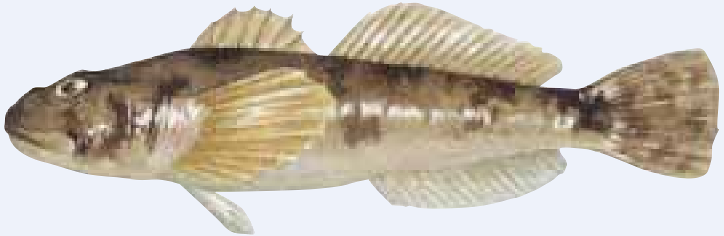
Rainbow trout (*Oncorhynchus mykiss*)

Other fish species. Besides salmonids, there are only a few fish species in high-altitude streams, among which is miller's thumb (*Cottus gobio*), distributed in the Alps and, locally, in northern Appennine streams, of both the Po Plain and Tyrrhenian sides. The species probably reached Italy from the Danubian district after it was "captured" on both sides of the Alps in upstream stretches and colonized the watercourses of the Po Plain and Veneto during marine regression after glaciations (and concomitant expansion of the paleo-Po).

Pleistocene "river capture" in watercourses of both sides of the Appennines, probably allowed it to penetrate Tuscany and Latium. Miller's thumb is a small fish (rarely exceeding 15 cm), active during twilight and at night, the shape of which denotes its benthic habits and poor swimming skills.

It is stocky, the head being larger than the rest of the body, with eyes in the upper part of the head, and a large, upward-turned mouth. It inhabits cool, well-oxygenated waters, from valleys to 1200 m. Miller's thumb and trout associate in characteristic ways, with mutual preying and food competition relationships.

Their food includes benthic invertebrates, but also the eggs of fish and fry, even of their own species. Miller's thumb reproduces between February and May; females lay hundreds of eggs on the ceiling of shelters dug by males



Miller’s thumb (*Cottus gobio*)

Blageon (*Leuciscus souffia*)

Minnow (*Phoxinus phoxinus*)

Minnow during the breeding season

under stones or other submerged objects. Each male induces more than one female to lay eggs in the same cavity, and then looks after them (although it may eat some of them!) until they hatch, two or three weeks later.

Other fish species typical of lower salmonid areas may, in particular hydrological conditions, swim upstream to high-altitude waters. Among these is grayling (*Thymallus thymallus*), the Italian distribution of which is similar to that of marble trout.

Until a few decades ago, grayling abounded in almost all the left tributaries of the river Po and in some on the right (Tanaro, Bormida), and in the Adige, Brenta, Piave, Livenza, Meduna, Tagliamento and Isonzo rivers: it has recently been introduced in some streams of the Po Plain side of the northern Appennines. This gregarious species has always lived in clean waters, and its numbers have fallen with the progressive deterioration of environmental conditions. This is why many Italian populations of grayling have recently been supported by restocking, with individuals often of Danubian provenance.

The distribution of trout partially overlaps that of two cyprinids, blageon (*Leuciscus souffia*) and minnow (*Phoxinus phoxinus*). Both species live in cool, well-oxygenated waters of valley and hill streams, but may also be found at high altitudes.

They are two gregarious species, with small individuals which shoal near the bottom, avoiding turbulent waters. They may even be found in small lakes at altitudes exceeding 2000 m. Minnow, the males of which develop a bright red underside during the breeding season, is autochthonous only to the Po Plain and Veneto, and the blageon also to Tuscany and Latium. The latter species undergoes more or less involuntary introduction (fishermen use them as bait), and isolated populations may now be found in various watercourses outside their original areas.

Lower salmonid areas in Appennine streams differ from Alpine ones. In the Appennines, lower altitudes have given rise to changed hydrological conditions, and different geological events have determined different fauna.

As we proceed towards the valley, trout gradually disappears, to be replaced by various species of rheophilous cyprinids: barbel (*Barbus plebejus*), chub (*Leuciscus cephalus*), blageon and, on the Po Plain side, Mediterranean barbel (*Barbus caninus*) and, in the Tyrrhenian tributaries of Tuscany, Latium and Campania, Appennine barbel (*Barbus tyberinus*) and Ombrone chub (*Leuciscus lucumonis*).

In the Appennines, the distribution of these species has recently been altered by man.

Amphibians and reptiles

Mountain streams are certainly not ideal places for amphibians. However, along the courses of streams there are often small areas - tiny side-bays, areas with standing water, small, slow-moving streams, tiny tributaries, temporary pools, or the edges of peat-bogs - where these animals are able to live and breed. Obviously, small lakes, mountain ponds, large peat-bogs and marshes are more favourable habitats, but we often find amphibians along mountain streams, due to their wet microclimate.

One of these, often visible on rainy days, is spotted salamander (*Salamandra salamandra*), found throughout Europe and typical of Italian woodland at medium and high altitudes over 1000 m. These elusive, nocturnal animals are suited to terrestrial life. They live near water during their juvenile stages: females retain fertilized eggs in their bodies and deposit dozens of gilled larvae in slow-flowing or standing waters. The larvae are already well-formed in autumn, although born in late spring (or summer, at high altitudes), feed on benthic fauna, and become adults in a few months.

In the Alps and Dinaric mountains lives Alpine salamander (*Salamandra atra*). This amphibian is seldom seen - in the southern Alps only at high altitudes, above the tree-line - and its presence is not due to water. Alpine salamanders may live without running or standing waters, as they are viviparous urodeles, i.e., after a very long period of gestation which may last four years, females bear 1-2 young (occasionally 3-4), which are perfectly metamorphosed.

Spotted salamander (*Salamandra salamandra*)

Alpine newt (*Triturus alpestris*) is aquatic from late spring to late summer. It spends the rest of the year in wet undergrowth, and has burrowing habits. Reproduction, during which males court females, is followed by winter hibernation in Alpine lakes, marshes and peat-bogs. The species may also be found in the tiny side-ponds of streams. The larvae develop during summer and live in water until metamorphosis, which is marked by re-absorption of gills. In August, the adults move to their autumn shelters. In Italy, *Triturus alpestris* is found in the Alps with its typical subspecies, in the Maritime Alps, in the Appennines of Liguria, Tuscany, Emilia and Latium (*Triturus alpestris apuanus*), and relict populations also live in some areas around the city of Cosenza (*Triturus alpestris inexpectatus*). Alpine newt is the only aquatic urodele found at elevations exceeding 1500 m a.s.l.. Species similar in biology, shape and behaviour may be found at lower altitudes, such as southern warty newt (*Triturus carnifex*), found throughout Italy, and smooth newt (*Triturus vulgaris*), absent in southern Italy.

In Italy, the smooth newt is represented by two subspecies which are so different from the morphological, eco-ethological and genetic points of view,

Alpine newt (*Triturus alpestris*)

Eggs of common toad (*Bufo bufo*)

that they have often been considered as two distinct species. The nominal subspecies (*Triturus vulgaris vulgaris*) is only found in the Julian and Carnian Alps, and lives in marshes near rivers and mountain streams. Its southern relative (*Triturus vulgaris meridionalis*) is typical of the Po Plain and surrounding hills, where it may be found at altitudes exceeding 800 m. In the Appennines, it is replaced by *Triturus italicus*, which may be found near rivers at high altitudes. The most important Italian urodele of Appennine streams is the spectacled salamander (*Salamandrina terdigitata*), which lays eggs in upstream stretches and completes its larval development there. This urodele is only a few centimetres long, but has considerable importance from the viewpoints of evolution and conservation. It is native to the Appennines and is the only surviving urodele of an ancient genus. It is probably the only exclusively Italian vertebrate, and has been adopted as the symbol of the *Unione Zoologica Italiana* (Italian Zoological Union).

All urodeles (and their larvae) are exclusively carnivorous and prey on live animals, particularly aquatic invertebrates, although adults also feed on the eggs and larvae of other amphibians.

Even marginal aquatic environments may host anurans: the side-bays of streams are often filled with the typical strings of eggs and black tadpoles of common toad (*Bufo bufo*), the largest European amphibian, which may live at altitudes exceeding 2000 m. Two small species, which only need temporary pools to reproduce, are tree frog (*Hyla* spp.) and fire-bellied toad (*Bombina variegata*, *B. pachypus*). Tree frog is seldom found at high altitudes, whereas fire-bellied toad (*B. variegata*), found in north-eastern Italy, may live at altitudes exceeding 1900 m. They generally breed in ponds, marshes and cattle drinking-troughs, but also in slow-flowing waters of mountain streams. In the Appennines, they are replaced by a similar variety (*B. pachypus*), with analogous ecology. The typical mountain anuran is European frog (*Rana temporaria*), found in the Alps and northern Appennines. It is a woodland species which can live at altitudes exceeding 2000 m, in dwarf pine forests above the treeline, damp meadows and grassy banks of streams. It breeds in peat-bogs or mountain lakes, but its tadpoles may also be found in small stream tributaries. Females lay a few thousand eggs, and large groups of tadpoles are a common sight. Only a quarter of them will reach the age of four years and become sexually mature. High mortality is due to predators, and to environmental factors. Indiscriminate introduction of trout and char in almost all mountain streams and particularly in small, high-altitude lakes which originally did not host fish, jeopardize the survival of amphibian populations in these delicate environments. Another mountain European frog is Italian frog (*Rana italica*), found in the Appennines over 1000 m. It is smaller than *Rana temporaria,* lives on the banks of streams, and is endemic to Italian fauna.

Among the few natural predators of high-altitude streams is grass snake (*Natrix natrix*), which has two characteristic white marks on each side of the head, surrounded by two dark, halfmoon-shaped spots. This snake is easily found in all Italian aquatic environments: it is an excellent swimmer and feeds on amphibians, their larvae, and small fish. Young may eat invertebrates. It is also found in the mountains: its large females may live in moderately dry environments far from water, at altitudes exceeding 1000 m. They feed on toads, frogs, tiny mammals and lizards.

Although grass snake is the only aquatic reptile of high-altitude environments, other species may be found on the banks of mountain streams. Moderately damp bank forests, particularly downstream, are inhabited by Aesculapian

Fire-bellied toad (*Bombina variegata*)

snake (*Elaphe longissima*); the rocks and gravel of stream banks may be thermoregulating sites for colubrids and viperids. Among the latter, adder (*Vipera berus*) prefers wet environments. In Italy, this snake is only found in the Alps, and is best suited to high altitudes. Chorologically and ecologically similar to the adder, with which it sometimes lives, is viviparous lizard (*Zootoca vivipara*), widespread in the Eurasian continent, of which the Alps and the Po Plain represent only the southern part. At Italian latitudes, this cool-loving reptile is limited to mountainous and submountainous environments above 600-700 m and plains cooled by springs.

■ Birds

Aquatic birds find valley streams suitable environments, as they are adapted to various habitats, ecological niches and food resources. The same cannot be said about mountain streams, which are harsh environments. Only Eurasian dipper (*Cinclus cinclus*) is closely associated with water throughout the year and lives in the Alps and Appennines.

The peculiar feature of this bird lies in its great ability to dive, swim and even walk on the stream bed. It usually walks upstream, using its wings and tail as pivots. Dives may last 15 seconds and enable dippers to catch mainly benthic invetebrates or eggs of fish and fry. The vegetal part of their diet is usually composed of seeds which have fallen into the water. Dipper usually nests at altitudes between 500 and 1700 m, but in pre-Alpine areas it may nest in valleys, and in the western Alps it has been found at 2200 m. Nests are round, made of moss and other vegetal material found near water and are built under bridges or small waterfalls, tucked into rock or wall cavities, roots of trees, or even hidden in the grass near the bank. Eggs are laid between March and April, according to altitude and seasonal trend. They hatch after 15-18 days, and both parents feed their young, which leave the nest after three weeks later. Although the young birds cannot yet fly, they already swim quite well, and gradually start flying independently. After a month or so, they inhabit their native stream or other watercourses, wandering for many kilometres.

Dippers often continue to live near their nesting areas. However, individuals which live at high altitudes may fly lower in winter, and reach valleys in particularly cold months. They may also leave their territory after changes in their environment. The species is sensitive to water quality and changes in the hydrological regime of the stream, which affects their food resources.

A few other bird species nest regularly along stream banks, although they are less aquatic than dippers. Among them is wren (*Troglodytes troglodytes*),

Eurasian dipper (*Cinclus cinclus*)

Garden warbler (*Sylvia borin*)

which nests between 500 and 2000 m. In March-April, the male, which is territorial and often polygamous, builds one or more round nests made of moss a few metres from the ground, generally in damp, shady undergrowth near watercourses. The female or females hatch the eggs and rear the young. In June, there is generally a second egg-laying. Wren is found throughout Italy in suitable areas. The few couples which nest in plains, have definite microclimatic requirements, and almost always live in bank woodland.

Garden warbler (*Sylvia borin*), a small sylviid, behaves in much the same way. In Italy, it nests in the Alps and northern Appennines at altitudes between 900 and 2000 m. It prefers sparse larch woods, twisted shrubs and particularly cool bushes near stream banks. The species seldom nests at lower altitudes, in hills or valleys, where it may be found in banks which contain willow and alder. Garden warbler is shy and only its song may be heard. This sylviid comes to Italy in summer, as it is a trans-Saharan migrant.

Instead, two similar species are often found near the banks of streams: white wagtail (*Motacilla alba*) and grey wagtail (*Motacilla cinerea*). The former is widespread, the latter is closely associated with water. Grey wagtail builds nests in any cavity near banks, and sometimes uses the old nests of wren or dipper. Both species are usually found in hills and mountains throughout Italy, to a lesser extent in valleys, where grey wagtail in particular is rare.

White wagtail (*Motacilla alba*)

■ Mammals

There are many mammals in Italian mountains, but few are closely associated with freshwater and particularly high-altitude streams. Stream banks are places where chamois run, marmots feed warily, ermines hunt, and invisible rodents bustle frantically. Truly aquatic species – those which usually carry out almost all their activities in water – may be counted on the fingers of one hand. Among them are two tiny insectivores: water shrew (*Neomys fodiens*) found all over Italy, except for the islands and southern regions, and Miller’s aquatic shrew (*Neomys anomalus*), found throughout the country. Although they are the largest Italian shrews, like all soricids, they are still very small (the former is 70-90 mm long, excluding the tail; the latter is slightly smaller), and they tend to get cold. They have a high rate of metabolism to keep their body temperature constant, particularly if they live in cold environments. Their heartbeat and breathing rates are also very fast, and their life consists largely of a frenzied search for food, both in water and on land. Water shrew is better suited to life underwater, as it has fringes of stiff hairs on the underside of the tail and along the edge of the hind feet which improve its swimming skills. Fringes in Miller’s aquatic shrew are small, and almost totally absent on its tail. Both species can close off their ears when swimming underwater.

Water shrew (*Neomys fodiens*)

Their food is composed of terrestrial and aquatic invertebrates, amphibians, small fish and their larvae. While hunting, they are aided by the fact that their saliva contains toxic substances which are injected into the prey they bite. Recent research has demonstrated that water shrew can search for food at considerable depths, whereas Miller's aquatic shrew limits its search to the surface of peat-bogs and damp meadows. These shrews burrow a long tunnel which is connected to the outside world through two other tunnels, one of which is usually at water level. Part of their burrow is covered with grasses, mosses and other vegetal debris, so as to form a nest. These shrew are highly territorial, and become aggressive when defending their nesting territory and hunting area from other shrews. Ensuing fights are very violent but ritual, and therefore do not have serious consequences. Water shrew is very territorial; Miller's aquatic shrew is more gregarious.

One of the forest carnivores most closely associated with cool, damp, heavily wooded river banks is polecat (*Mustela putorius*) which, in this type of environment, mainly hunts amphibians and mice. The species is falling in numbers throughout western Europe.

Among aquatic mammals is otter (*Lutra lutra*). This beautiful carnivore, extremely selective as regards its food and environment, could be found in almost all Italian aquatic environments until the mid-20th century. Today, this is the mammal which most risks extinction, in both Italy and throughout Europe. The dramatic and simultaneous plummeting of European populations of otter is due to many factors: its vulnerability as a superpredator, and its naturally few individuals; fewer suitable habitats - bank forests – due to reclaiming of land and extensive agriculture; degradation of water quality and changes in food resources; prolonged hunting of this species, which was considered "harmful" in Italy until 1978; negative, random events, like being killed on roads. But the most important factor which caused the sudden, quiet, unobserved and initially underestimated fall in the numbers of this mammal was certainly the extensive use of organo-chlorinated pesticides (DDT, aldrin, dieldrin, lindane, heptachlor). These substances are now forbidden in Europe, but there is another dangerous pollutant, polychlorobiphenyl (PCB),which has been used in Italy since 1983 as a hydraulic fluid, plastifier, dielectric, heat exchanger and lubricating oil additive. Until today, combustion of various plastic materials discharges PCB, which may be carried in the atmosphere to considerable distances. All these substances are liposoluble, very stable, only decompose very slowly, and cause reductions in fertility as they are absorbed by the bodies of predators. As regards Italy, these consequences emerged dramatically with a survey carried out a few decades ago by Italian researchers. The results were published in 1986 and indicated that the last otter populations were scattered and confined to a few rivers. However, their numbers have continued to fall. The Italian otter now lives in some depressed areas of central and southern Italy, and 130 individuals would be an optimistic count.

Otter tends to live in valleys or hills. The productivity of river ecosystem decreases upstream, watercourses become oligotrophic and food resources are scarce. This is why, even in optimal conditions, the population density of otter is inversely linked with altitude; at 400 m it plummets.There are very few individuals in high-altitude streams at specific life-stages. Most of them scatter while still young. During this stage they move upstream and spread along mountain flanks, over ridges, reaching 2000 m. This enables them to exchange genes with populations living in other streams. In Italy, this seldom happens, and genetic isolation is another of the many problems of Italian otter.

Polecat (*Mustela putorius*)

Ecology of mountain streams

FABIO STOCH

As land is often considered in relation to man, mountain streams are regarded as outflow, the draining of waters which flow in stream beds to reach the plain as quickly as possible. “Draining” often corresponds to drainage of human waste. This view is often called hydraulic engineering, which justifies interventions on watercourses, the constant attempt at bending nature to man’s will, in order to make water reach the valley as fast and safely as possible, avoiding the damage which floods cause to man, his towns and his activities. This view is restrictive and only corresponds to part of the truth.

According to ecologists, streams are ecosystems or rather, a series of ecosystems, each of which hosts different animal and vegetal communities. This chapter analyses how these ecosystems work, and the factors which determine their structure and diversity.

■ Zonation in running waters

The study of floral and faunal distribution in running waters provides for the identification of “ecological zones” which may be found from the spring to the mouth of streams. Zones were originally identified with reference to fish distribution and, in the post-war period, a pioneer in this field was the French ichthyologist Marcel Huet. His work shows how the structure of fish populations change with the gradient of streams, which determines chemical, physical and morphological parameters.

This is the well-known “gradient law”, which distinguishes fish populations in a stream according to some *guide species*, proper to each fish zone (other species, which prefer a well-defined area, are called *cortège species*. This classification was, and still is, widespread in central and northern Europe, where it was tested and, although slightly modified, it is also used in Italy. The use of “fish zones” has a mainly practical rather than theoretical value, as it does not take into account other fauna.

According to Huet, watercourses are divided into four zones:

● *trout zone*: cold, well-oxygenated, fast-flowing waters, with substrates of heterogeneous particle size (stones, rocks, pebbles, coarse gravel) and no

High-altitude streams are supplied by continual melting of ice and snow

Hyporhythral (lower mountain stream zone)

aquatic vegetation; *guide species*: brown trout and Miller's thumb; possible *cortège species* a few rheophilous cyprinids, such as minnow and blageon;

- *grayling zone*: slower, but always cold, well-oxygenated waters; gravelly substratum with constant particle size; algal and mossy submerged vegetation, with macrophytes in the slowest stretches; characteristic species: grayling, with salmonids and some rheophilous cyprinids;
- *barbel zone*: the stream bed flattens and current is slower; oxygenation is stll good; gravelly or sandy substrates with thick macrophytic cover; barbel is the guide species, with chub and other cyprinids;
- *bream zone*; very low gradient, current slow; muddy substrates with thick macrophytic cover; as bream (*Abramis brama*) is absent from Italian fauna carp is considered the guide species, together with tench, rudd, bleak and roach.

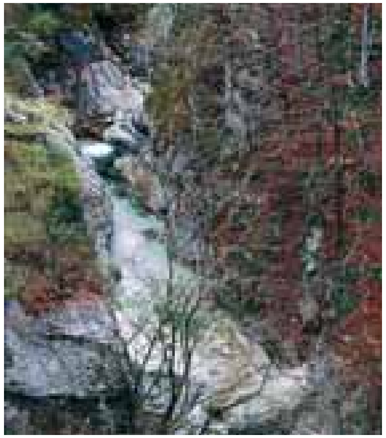
The first two zones constitute "salmonid waters" in mountain streams. The last two are "cyprinid waters", linked with hilly, foothill and valley areas. This simple division is so practical that it was recently adopted by a decree (D.L. no. 130 of January 25, 1992) which assimilates a European Community directive (in accordance with Law 78/659/EEC regarding the quality of freshwaters which must be protected and improved to make them suitable for fish).

The concept of "ecological zones" in flowing waters was later confirmed by Illies and Botosaneanu in a pioneering work published in 1963, which treats the problem in an organic way, with special reference to macrobenthos. The work by the above authors concentrates on "zones" and identified three large "ecological zones", which were and still are called *crenal* (or krenal, spring area), *rhythral* (streams) and *potamal* (valley rivers). Each heterogeneous zone has sub-zones (*hypocrenal, epi-, meta-* and *hyporhythral* and *potamal*). In each of these three zones live macrobenthic populations which differ greatly from one another (the animal communities of these zones are identified by the suffix *–on*, e.g., *crenon* is the typical crenal population).

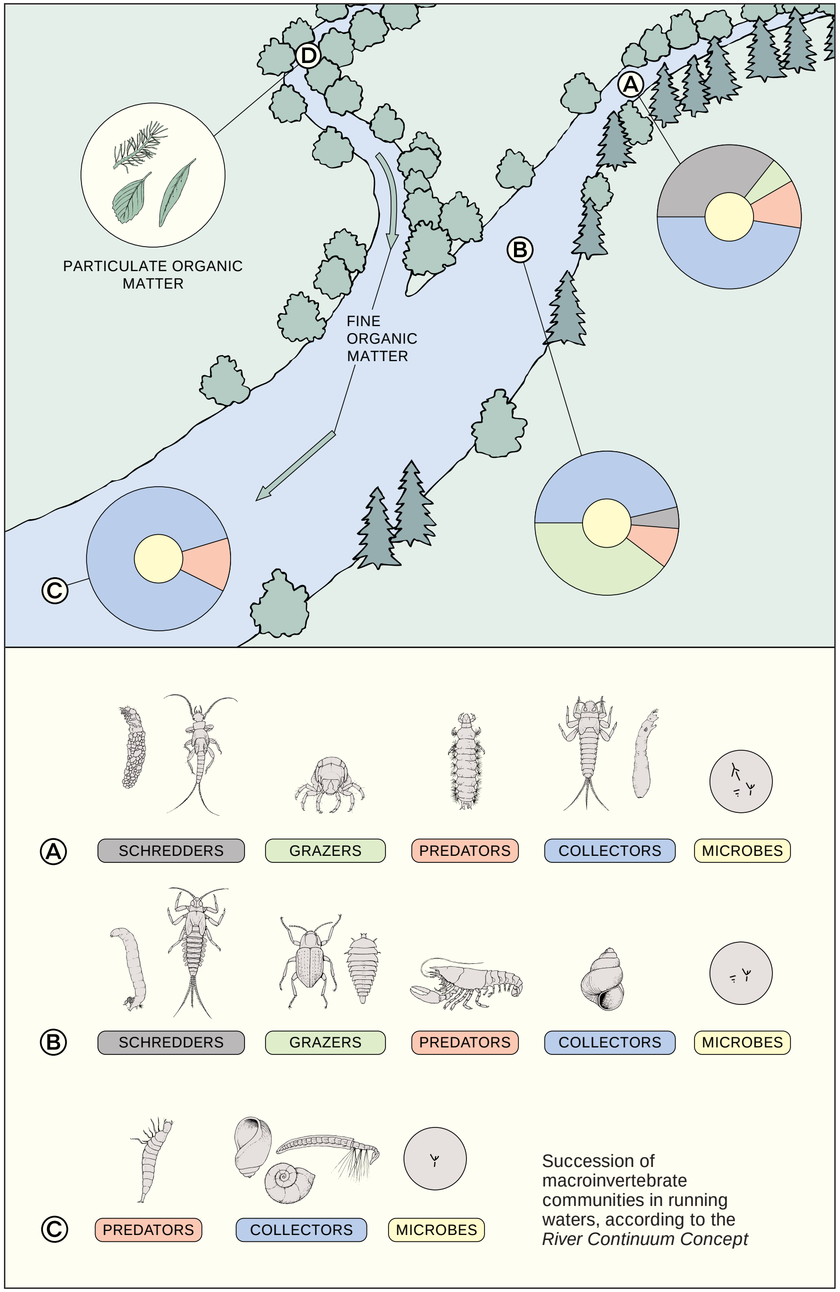
Obviously, macrobenthic and fish populations correspond in some way; therefore, *rhythral* corresponds to the salmonid zone, and *potamal* to the cyprinid one.

These zones are not clearly defined and this classification cannot be easily applied to all regions, as the morphology of the land near streams may alter the classification drastically. According to many hydrobiologists, the "traditional" methods of identifying ecological zones are inadequate because they lack the scientific rigour necessary to determine the type of running waters, and may thus lead to too subjective interpretations. Further complications derive from the fact that the zones are not clearly limited and often overlap. Although Illies and Botosaneaunu considered that, whenever tributaries flow into a certain watercourse, variations in flow cause changes in macrobenthic populations, there is no proof of this. In recent years, these "historical" methods have been supported by mathematical models (multivariate statistics), which group watercourses (hierarchical classification) or organize them along an axis (ordination) according to the similarity of their fauna.

Crenal (spring zone)



Metarhythral (intermediate stream zone)



Succession of macroinvertebrate communities in running waters, according to the *River Continuum Concept*

The River Continuum Concept

Although identification of “ecological zones” is interesting and practical, the very concept of *zonation* has been considered by many researchers as imprecise or even meaningless, as it does not contemplate the influence of upstream communities on downstream ones by means of organic matter carried by the current.

According to these researchers, watercourses consist of a succession of ecosystems from spring to mouth. In their pioneering work, American authors Vannote, Minshall, Cummins, Sedell and Cushing proposed the *river continuum concept*, whereby the structure of communities, from the spring to the mouth of rivers, changes gradually but constantly, and is influenced by gradient, current speed, chemico-physical factors (temperature, oxygen, dissolved salts in water), morphology (particle size of substrates) and food resources (presence of particle-sized organic matter). This is a good theoretical solution, but it does not explain the sudden changes in environmental conditions which occur in many watercourses - particularly in their hydraulic regime - which identify areas of biological communities.

The *continuum* concept has therefore been rightly criticized. Actually, the solution to this scientific dispute lies in the middle - or rather, both hypotheses are acceptable. Ecological zones and *continuum* are two different ways of representing the same phenomenon, and they have been amply discussed in other fields, such as phytosociology (that branch of botany which studies vegetal associations). The *continuum* is a theoretical concept associated with a gradient, from spring origin to river mouth, which may be partly hypothetical and is used to formulate theories which must be tested experimentally. Any theoretical *continuum* applied to local streams splits into many ecological zones, according to the characteristics of land. Zonation is therefore the concrete aspect of the continuum, and it organizes communities in a practical and comprehensible system.

Ecology of benthic invertebrates

Benthic invertebrates in running waters are those organisms which live near the substratum or inside it. They may be divided into three large ecological groups. *Microfauna* are all microscopic organisms which may be filtered by a 60-µm (60 thousandths of a millimetre) net. Most protozoa, many nematodes and large larvae of organisms belong to this group. Little is known of the microfauna of watercourses, and it will not be discussed further here.

Meiofauna includes organisms which may be trapped by a 60-µm net, but are filtered by a 500-µm net. These organisms are slightly smaller than one millimetre, and include oligochaetes, nematodes, mites, copepods and ostracods.

Macroinvertebrates are those organisms which are trapped by a 500-µm net, and are the most famous inhabitants of moving waters. They have been thoroughly described in the chapter devoted to invertebrates.

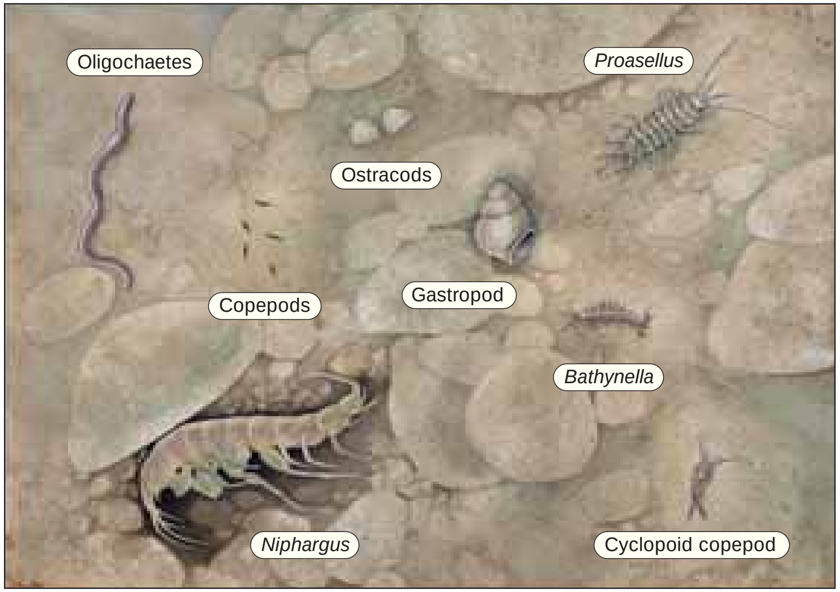
Superficial examination of this classification might lead us to consider macroinvertebrates as the most important stream community. Due to their large size, they are the most abundant in terms of biomass and as they have been thoroughly studied and are often used as indicators, this suggests that they alone are sufficient to characterize running water ecology.

Experience demonstrate that this is not so. The few studies carried out on meiofauna density in streams show that this community - in terms of number of individuals and biomass - is sometimes much larger than that of macroinvertebrates.

The conclusion is that macroinvertebrates are extensively studied only because they are easily caught and identified, i.e., because they are easily recognized by human eyes.

Meiofauna. In mountain streams, meiofauna lives in the so-called “interstitial” waters, i.e., waters which flow in the interstices between gravel and grains of sand. The most important factor which determines the numbers and distribution of meiofauna is particle size: interstitial width physically limits the size of fauna. If sand grains are too small (which seldom occurs in mountain streams but often in valley watercourses), interstitial spaces are also small – and often filled with organic debris - and meiofauna is scarce. If gravel grains are large, as in steep stretches, water flows through them easily, and also in this case meiofauna is scarce. Large numbers of interstitial organisms are found where gravel is fine and sand is coarse.

The stability of chemico-physical conditions is also important. In the area just under the substrate surface (called “hyporrheic”), there are considerable variations in environmental parameters, and meiofauna is mostly composed of organisms which are occasionally found in this environment - phreatoxenes - or organisms which spend only part of their life-cycle in this area (phreatophyles, particularly plecopteran larvae and chironomid dipterans). Deeper in the sediment, environmental conditions are stabler and waters, although less well oxygenated, flow more slowly and constantly. This is where phreatic water animals are found, i.e., organisms which typically live in interstitial environments. They belong to the category of stygobitic animals, a popular name identifying animals which live exclusively in subterranean waters.



Fauna in interstitial environments

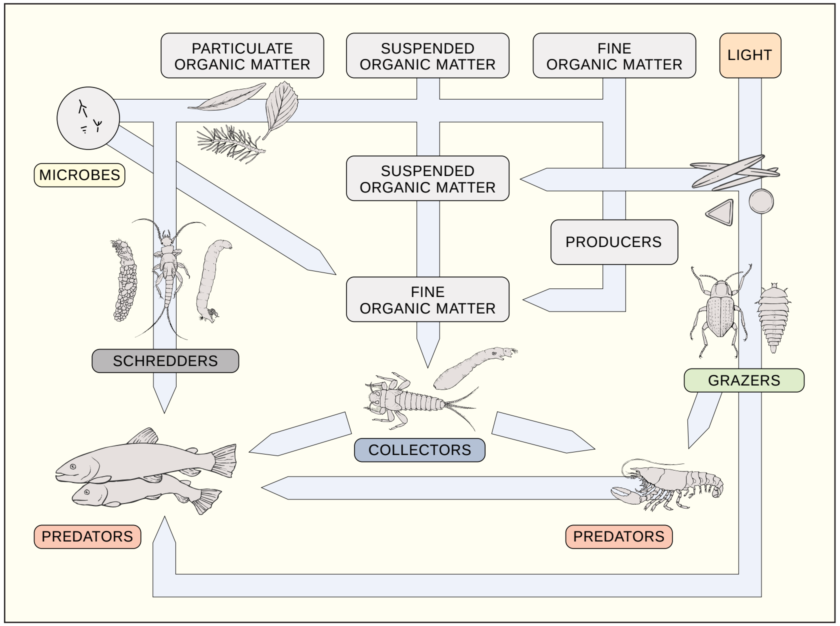
Phreatic water organisms were first studied in the second half of the 20th century. It is difficult to find a suitable sampling method for interstitial environments. There are two main types of collecting, which are technically very simple. The first (which derives its name from its inventors - the Karaman-Chappuis method) provides for holes to be dug in sand or gravel, not far from the stream banks. After a while (depending on substrate permeability), interstitial water fills the holes, is collected in a container, and then filtered through a thinly meshed net. The second method (Bou-Rouch method) uses a manual pump which is attached to a metal probe with tiny holes at one end. The probe is inserted to a depth of 1-2 m in gravel (according to kind of substrate) at the bottom of the stream, and water containing phreatic organisms is sucked up. These methods have enabled scientists to discover a completely new world made up of very strange, blind, depigmented animals, with highly developed senses and body characteristics which enable them to curl up among gravel grains (volvatoid shape), or to tuck themselves in interstices between grains (elongated or vermiform shapes).

Proceeding upstream, at higher altitudes, substrate particles become coarser, nutritients decrease, and there are fewer phreatic organisms. But this does not mean they are not present. In fact, these upstream stretches contain rare and endemic species which live in restricted areas of a few Alpine massifs.

Macroinvertebrates and functional categories. Ecologists have always studied the functional role of invertebrates as consumers in the food chain, i.e., the ways they feed in watercourses. In 1974, the pioneer in these studies was the American Cummins, who organized stream invertebrates into four main groups:

- *shredders*: these invertebrates are detrivorous and, when feeding, shred coarse organic matter (with particles the diameter of which exceeds 2 mm); trichopteran and limoniid larvae, many plecopteran larvae and amphipod crustaceans belong to this group;
- *collectors*: these detrivorous animals feed on fine organic matter (less than 2 mm) which they obtain in two ways: *gatherring* it from the bottom, from organic debris and sediments (e.g., mayfly scavenger larvae of the genus *Ephemera*, oligochaetes, many chironomid larvae, most meiofauna); or *filtering* flowing water for food particles carried by the current (e.g., simuliid dipteran larvae, hydropsychid trichopteran larvae);
- *grazers-scrapers* feed on algae and on the organic layer attached to the substrate and coarse debris (twigs, leaves, etc.) which they can pick at or scrape with their mouth apparatus; among them are riffle beetles, mayflies and, among scrapers, gastropods;
- *predators* are carnivores which feed on other invertebrates; among them hirudineans (leeches), odonate larvae, diving beetles and tanipodine chironomids. This group also includes fish such as salmonids and cottids, although they are not invertebrates.

Obviously, the numbers of individuals of each species change in the watercourse according to the availability of organic matter. The *river continuum concept* focuses on the variations in differing types of organic matter available from springs to river mouths, and therefore assumes that food chains vary accordingly, as stated in the theory. *Shredders* are abundant in upper stretches (where, depending on current speed, there is more coarse organic matter); the numbers of *filterers* increase downstream, as far as the point where the current is too slow and makes filtering mechanisms inefficient; *grazers* are usually found in mid stretches; *collectors* are typical of lower stretches, in valley streams and the side-bays of mountain streams where debris deposits. All these organisms provide for the so-called "recycling of organic matter" – that is, except for herbivores, they all feed on coarse and fine debris. They therefore play a fundamental role in the recycling of organic matter produced by pollution (e.g., sewage), and contribute to the so-called "self-purifying power" of watercourses.



Food chain in a mountain stream

■ Factors which determine biodiversity

The rhythral of streams, with its cool waters and pebbly or gravelly substratum full of interstices which host many organisms, is called an environment with high biodiversity and, for many species, it is the best place to live.

The biodiversity of streams may be explained both from historical and ecological points of view. Historically, starting from the first colonizers, diversity is the final result of adaptive radiation in environments which change slowly over long periods of time: here, the birth of new species is due to faunal distribution, isolation of catchment basins, and natural selection over time. Ecologically, variations in environmental conditions are very important. They may be caused by sudden, exceptional events (such as floods or human interventions), continue over time (such as seasonal variations in temperature and nutrients) or space (variations in current speed and substrate particle size in watercourses).

Riffles and runs alternate with pools in mountain streams

In some watercourses, there are few variations in environmental conditions in the course of time - for instance, in small streams which gush from springs. Instead, *rhythral* stretches undergo cyclic variations which may be predicted by means of simple mathematical models in relation to the climatic conditions of the area. Intermittent or ephemeral streams undergo sudden variations which are only partially predictable, such as sudden floods or drought during dry periods. Aquatic invertebrates contrive several strategies to adapt to changing environmental conditions. Environments which undergo variations in time and space, like the rhythral, contain many more species than springs with constant conditions. When variability exceeds a certain threshold value and streams become intermittent, diversity drops suddenly. This theory was first devised by the American Connell in 1978, and is known as the *Intermediate Disturbance Hypothesis*.

Watercourses are not only characterized by longitudinal variations in environmental conditions, i.e., changes which occur from spring to mouth, but also by different environmental conditions in the same area. If we approach the bank of a stream and observe the environment critically, we hardly ever see it as uniform. Rather, we have the impression that it is a patchwork of micro-environments: deep pools alternate with riffles and runs; pebbles and stones with coarse and fine gravel or sand deposits; banks are sometimes gently descending, bare or green, or steep and subject to landslides, or covered with moss. The hydrological regime also varies, and there are *downwelling* stretches, where water disappears in gravel on the bottom, or *upwelling* stretches, where subterranean water emerges to the surface.

Ecologists know this *patchy environment* very well, since each animal species finds its ecological niche in it. Complex ecological patches, therefore, host many different species; naturally homogeneous or man-made homogeneous environments contain simple a poorer fauna.

Micro-habitats (*patches*) are not static but dynamic, and change in time with the hydraulic regime of watercourses. These changes cause cyclic variations which enrich biodiversity. This theory, put forward by the English scientist Townsend, is called *patch dynamics*.

In order to understand the environmental complexity of a stream better, we should observe streams from the point of view of fish or invertebrates. If we could see the bottom of a stream as mayflies do, everything would look very different. Interstices and spaces between pebbles and gravel grains would be enormous, although almost invisible to humans; variations in current speed, which people consider insignificant, would sweep us away; small mosses would look like close-packed forests. If we were observing everything under a

The mysteries of drift

Bruno Maiolini

Organisms living in moving waters have important advantages, but also disadvantages with regard to aquatic organisms which live in stationary waters such as lakes, ponds, marshes and pools.

Advantages are constant flows of organic matter and continual renewal of water, which is well oxygenated and balances any sudden chemical or physical changes. Disadvantages are mainly the danger for organisms of losing their habitats when carried away by the current.

Only skilled swimmers can move upstream, particularly salmonids like trout, which usually migrate upstream to reproduce. But invertebrates can only be carried downstream. This phenomenon is widespread, and part of the benthic community is always dispersed or floating. Organisms passively carried by the current are called “drifting organisms”, and have been thoroughly studied for the important role they play in the river ecosystem.

There are four types of drift: catastrophic, behavioural, distributional and constant.

Catastrophic drift is caused by sudden and enormous changes in water flow, speed, temperature, or chemical conditions. These stressful situations make benthic organisms leave their habitats and swarm into the current.

Behavioural drift is caused by the specific activities of each individual, and is divided into active (organisms carried by the current to escape predators) and passive (organisms carried away by the current while feeding in areas with few holds). Both events are rather infrequent and are due to the risk behaviour of each species.

Distributional drift regards juveniles migrating downstream. Many individuals may be involved and each taxon has typical seasonal and daily periodicity. Constant drift is not due to specific behaviour but to “accidents", whereby organisms lose contact with their substrate. These events regard only a few specimens and cannot be predicted.

When individuals flow into the drift, they move downstream until they find another hold on the substrate, which occurs in favourable conditions, such as slower currents in side bays, or passages over rough areas.

Distances covered vary from tens of metres to many more, according to environmental conditions and the swimming capabilities of each species, e.g., the differences between the larvae of midges without appendices, and mayflies, which can swim in any desired direction and have six legs with claws.

Aquatic larvae may be drifted many times during their life and therefore the distances between where their eggs are laid and where they hatch and become adults may be considerable.

In order to balance downstream transport, adults fly upstream to lay their eggs, and a new cycle begins (colonization).

According to their habit and body shape, aquatic organisms have a different drift trend. Mayflies enter drifts easily, followed by black flies, midges, stone- and caddisflies. The least drifted are amphipods, flatworms and leeches, due to their inability to fly upstream to compensate drifts downstream.

Drifts are more intense at night, and peak after sunset and before dawn. This is probably due to the need to avoid predators like fish.

In areas where fish are absent, e.g., upstream stretches, drifts do not often occur at night.

This has been confirmed by experimental research, although evidence also shows that some organisms, which are not desirable prey, have nocturnal drifts.

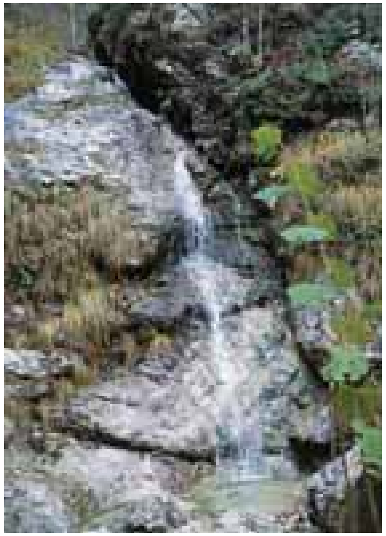
microscope and identified ourselves with mites or copepods, the environment would appear even more complex: small interstices between sand or gravel grains would become caves or mazes, and available space would increase beyond measure. Environmental complexity increases as size decreases. A 10-metre long stretch of water, seen by a mayfly, is incredibly longer than we can imagine, as these animals view everything in millimetres and notice the slightest unevenness of the substratum. This is a well-known phenomenon in ecology (it is known as the fractal nature of watercourses) and it explains aspects of these environments at which we had only guessed so far. It also explains why meiofauna is much more important than macroinvertebrates: it has much more available space. But it also demonstrates that streams are richer in living organisms than channels built by man: in streams, there are many micro-habitats that man will never be able to recreate in artificial watercourses, no matter how hard he tries to imitate nature.

■ Ecology of springs

Mountain springs (which belong to the crenal) are divided into two groups.

Rheocrenic springs. In rheocrenic springs, fast-moving water flows

Rheocrenic spring in undergrowth: these areas are colonized by shredders



Rheocrenic spring with hygropetricolous layers on high-gradient slopes

from rocks, coarse debris or even undergrowth soil. The organisms which are typically found in this type of springs are shredders, such as plecopteran and trichopteran larvae and many dipterans, particularly non-biting midges. There are also some mayflies, moth flies and amphipod crustaceans; among meiofauna, there are water mites and harpacticoid copepods, which usually live in mosses or interstices. Springs with slow currents, less inclined, in the undergrowth, or rich in mosses which host high numbers of invertebrates, are qualitatively and quantitatively rich. If springs flow down rocky slopes, they may form thin water layers which flow vertically: in this case, the environment is *hygropetric*, with particular fauna, such as harpacticoid crustaceans, trichopters and dipteran larvae (chironomids, thaumaleids, moth, crane and soldier flies), which are sometimes exclusive to these areas.

Helocrenic springs. These springs flow from soil with low gradients, and therefore do not form a single flow of water, but spread in pools which are slowly drained by many small, slow-flowing rivulets and converge in one or more large pools. They are typical of meadows, but are found in undergrowth. Their fauna is different from that of *rheocrenic* springs, and is typical of slow-flowing waters (collectors, grazers, scrapers, such as ephemeropteran, trichopteran and limoniid larvae, diving beetles and, among meiofauna, cyclopoid copepods). Gastropod and freshwater mussels abound when the calcium content is sufficient.

Spring environments are usually considered “stable”: there are slight circadian (spanning 24 hours) and seasonal variations in water temperature and chemistry. Temperature depends on spring altitude; recent research in the Trentino region has shown that daily variations in temperature are slight and lower than the level of instrumental error. In mountain springs, there is more dissolved oxygen than in low-altitude springs.

This is probably due to the fact that mountain waters flow through highly permeable coarse sediments before emerging, whereas foothill or valley waters flow through layers of soil the decomposing processes of which reduce oxygen contents. Unlike what might be commonly thought, *helocrenic springs*, where water flows from the soil, are richer in oxygen than *rheocrenic* ones. Rather, water chemistry changes with the spring and the rocks through which it flows.

■ Ecology of high-altitude streams

High-altitude streams have recently been classified in various ways, the best model being that proposed by Ward in 1994. He distinguished *kryal* (meltwater stretches) from *crenal* and *rhythral* above the tree-line and according to origin. Meltwater from glaciers or perennial snow, rain and spring waters give rise to considerable differences in the hydrological regime and chemico-physical qualities of water, but also in the structure of their vegetal and animal communities.

The kryal, crenal, and rhythral share some general characteristics, which are typical of mountain streams above the tree-line. Water temperature is usually below 10°C, even in summer. High gradient causes waters to be fast, turbulent and well-oxygenated, with no plankton or macrophytes.

A typical high-altitude stream springing from a small snow-field (Carnian Alps)

Bank vegetation is constituted of small shrubs and grasses or, at higher altitudes, is completely absent. There is, therefore, no vegetal supply, which is the most important energy resource of river metabolism at lower altitudes. The absence of trees also implies more intense exposure to sunlight, and fewer microhabitats are composed of branches, emerging roots and leaf debris.

However, kryal, crenal, and rhythral do differ in several ways. Aquatic life is more difficult in the *kryal*, which is mostly made up of meltwater. Water comes from two different sources: from the foot of glaciers, where water melts as a result of friction between ice and underlying rocks, and from surface melting due to the heat of the sun.

The former is relatively constant throughout the year and independent of outside temperature; the latter is seasonal, depends on the weather, and varies considerably during the day. In summer, the two sources combine and flow may vary by as much as 5-10 times in 24 hours.

Water flow typically increases in the morning, peaks late in the afternoon, and plummets at dawn. Waters which flow from beneath the ice cover include water from the water-table and are usually richer in salts than meltwater, which is almost “pure”. This gives rise to dilution and, in much the same way, variations in summer flow are associated with chemical variations.

Besides hydraulic “stress”, there are very low temperatures (below 4°C) and considerable solid transport. The latter consists of sand and clay particles deriving from ice erosion which are suspended in fast-moving water. They make the water cloudy and have erosive effects, which complicate vegetal life still further. The zoobenthic community is often very simplified, with highly specialized species.

In the kryal, crenal and rhythral, there is a clear longitudinal gradient of colonization by benthic invertebrates. Proceeding downstream, communities change qualitatively and quantitively as they adapt to changing environmental conditions. Although these continual and constant variations are well-known (see *River Continuum Concept*), there is little information regarding changes which occur in initial stretches, from “point zero” i.e., almost pure water, with very few living organisms, to places where the first structured communities live.

In the Alps, this area stretches from the origin (glaciers or perennial snow) to the tree-line (1800-2000 m). In 1994, two English researchers devised a model for all glacial streams which organizes zoobenthic communities from the mouths of glaciers to valleys, according to variations in certain basic parameters like water temperature and stability of stream bed. The model is drawn from data of European and American studies, and has recently been tested by European researchers.

However, the macroinvertebrate community of upstream stretches is mainly composed of chironomid dipterans, in terms of both numbers of individuals and species. In glacial streams, this family makes up almost 100% of the community near the mouths of glaciers.

The numbers of chironomids fall as distance from the spring increases, irrespective of its origin, and they are replaced by other insects, such as plecopterans, ephemeropterans and trichopterans. Chironomids drop to 50% of the entire community at altitudes and distances from the glacier which vary considerably and depend on several factors, including glacier activity, morphology of the bed, and daily and seasonal trends of water temperature and flow.

Invertebrates which are not insects, like nematodes, oligochaetes, triclads and crustaceans, may abound in upstream stretches, and are associated with side-bays (oligochaetes), or areas where watertable waters emerge in the sub-bed. Not only are there variations in space, but also in time. In these ecosystems, food is usually scarce and therefore slight variations in primary production have a strong impact on animal communities. In kryal stretches, primary production is due to algal crusts (cyanobacteria and diatoms) and to the chrysophite *Hydrurus foetidus*.

Concluding, running waters above the tree-line have generally restricted biodiversity upstream and great variations in time and space.

■ Ecology of foothill streams

Unlike high-altitude streams, watercourses which cross forests are richer in organic matter derived from leaves, decomposing wood or run-off from the soil itself. The macrobenthic community is more abundant and characterized by detrivores, the presence of which is restricted at high altitudes by lack of food.

These streams are said to be more productive, i.e., in comparison with high-altitude ones, they produce more organic matter throughout the year, due to plant reproduction and growth. This is a secondary type of productivity, because, as mentioned in the botanical chapter of this book, there is little primary production of algal layers in these shady stretches where macrophytes are almost totally absent.

The high-altitude *rhythral* is a “severe” environment (very low temperatures, scarce food) and abiotic factors play an essential role in the structure of animal communities; instead, in foothill streams, biotic interactions are also important (particularly competition and predation). However, although on one hand abiotic factors are well-known, on the other, biotic factors are so complex that they have been studied very little.

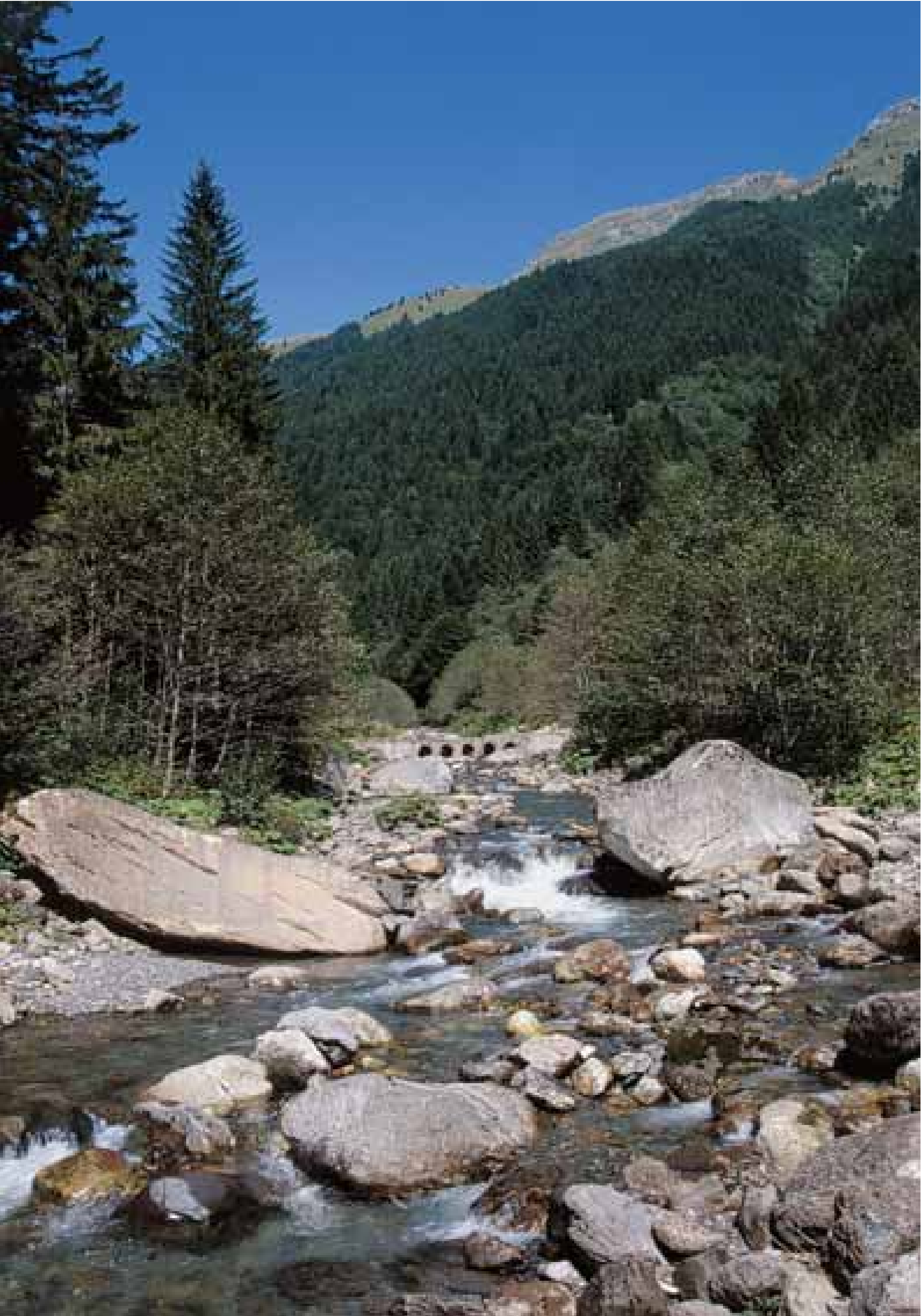
A foothill stream stretch (Carnian Prealps)

What is known, is that competition only occasionally determines the structure of benthic communities, i.e., only when favourable trophic conditions and moderate predation enable populations to develop.

Predation is more important and characterized by the presence of fish, which make interactions even more complex and vary the structure and density of invertebrate populations. Predation is more intense in some areas, e.g., in pools rather than in riffles and runs, probably because invertebrates cannot find suitable hiding places in these fast-flowing environments.

It is more intense when the current is slow and temperature higher, as in late summer. High drift, i.e., intense emigration and immigration and fast currents, minimize the effects of predation.

Preying of salmonids on aquatic invertebrates is also reduced by the supply of external material: in the undergrowth, high numbers of terrestrial insects falling into the water constitute food for trout, which are attracted by the movement of these tiny animals (as fishermen know).



Conservation and management

MAURO MARCHETTI · MARIO PANIZZA · SERGIO PARADISI · FABIO STOCH

■ Disorders: causes and interventions

Main disorders. Two fundamental distinctions must be made when describing the main disorders of mountain streams. Their causes may be closely linked with geomorphologic processes evolving inside the streams themselves and thus with the dynamics of surface waters, or they may depend on the evolution of basin flanks. Bottom and bank erosion, the undermining of artificial works in the river bed, and transport of great quantities of sediments during paroxysmal phases are among the processes due to stream dynamics. Very many processes cause disorders on flanks and thus directly or indirectly on river beds. The most important are purely gravitational and cause landslides and falls of rock masses above the stream. But there are also avalanches and the results of man’s activities on the land (e.g., ploughing and terracing), or changes in the use of land (from wood to pasture, or vice versa).

Erosion of stream beds. The energy of erosive or “excavating” streams is so great that it cannot be entirely dispersed by their waters which use up all their residual energy by eroding their beds and carrying growing quantities of sediments. A balanced stream may start to become erosive for many reasons, and even minor changes may cause great erosion of the bed. Erosion is mainly due to greater water speed, which increases if the channel suddenly narrows or the gradient becomes steeper. These two morphological variations may have natural or artificial origins which cannot be described exhaustively here, but one of the most important is the lowering of base level, which, upstream, causes a steeper gradient and thus an increase in current speed. The latter is responsible for erosion, also called *regressive erosion*, as it rises from the base level upstream. Channel narrowing may be due to excavation, artificial remodelling of the stream bed, or associated with narrowing caused by landslides, avalanches or alluvial fans which carry material from banks and tributaries.
The presence of dammed reservoirs in high mountain basins may cause severe erosion downstream. This is mainly due to sedimentation of material in

Man's intervention may also be perceived in high-altitude stretches of mountain streams the retaining basin, which decreases solid transport below the dam. In turn, this reduction gives rise to a proportional increase in energy, which is thus potentially available for further erosion and transport becomes highly aggressive. Water flow control of dammed reservoirs may also cause severe erosion and sedimentation when they are periodically emptied.

These operations are either carried out to clean reservoirs of fine sediments which tend to fill them, or are applied to lower the level of exceptionally high waters upstream, which exceed the capacity of the reservoir. Quick emptying, downstream, gives rise to sometimes very fast water flow and accelerated erosion, followed by sedimentation of fine sediments over long stretches. These sediments often contain high percentages of organic matter, and sometimes pollutants, which may disturb the ecological balance of streams for lengthy periods. Only recently has there been interest in the emptying effects of large reservoirs along the main Alpine watercourses of France and Switzerland, where the problem has been worsened by heavy anthropic pressure (urbanization, industrialization) and the large capacities of rivers such as the Rhône, Isère, Drôme, etc...

Counter-measures against erosion include reducing water speed and making the stream beds erosion-resistant. The latter system is generally adopted near and through towns and near large constructions like roads.

Catchment basin in a valley of the Tuscan-Emilian Appennines

Banks and beds are protected in many different ways. The river bed may be covered with material which is not removed by fast-flowing water, thus preventing cross-river constructions which raise the level of the bed. When watercourses flow through villages, the section of their bed must be kept sufficiently wide to accommodate high water. In this case, attempts are made to avoid raising the level of the bed, which would reduce its cross-section, by building high embankments and walls. In recent years, the impact of constructions on the environment has become a fundamental issue for designers, who increasingly try to use more natural materials and methods, and reinforced concrete works above low water are rare. Channels may be covered by large broken stones arranged to form dry walls. Concrete gutters are not recommended if the stream carries much debris and current speeds exceed 2.5-3.0 m/s; rubble covers are more suitable. Gutters in the river bed sometimes alternate with sills firmly anchored to the banks.

When current speed is not very high, only bank protections are made. Their weak point is at the foot, which is intensely eroded by water, so that girder foundations, foundation piles and gigantic rocks support the basis of bank protection systems. Gabionades are cheaper but less safe. These ductile constructions have the great advantage that they warp according to differential settling. In the past, they were thought to be short-lived, but they are actually quite long-lasting (20-25 years), may be mended, and even laid during periods of frost. Above all, the clasts inside may deposit fine material and provide a substrate for vegetation. The efficiency of gabionades plummets if the container breaks because the clasts are so small that they start moving quickly.

Protective structures which provide even faster processes of “renaturalization” are made in natural materials, like poles of larch or other resistant species of trees, connected to one another with steel cables. Lastly, protections can even be made up of willow or alder cuttings.

The gradient of stream beds can also be reduced with weirs, which create a series of throws which dissipate a great amount of energy but also retain the bed at pre-established levels. Such artificial stream gradients balance or compensate removed and deposited material, and are therefore called *compensation gradients*. Hydraulic engineers and forestry experts calculate a theoretical rather than real gradient, as stream characteristics change in time (e.g., extremely low waters with respect to high waters) and space (the geometry of stream beds and mean and maximum sizes of sediments in them change continually). Steps and pools can also be created with sills: the former are under water, whereas dams jut out of the stream bed and are constructed after identifying the desired longitudinal profile, also called *compensation profile*.

Embankment and preventer bobstay in the river Panaro (Emilia)

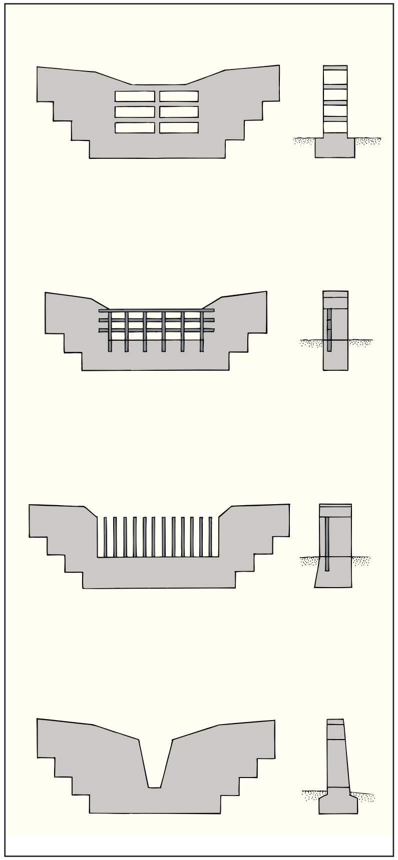
Weirs set along a stream may affect water oxygenation. Reduced gradients and turbulence cause a fall in aeration above the weir; the opposite occurs below it. Weirs also affect the upstream formation of bars which emerge from the stream bed.

Erosion of stream banks may cause partial or total collapse of the flank, if its base has been scoured out. Highly erosive streams that carry landslide material into the network and upper part of basins reduce erosive processes in the whole network, even downstream. In this case, fortification of flanks may not be necessary. Otherwise, when slope instability interferes with roads or other buildings and human activities, the effects of bank erosion must be reduced and the situation stabilized. Obvious steps have to be taken. Firstly, erosion of the landslide foot must be stopped by fortifying it or creating obstacles that divert the current from it. This is achieved by emplacing constructions made up of loose material (large rocks) or gabionades. In streams, diversion structures (which hinder the current) produce calmer water further downstream. Another way of reducing speed is to construct weirs just below the landslide. This operation reduces the gradient of the stream bed by raising its level, and also gives the eroded area some minimal support.

Sedimentation in stream bed. Streams in a state of sedimentation, or “transport streams”, generally indicate that the basin is undergoing severe degradation. A balanced stream may change its state into one of sedimentation when increased quantities of debris reach the bed as a result of gravitational instability (landslides, surface erosion, avalanches, etc.) or reduced current speed. The latter is determined both by man’s interventions which raise base levels, e.g., weirs, dams and other constructions, and by natural causes like landslides, formation of alluvial fans at the confluence with other streams, and occasionally by avalanches or tongues of ice which narrow the water channel.

Transport streams have higher turbidity than erosive ones, and this affects their animal and vegetal populations.

Although raising stream beds does not generally endanger human activities in the surroundings, it may sometimes be hazardous. This is the case when watercourses flow through towns, particularly if these are built on alluvial fans. If the cross-section of the stream is determined or narrowed by the spans of bridges, raising the bed may cause floods and the collapse of bridges. In such cases, works along watercourses are insufficient: the whole catchment basin needs reorganization from the hydraulic and forestry viewpoint. Since these works are expensive and produce results only after long periods, very often they are not adopted systematically.



Examples of open embankments and their sections

Risks to structures along streams may be minimized by the immediate construction of retaining walls and other reinforcements that can store sediments without reducing the bed gradient. These works are generally isolated and capable of resisting the impact of coarse material, mainly carried by flood waters.

During extreme high water, streams become floods of mud and debris, defined in many ways according to slight differences in their process (e.g., debris flow, debris torrent, etc..). Reinforcement dams have different shapes and purposes. They create retaining basins which can collect all the sediments carried by floods; in this case they are built at the end of sufficiently wide, low-gradient areas. The material which accumulates after every flood must be removed to maintain the same retention capacity of the conveyors. Openings in weirs have the advantage of reducing the throw downstream and also enable fish to swim more easily upstream, although the water is less oxygenated.

When watercourses flow through villages, gutters are used for both excavating and transport streams. The bed cross-section is remodelled to make it deep and narrow enough to increase current speed and remove sediments.

Alluvial fan areas require special attention. When mountain streams flow together into a main valley, their gradient drops drastically, and the resulting sudden sedimentation causes formations of sediments called *alluvial fans*. They are cone- or fan-shaped, with apexes facing upstream. Fans may have very different sizes; they may be extremely large, divert the main watercourse towards the other side of the valley, or even obstruct the valley bottom. In mountainous areas, particularly along the main Alpine valleys, alluvial fans are inhabited and are at high hydrogeological risk. These areas are generally very difficult to manage, as planning cannot solve every individual situation, and protective counter-measures must be applied to specific local conditions.

Erosion in the catchment basins of mountain streams. Erosive processes in catchment basins produce most of the sediments deposited in mountain stream beds. The more intense in the erosive process, the more sediments in the mass balance of the stream. In Italian mountains, gravitative processes prevail and give rise to many different shapes, such as different kinds of landslides, talus slopes, debris cones, etc.. In high mountain areas, especially in the Alps, the effects of frost, melting of ice and snow are extremely important, as they may cause avalanches. In other areas without vegetation, surface water run-off may become problematic, mainly on less permeable and easily eroded lithologies like those of the clayey parts of the whole Appennine chain.

Man’s activities may accelerate or favour the beginning of disorders initially caused by natural processes.

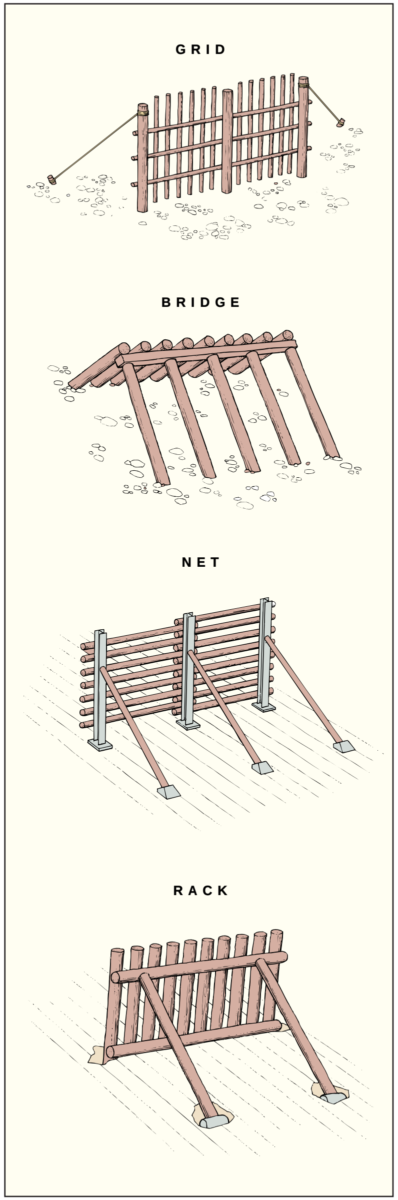
For example, in some historical periods, deforestation has given rise to severe erosion of reliefs. This occurred when deforestation was carried out at the end of periods when the forest management was guaranteed by properly laid down rules and regulations, and woodland was actively protected. The advanced forest legislation of the Venetian Republic affords an excellent example: the forests in Cadore, which provided the timber essential for shipbuilding, were particularly protected. After the Unification of Italy (1870), entire areas, like that of Montello, were “levelled” to allow cultivation. The same thing happened when the extensive forests belonging to the Kingdom of Naples were annexed to the House of Savoy and underwent irremediable deforestation and damage. The devastating results became clear in all their severity with post-war economic development, when coppices were destroyed by fire for reasons which were not only those of agriculture and livestock rearing.

Excessive grazing by livestock causes such over-trampling and damage to turf that initial slope erosion or its acceleration may occur. Buildings on slopes generally cause scars, the formation of new slopes, stagnation and flow problems of surface and subterranean waters which alter the slope balance irreversibly. Agricultural practices such as ploughing along maximum contour lines, the planting of plant species which do not protect the soil (for example, cereals, between harvest and new seeding) and heavy rainfall and storms, were responsible for severe soil erosion in the central Appennines after the Second World War.

Settling of a stream bed, Julian Alps

Various biological and engineering counter-measures may reduce disorders in catchment basins. They must be complementary if they are to produce a common result; unfortunately, large-scale disorders cannot always be halted at reasonable cost. Therefore, slope re-organization cannot be carried out by means of a single, final intervention, but must proceed with small-scale, almost daily attention over lengthy periods of time. Landslide accretion requires complex, expensive operations, such as stripping, drainage, waterproofing and diversion of springs. Small flank disorders may be reclaimed by surface drainage which removes run-off from the landslide, preventing it from expanding. Palings, stockades and trellis-work may stop the descent of surface sediments down slopes and consequent loss of soil, and also slow the flow speed of run-off waters down the slope. Later, frequent practices to consolidate the slope surface consist of sowing grass to anchor the soil and planting trees.

Furrow erosion is very fast and difficult to halt. Remedies include embankments along the main furrows to block further channel lowering; small channels dug in the ridge area, to contrast the landscape ruggedness; and small cuts arranged in a herring-bone pattern, to drain water towards crest channels. Avalanches, particularly when they affect the entire thickness of the snow cover and travel at high speed (powder avalanches in dry snow) may sweep away all the trees along their path and cause slope erosion. Active defence constructions generally reduce the danger of avalanches by preventing their formation, whereas passive defence constructions protect well-defined areas. Active defence is more common and results from small constructions which break up the snow cover along slopes. The ideal solution still involves flank reafforestation with high-density, tall woodland, or if this cannot be done or has been degraded, artificial costructions. In the past, ditches, embankments and, later, dry-wall terraces were used in areas where avalanches were common. Nowadays, anti-avalanche measures include grids, bridge, net and rack snowsheds.



Examples of anti-landslide devices; in the past, ditches, embankments and later dry-wall terraces were constructed in areas threatened by landslip

■ Water exploitation

Mountain streams may locally be dammed to form reservoirs for hydroelectric or irrigation purposes, sometimes to control high waters, and also for tourism. Since ancient times, man has felt the need to control water in many ways, by building dams, reservoirs and irrigation systems.

Dams became of considerable importance with the development of the hydroelectric industry in the last century. In 1905, 70% of Italian electrical energy was of hydroelectric origin. Italy was the main producer of electrical energy in Europe and third in the world.

With the advent of Fascism, the percentage of hydroelectric energy reached 85% of the world total (17.44 billion kW/h). The exploitation of water to produce energy, encouraged by a wish for economic self-sufficiency, and by the almost complete absence of coal in Italy, was incentivated by law no. 3124 of December 24 1928, called “Mussolini’s law”, for complete reclamation.

It allocated funds to carry out land reclamation, hydraulic defence works, creation of irrigation networks, improvements in mountainous areas and supplies of drinking water over a period of 14 years.

The development of artificial deviations in the Alps continued into the 1980s, even after the dramatic breaching of the dam at Vajont. Large companies like

Ridracoli dam, Tuscan-Emilian Appennines

Debris flow

Mauro Marchetti · Mario Panizza

Debris flows are composed of non-classified, highly concentrated debris containing small quantities of clay. Solid contents may amount to 90% of the whole mass. Water and fine debris trapped in the pores of coarse particles facilitate movement. These flows are produced in permanent or semi-permanent channels (canalised debris flows). They are usually caused by channel obstructions - accumulations of tree-trunks and debris - which break the barrage and cause a sudden surge of material and water.

Debris flows usually start in high-gradient slopes with little vegetation, large quantities of material, and heavy rainfall. For instance, in the Dolomites, these events occur in the enormous debris fans at the foot of the highest mountains. In the Alps, they are caused by late summer storms, sudden emptying of reservoirs, or melting of snow and ice after fast rises in temperature above 0°C (a frequent phenomenon in autumn and spring).

Transport areas are characterized by channels with steep natural banks. Debris flow speed is between 0.5 and 20 m/sec.

In accumulation areas, natural banks join to form a final fan. Sediments are usually composed of inversely sized particles, i.e., coarse material is deposited on top of the heap. Debris flows stop when the liquid part (water, with clay and silt) separates from the flow and internal friction increases in the solid mass.

One of the methods used to stop these phenomena is to make debris flow across horizontal grids, which thus act as sieves, draining water from the mass.

The destructive power of the flood at Sarno (1998) was intensified by the enormous quantity of material carried downstream; after a few years, notwithstanding repair works, the large scar is still clearly visible

SADE and ENEL built artificial networks of deviations for hydroelectric and irrigation which led, for example, to radical hydraulic transformation of the basins of the Piave and Tagliamento, two of Italy's most important rivers after the Po.

The construction of dams involves various issues regarding forecasting and the use of reservoirs or other basins of water, proper dam location, characteristics of foundation soils, construction safety, etc.. Reservoirs must guarantee conditions of proper retention and stability. In the past, dams were made in masonry, then in concrete or reinforced concrete, or loose material (earth dams).

According to their static behaviour, dams may be divided into two groups, gravity and arc dams. The former resist hydrostatic loads by opposing their own weight. They are monolithic structures or made up of loose material. In the latter, the static function is achieved by transferring some of the total load on to the flanks of the narrow valley later to be filled. They are usually made in reinforced concrete and require careful geological surveys, as their foundations need to be supported by compact, stable, impermeable and resistant rock.

In Italy there are no longer any high dams made up of loose material. Of the concrete dams, the highest and most capacious ones are the Vajont dam (262 m) in the Piave basin, completed in 1961, the Alpe di Gera in Val Malenco in the Adda basin, with a capacity of 2.500.000 m^3, completed in 1965, and the Place Mulin on the Buthier (Dora Baltea basin) with a volume of 1,650,000 m^3, completed in 1965.

In the Alps, dams are generally built on magmatic or metamorphic rocks. The former include those built on tonalite in the Adamello group (e.g., Pantano d'Avio, 65 m), on granite at Cima d'Asta and Fortezza (e.g., Fortezza, 63 m) and porphyry near Bergamo and the Adige region (e.g., Forte Buso, 110 m). The latter are built on gneiss and schist of various compositions in the Lombard and Piedmontese Alps (e.g., Valle di Lei, 141 m; Frera, 138 m). Some dams are built on sedimentary rocks, mainly limestone and dolomitic limestone (e.g., Vajont, 262 m; Specchieri, 154 m; S. Giustina, 152 m).

The Appennines have less than one-third of all Italian dams, usually located near ridges. Sedimentary rocks outcrop along the chain, prevailing over igneous and metamorphic ones, so that most dams are built on limestone (e.g., Salto delle Balze di S. Lucia, 108 m; Fiastra, 87 m) or sandstone (e.g., Suviana, 96 m; S. Eleuterio nel Liri, 86 m).

Some dams are built on granite in the Calabrian Appennines or on metamorphic rock in the Ligurian Appennines.

Legislators are deeply concerned about stream waters because they may be exploited for the production of energy

■ Legislation

Mountain streams are public waters and belong to the Italian State, i.e., they cannot be appropriated or confiscated. The 1933 Water Consolidation Act confirms the priority of hydraulic law, of Latin tradition, over that deriving from new industrial rights; similarly, navigation and floating rights prevail over all others.

A milestone in determining water quality is law no. 319 of May 10 1976 (safeguarding drinking waters), which provides a series of reference values regarding pollutants.

Law no. 183 of May 18 1989 (functional and organizational implementation of soil protection), completed by successive provisions (law no. 253 of August 7 1990) and co-ordinative acts (DPCM of March 23 1990, DPCM of March 1 1991, DPR of January 7 1992) provide for innovative interventions in water management, to be carried out in the catchment basins. Authorities responsible for them become intermediary institutions between the State and the Regions (and autonomous provinces).

Law no. 36 of January 5 1994 confirms the importance of water resources, which must be exploited while safeguarding the expectations and rights of future generations. This law foresees the possibility that the waters of a certain catchment basin may not be sufficient to guarantee all uses planned so far, and therefore defines a minimum level of vital water flow to protect the equilibrium of nearby ecosystems, referring these duties to the competent authorities. Lastly, water is regulated by ensuring the priority of human over agricultural uses.

Today, many laws protect the quality of waters and their biodiversity. Previous laws, which only limited the amounts of pollutants in drainage (“Merli Law” in Italy), have recently been replaced by laws in accordance with European Community directives. In law no. 130 of January 25, 1992 (in accordance with EEC Directive 78/659 on the quality of freshwaters which must be protected and improved for the lives of fish), the concept of pollutant concentration in wastewater was replaced by that of concentration in the receptor. Further progress came with law no. 152 of May 11 1999, which protects waters against pollution; it provides for the use of macroinvertebrates as ecological “bio-indicators” of watercourses, and aims at protecting waters to be used by man (for drinking, agricultural, industrial or bathing purposes). But the most important law is probably 2000/60/EC of October 23 2000, of the European Parliament and Council, which provides for the management of waters on a European level (Official Bulletin L. 327 of 22/12/2000). In particular, Article 4

The spectacled salamander is protected by the EC Habitat Directive

states that, among “environmental objectives”, European Community member countries shall “adopt the necessary measures to prevent the deterioration of conditions of all surface watercourses”; “they protect, improve and restore all surface watercourses” to reach “a good condition of surface waters within 15 years from the moment the Directive came into force” (respite excepted); they adopt these measures… “to gradually reduce pollution caused by priority harmful substances and to stop or gradually reduce emissions, discharge and spills of priority harmful substances”; as regards streams, programmes concern “the proportion of water flow sufficient for ecological and chemical conditions and ecological potential”, as well as the monitoring of these parameters (“ecological and chemical conditions and ecological potential”).

These objectives complement those of the Habitat Directive (Directive 92/43/EEC of May 21 1992 of the Council, for the conservation of natural and semi-natural habitats and wild fauna and flora).

This Directive, which is regulated by presidential decree no. 357 of September 8 1997 and was first updated by the Council with Directive 97/62/EC of October 27 1997, provides for the protection of watercourses, forbidding the introduction of alien species and protecting those which are rare, endemic or at risk. The species listed in the Directive are mainly vertebrates; it is particularly important that mountain stream environments include marble trout - sub *Salmo marmoratus* - and macrostygma trout - sub *Salmo macrostigma* - together with many amphibian species such as spectacled salamander (*Salamandrina terdigidata*). Unfortunately, the Directive is still insufficient for invertebrates, as it only lists freshwater crayfish (*Austropotamobius pallipes*) and a few infrequent odonata. Although the Directive still needs implementing, it is now the most suitable law to protect the biodiversity of natural watercourses throughout the European Community.

■ Water diversions and hydraulic-forestry works: environmental impact

Watercourses are often constrained by embankments, dams and intake works, so that the water flowing in them is usually restricted to a rivulet or is totally absent. At first, what strikes us most is the presence of cement - unusual in a completely natural landscape - the desolate whiteness of dried-up stream beds, and the elimination of extraordinary natural events which are sometimes limited to short periods of time (some dams only open on August 15 - the Feast of the Assumption, and an important public holiday in Catholic countries - to produce waterfalls for tourists to see). These works do not only have a single impact on the environment, but produce a complex series of negative effects on the soil, the landscape, the use of the area, the hydrogeological order, the vegetation, and the river ecosystem. All of these effects - and other potential negative aspects - must be carefully taken into account when planning any kind of hydraulic works, as they may turn out to be so hazardous as to preclude their execution.

Impact on underground fauna. The most severe problem is the drastic alteration of underground water circulation. Streams are known to be composed not only of what is visible: surface water is only the tip of an iceberg, of a vast and complex underground circulation.

Losses beneath the river bed through permeable gravel on the bottom supply the watertable. Obviously, when water is pumped from mountain streams and diverted to usually

A mountain stream showing evident signs of human intervention

Minimum vital flow

Sergio Paradisi

The most obvious consequence of water diversion is a reduction in flow; when waters are totally diverted, drought often causes outlets to disappear completely. Partially or totally dried-up stream beds are easily colonized by vegetation which may hinder regular flow during floods, or require expensive maintenance.

Although these works do not necessarily take all the stream water, they do have serious consequences for aquatic ecosystems and their organisms. The downstream flow of high-altitude mountain streams may be reduced for sometimes lengthy periods - to such an extent that many organisms cannot survive at all. Recently, increased concern for environmental issues like minimum vital flow - the minimum quantity of water in streams which guarantees acceptable living conditions - has not only regarded those involved in works and an increasingly sensitive public, but also legislators.

Legislators have probably been prompted to act for economic rather than ecological reasons (e.g., tourist exploitation, fishing facilities), but the new laws certainly protect aquatic life. But whose life? This is not a rhetorical question, as differing hydrological conditions imply different organisms, and therefore a sufficient quantity of water does not guarantee the conservation of communities normally present in natural conditions. For fish, flow restrictions both reduce current speed, causing the death of highly rheophilous species, and raise the water temperature, favouring the substitution of salmonids with cyprinids.

As regards Italy, legislation covering minimum vital flow are Laws no. 183 of December 5 1989 (protection of soil), no. 275 of July 12 1993 (which modifies the consolidation act of 1933 on waters and hydroelectric plant) and no. 36 of January 1 1994 (which organizes water supply).

Only the last law covers "ecosystem equilibrium", and all of them only provide guidelines, without indicating the exact quantities of water flow. However, it is highly important that at least the concept of minimum water flow is embodied in these laws - not only from a cultural point of view, as guidelines must also be followed by regional measures.

A few Italian regions and autonomous provinces have already issued laws regarding these problems, although their proposals are not homogeneous.

It must be noted that there are many different methods for calculating minimum vital flows: they may be divided into theoretical methods or those using experimental variables.

One method adopts morphological or hydrological variables of the catchment basin or single stretch of water, exploiting data on flow, duration curves of flows, and quantity of rainfall.

Many regional laws anticipate the supply of a certain number of l/sec/km^2 of the catchment basin. Methods using experimental variables depend on hydrological, morphological and biological data, collected on the spot, by analysing the minimum vital flow.

Calculations determine if parameters obtained are compatible with the needs of one or more reference species, and gauge the flow which is most suitable for their survival.

Although these procedures are more complex and more costly to apply, they are certainly more precisely targeted and capable of supplying a better quantitative evaluation of the suitability of a watercourse to host certain animal populations in several differing types of conditions.

impermeable channels, the watertable loses water; this alters regular circulation and lowers piezometric levels.

The negative consequences on irrigation and drinking-water supplies are evident, but what is still little-known is the impact on phreatic water animals, i.e., those organisms which are exclusive to underground waters in alluvial soils. We have already seen that phreatic fauna is of enormous importance for its endemic and rare species which need particular protection.

Diverting the watertable and modifying underground flow may have unpredictably devastating effects on these delicate animal communities.

Impact on vegetation. The effects on vegetation may be direct and indirect. Direct effects are deforestation, excavations, and arrangements associated with works and their related infrastructures.

We often forget that the environmental consequences of diversions are not restricted simply to water loss. Retaining works and their necessary infrastructures (roads, electric lines, conduits, etc.), the large amounts of filling material which has to be organized, the passage of mechanized vehicles, the creation of building sites, and the discharge of inert material affect extensive areas, well beyond

A straightened and cemented stream stretch which has completely lost its natural aspect

stream beds. The environmental impact of all these works must be taken into account.

Indirect impact includes damage that such works cause to vegetation. Deforested areas, root damage, and deterioration of plant communities have negative consequences on the structure of vegetation and give rise to long-term modifications.

In valleys, climatic changes caused by the subtraction of water or creation of artificial basins (reservoirs) modify flora. Alterations in both surface and underground water circulations reduce the fertility and productivity of soils; the retreat, disappearance or destruction of springs damage areas which are highly important for their biodiversity and productivity.

Impact on macrobenthic and fish populations. The consequences of reduced water flow (which are obvious when water is totally diverted and causes the death of the entire resident communities), may be listed as follows:

1. Simplification of community structure. Although the numbers of organisms usually increase downstream from dams or other artificial structures, the numbers of their species decrease. When the “mosaic” of micro-environments is disturbed by reduced water flows, biodiversity decreases and tolerant species develop - phenomena similar to those caused by organic and chemical pollution.

2. Increased pollution and lower self-purifying power of watercourses. This is associated with reduced flow and simplification of resident animal communities, which decrease the numbers of organisms which recycle organic matter as natural watercourse purifiers. Watercourses with various, differing morphologies, natural banks, and beds with irregular particle size and suitable current speed usually host large numbers of animal and plant communities which contribute to the recycling of both decomposing matter and possible organic pollutants. Watercourses which are diverted or the flows of which drop below a certain level host simplified communities which cannot carry out their natural functions. Pollutants introduced in altered environments are not properly recycled, water quality deteriorates, environmental equilibrium is jeopardized, and so is human consumption of water itself.

The exploitation of streams for tourist purposes requires natural and unpolluted environments

3. Temperature ranges increase as waters become shallower, and this affects the biological cycles of many species. Each species carries out its life-cycle, particularly during its reproductive period, at a specific temperature. When the temperature of watercourses changes, the reproduction of resident species is endangered, giving rise to modifications in aquatic communities which usually lead to their simplification.

4. Variations in the structure of fish populations. As a consequence of the above-mentioned factors, fish communities, which are at the end of food-chains in watercourses, are disturbed by alterations and damage caused to spawning areas due to reduced flow. Watercourses become less hospitable and hinder the movement of fish in search of food or spawning sites. This implies reduced reproduction and deterioration of the environmental quality of watercourses.

Impact on the landscape and use of streams. The alterations listed above severely affect the aspect of the landscape. Modifications which may be predicted are controllable; otherwise, they are uncontrollable.

Controllable modifications are settling works and their infrastructures (as mentioned before), which usually have negative impacts on the landscape, and reorganization works to recreate that landscape (reafforestation, restoration, embankments), which are not attractive and do not enrich the environment.

Uncontrollable modifications occur later as a consequence of altered microclimatic, vegetational and also hydrogeological conditions (slope instability, endangered watertable, lowered springs).

One substantial negative effect concerns the recreational value of watercourses (fishing, tourism, canoeing, etc.), which also have economic consequences for the entire area.

■ Environmental impact of excavation of stream beds and reservoirs

Unfortunately, quarrying in mountain stream beds is very common and widespread. Excavations are not only occasional and limited to short periods for the creation of public works (roads and banks), but also include quarrying, which has a protracted, continual impact on watercourses. The main consequence is the release of fine, run-off gravel which is carried downstream. Fine material is released in such great amounts that the current cannot wash it all away, and it therefore accumulates on the bottom, compacts the substrate, and sometimes becomes as solid as cement.

Similar effects are also caused by the periodical cleaning of hydroelectrical reservoirs. Basins slowly but inexorably tend to bury themselves under the accumulation of silt and mud carried downstream, particularly in dammed valleys. Reservoirs downstream must therefore be periodically emptied and cleaned. If this is carried out quickly, debris flow may occur (see section on the hydrogeology of streams).

Many scientific works have recently described the direct and indirect negative effects of these operations on macrobenthic and fish populations.

The indirect consequences of the infilling of interstices are destruction of meio- and macrofaunal habitats and deterioration of salmon and trout spawning sites.

Watercourses downstream from these works contain both impoverished benthic communities with reduced self-purifying powers (which therefore tend to be polluted), and also smaller fish populations. If works are particularly intense and protracted for lengthy periods, there are also direct effects, whereby the gills of fish and invertebrates become obstructed, causing death.

The indirect effects caused by the infilling of interstices are the most severe and take years to solve.

■ Introduction of alien species

An alien species: American crayfish (*Procambarus clarkii*)

Species which do not belong to the original fauna of a certain area are called alien (or exotic, or allochthonous). Unfortunately, their introduction has recently become a frequent phenomenon. In mountain streams, introduction may be accidental (i.e., involuntary) or controlled, i.e., for restocking for fishing purposes. In both cases, the consequences on the original ecosystem may be devastating. Accidentally introduced alien species are those which have escaped from fish-farms or been involuntarily introduced by man (often in fish-farms themselves). Recently, one of the most dramatic phenomena occurred in Piedmontese mountain streams with the introduction of American crayfish (*Procambarus clarkii*). Initially, this species was imported for farming purposes, but was then abandoned because it was unprofitable. However, these crayfish accidentally and successfully spread in watercourses owing to their great adaptive capacities and large size. Now, at the top of the food-chain, they are super-predators with no natural enemies, and have quickly and inexorably colonized large areas in Italy (Liguria, Tuscany, and Emilia Romagna, even in the valleys). Their devastating effects regard not only the species they prey on, but the food-chain of the whole ecosystem.

There are many fish species which are introduced to restock streams. This is usually carried out both to satisfy people who fish for sport and to repopulate stretches impoverished by floods or man’s intervention (today, most embankments prevent fish from swimming upstream).

These introduced species are not only alien, but also individuals of indigenous species from fish-farms, which are genetically different from the original ones: this phenomenon is called “genetic pollution”. Indigenous species develop from complex natural selection and are suited to the environment, whereas outside genetic breeds may have various problems, especially as regards health.

Today, the introduction of any “non-local” species is forbidden by Art. n. 12 of

Fish ladders

Sergio Paradisi

Fish ladders were created for fish to avoid obstacles (not always artificial) which prevent them from reaching their spawning areas. Initially, these works were carried out for economic rather than naturalistic reasons, so that the first fish ladders were built where the reproduction of commercially valuable species, like salmon, had to be protected.

Italian freshwater fish species have never been profitable: this is why these structures were created only recently, and their construction - unlike the situation in other countries - is not subjected to any law.

In countries where fish ladders have been built for many years, analysis of their practical use has given rise to two main types: fish (or cross-sectional) ladders. and slowing fish ladders (also known as Denil ladders, from their inventor's name).

In the former, gradients are split up into a series of degrading pools supplied by waterfalls. Pools must be sufficiently large both to shelter and protect the fish and to absorb the kinetic energy of falling water.

Denil fish ladders are high-gradient channels (up to 20%), the bottoms and banks of which are covered with variously shaped baffles to reduce current speed.

Obviously, fish ladders must be designed with the physical characteristics of fish in mind, although this apparently evident fact is not often considered.

Splitting up the section into many steps with reduced gradients and slower currents is not enough; knowledge of the migrating behaviour of fish and their swimming capacities (particularly forward thrust and resistance) is essential, otherwise artificial works are useless.

The maximum swimming speed of a fish (also called propulsive thrust, which can only be sustained for short periods) is attained by contraction of its white (anaerobic) muscle tissue.

When a fish swims at slower speeds and for many hours, it uses its red (aerobic) muscles.

The maximum swimming speed of a fish may be calculated with formulas which relate the contraction period of white muscle with the length of the fish. Contraction periods depend on temperature: cold muscles contract more slowly than warm ones.

Resistance is also calculated with formulas, and again depends on the length and temperature of the fish.

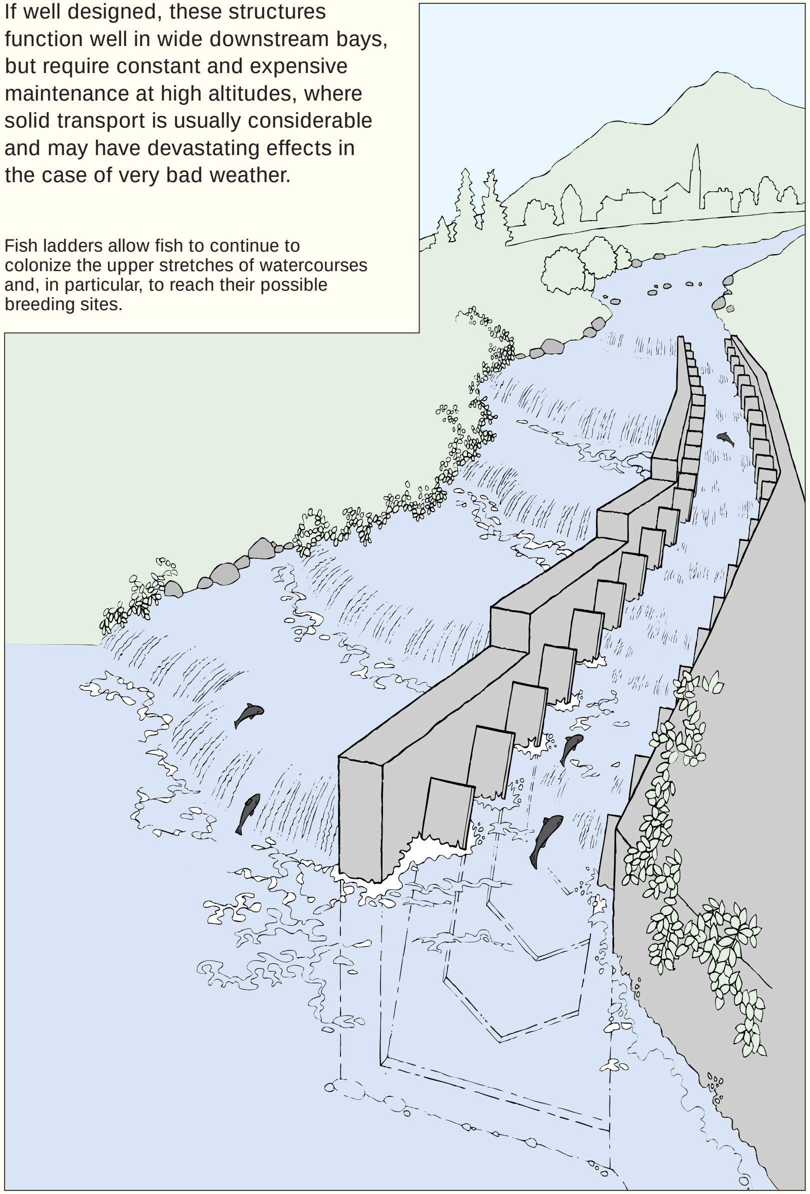
This means that, if two specimens are the same size, the warmer one thrusts forward more quickly but is less resistant; if they both have the same temperature, the larger one is more resistant.

All fish ladders built so far take these physiological characteristics of fish into account.

However, projects must also contemplate other aspects, such as the flow capacity of the structure, easy access to its point of entry, and attractive features which must induce migrating fish to swim towards them as soon as they recognize them at a distance.

These structures require competent workmanship and large investments, which may be reduced if construction of fish ladders does not follow that of dams, but is carried out at the same time.

If well designed, these structures function well in wide downstream bays, but require constant and expensive maintenance at high altitudes, where solid transport is usually considerable and may have devastating effects in the case of very bad weather.



Fish ladders allow fish to continue to colonize the upper stretches of watercourses and, in particular, to reach their possible breeding sites.

presidential decree no. 357 of September 8 1997. Introductions which are not sustained by valid scientific purposes and related research work and which have not been previously authorized by the Italian Ministry for the Environment and Territory Protection are subject to prosecution.

■ Pollution and the biological quality of waters

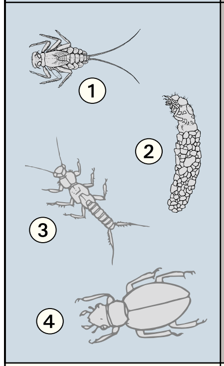
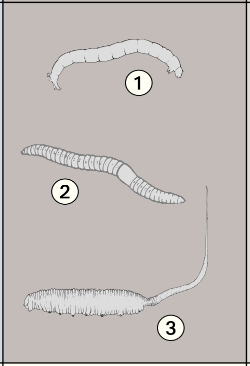
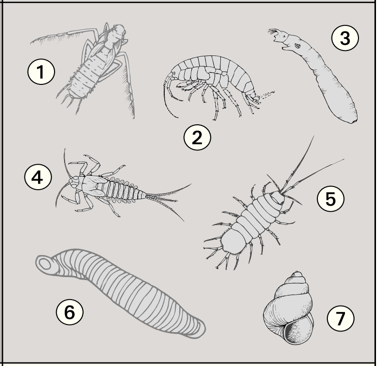
Although mountain streams seem to be less polluted than those in valleys (more populated and industrialized areas, where agricultural exploitation is also more extensive), this issue must not be underestimated - especially in Alpine streams, where valleys are easily reached by man. However, if we consider pollution as any form of deterioration of watercourses (aesthetic, mechanical or chemical), then most Alpine streams are severely polluted.

As regards the classic forms of pollution, i.e., organic and chemical (urban, industrial, animal farming waste, etc.), invertebrate communities in streams may be affected both directly and indirectly.

Direct effects are brought about by toxic substances which affect aquatic organisms by poisoning and killing them. Macroinvertebrates are usually good bio-accumulators, i.e., they accumulate particular toxic substances in their tissues, with the result that only specific links in the food chain are involved. Indirect effects are more subtle, like chronic organic pollution. As regards quality, they change the specific components of animal and plant communities, and the most sensitive species die out. Fauna is therefore simplified and composed of tolerant species, with large ecological valence. Instead, quantitatively speaking, the most tolerant species have greater biomasses and reproduce in large numbers due to increased food availability and lack of predators and competitors.

Invertebrates may therefore be considered excellent indicators of environmental conditions and are often used in determining the pollution rate of watercourses, also called *biological quality*. This term refers to the integrity of ecological balances in watercourses. Pollution usually deteriorates microhabitats which host aquatic organisms and modifies the quantity of dissolved nutrients, and chemical substances may even have direct toxic effects. This has negative consequences on macrobenthic communities, which are qualitatively and quantitatively modified. Overall, the specific diversity of the community decreases, and this affects the whole food-chain negatively.

Evaluation of the biological quality of waters is based on the value of living organisms as biomarkers. Many biological methods have been devised for this

UNPOLLUTED ENVIROMENT	POLLUTED ENVIROMENT	LOW POLLUTED ENVIROMENT
		
1. ephemeropterans 2. trichopterans 3. plecopterans 4. hydraenid coleopterans	1. chironomids (larvae) 2. oligochaetes 3. syrphid dipterans (larvae)	1. trichopterans 2. gammarids 3. simuliid flies 4. baetid ephemeropterans 5. asellid isopods 6. leeches 7. gastropods (snails)

Invertebrates are markers of the biological quality of upstream, downstream and nearby polluted stretches

The crystalline water of a mountain spring flows into milky meltwater purpose, and divide organisms into various taxonomic categories or structural levels. The most commonly used methods are applied to benthic macroinvertebrates (which are invertebrates trapped by a 500-µm net and are therefore longer than 1 mm) and have been adopted by the European Community.

Study of benthic macroinvertebrate populations to determine biological quality produces a *biotic index*, i.e., a number which diagnoses the deterioration of natural balances and which is associated with the degree of pollution of a watercourse. As the pollution degree increases, the species which are sensitive to environmental quality gradually decrease and, when pollution reaches a certain threshold value, some taxonomic groups (whole families or genera) disappear completely. Instead, tolerant species take advantage of this situation, which implies increased food availability and reduced competition. The more degraded the water quality, the more the community composition changes. As there are few tolerant species, there is little biodiversity.

Since the early 20th century, many practical methods have been devised to obtain these indexes, which are subdivided into two groups: in the first (called the *Saprobien-System* by German scientists), attention focuses on the sensitivity of certain taxa to increased organic pollution; the second (true biotic indexes, such as the Extended Biological Index - E.B.I. - used in Italy), takes into account both the value of some taxa as biomarkers, and the numbers of systematic units (families or genera) in a community. Italy has recently adopted an integrated index especially created for highly oligotrophic Alpine streams (Extended ratio index, "*Indice a rapporto esteso"*, I.R.E.). This method is based on the number of families belonging to four categories, according to their sensitivity to pollution (it does not include the total number of taxa, which varies according to the differing habitat structures).

The commonly used E.B.I. is based on the families or genera (according to systematic group) of macroinvertebrates trapped in a stream stretch by a fine-meshed net. The ratio between the sensitivity of identified taxonomic groups to pollution and their numbers collected at the sample station yields a number which, in Italian waters, ranges between 0 (poor-quality, poorly oxygenated waters) and 13-14. However, these values are difficult to interpret, as clean waters may have E.B.I. values which vary according to habitat diversity. Higher E.B.I. values do not necessarily imply better-quality stream stretches with respect to those with lower E.B.I. values. Indexes may provide dubious results in the case of impoverished populations (particularly in high-altitude streams and springs).

The I.R.E. is a simple integration of the quality values which has been especially devised for these environments. It requires determinations at family level and ranges between 0 and 11. The value 11 indicates the best possible biological quality of a certain environment, and is independent of the number of taxa. Biotic indexes estimate the quality of waters with reference to conditions of ecosystem conservation. Copying these values on a coloured map, which has considerable visual impact and is immediately comprehensible, is called *biological quality mapping*. The map provides an immediate picture of the health conditions of catchment basin watercourses, highlighting their critical features.

In research on biological quality, mountain streams must be considered as units, and their interrelations with the surrounding natural environment must be taken into account

In Italy, biological indexes have recently been implemented by the Fluvial Functionality Index (F.F.I.). This method provides rapid evaluation of fluvial functionality, precious information about the causes of deterioration, and also precise indications on re-qualification and rehabilitation operations with estimates of their efficiency. This method is particularly interesting because it evaluates river ecosystems thoroughly, including their interrelations with the surrounding environment. The application of the F.F.I. does not require sophisticated instruments, and is carried out by means of a simple questionnaire. However, *simple* does not mean *banal* - it is in fact a guide to true ecological investigation of watercourses.

Suggestions for teaching

MARGHERITA SOLARI

Young people may find mountain streams very interesting, as water is often associated with summer leisure activities. Streams are particularly fascinating because they imply exploration of wild areas, isolated valleys or mouths of streams which are difficult to reach.

However, these environments may be inhospitable, and it is therefore hard to appreciate them. Their study unfolds less evident or perhaps totally unknown aspects and secrets.

These sections are devoted to those who want to convey their commitment to the study and preservation of the environment and would like to encourage children to discover mountain streams.

Another teaching proposal which could be applied to this environment may be found in the book “Springs and Spring Watercourses”, of this series, under the title “Use of macroinvertebrates as biological indicators in spring watercourses”. Simplified application of E.B.I. indexes.

■ Study of a stream in its mountain stretch

- Objectives: to stimulate the study of the environment, to promote respect for it and to protect it; to encourage study through bibliographic research and on-site explorations; further research, experimentation and testing of theoretical notions; to promote accurate observation, analysis and comparison of data and interpretation of observed natural phenomena; to make children aware of the constant evolution of the environment in the places they visit.
- Level: boys and girls of 13-16 years of age; a simplified version of this work may be adopted with younger pupils, by reducing preliminary study and concentrating excursions on easier aspects.
- Equipment: trekking boots and spare clothes for the excursion. Cameras. Compasses. Possible equipment for water analyses.
- Information: further information on tracks to follow is available at CAI (Club Alpino Italiano = Italian Alpine Club) offices, together with informations on the availability of topographic maps.

Fontanon di Barman spring, Julian Prealps (Friuli)

Impetuous stream waters forge ravine walls

PRELIMINARY STUDY

1. Identify a natural stream the course of which may be viewed almost entirely, accessible to the group without difficulties: the route must be safe and easy to evacuate, without cliffs or falling stones (avoid ravine areas).
2. Ask students to find written sources or maps, even historical ones.
3. Study topographic maps on an appropriate scale (preferably 1:5000 or 1:10,000 enlarged). During classwork, students should do individual work on photocopies of the map; marking of catchment basin limits, tributaries and secondary branches, possible hydrographical symbols such as springs, wells, conveyors, marshes and glaciers, or reliefs like wedges, cross-hatching, etc. which identify rocky flanks, sharp bends, etc.
4. Cartographic or bibliographic research of possible supply of water sources such as perennial snow, glaciers, artificial basins, channels or overflow of nearby conduits.
5. Research on seasonal rainfall trend: hypotheses on maximum and minimum flow (the concept of flow must be explained in advance). Choose two periods in the year for the excursion, in order to see the environment in very different situations.
6. Study a geological map and extrapolate data, with particular reference to rock type, debris deposits on flanks, landslides, etc..
7. Draw up a survey form (or ask students to do this) which should contain, for example, presence of reinforcements or banks, mean width, flank gradient (low, medium, high), vegetal cover of flanks (rock, loose debris, meadow, shrub, forest); stretches undergoing erosion or accumulation; particle size and main rocks in the stream bed; presence of large stones and hypotheses on their origin, presence of waterfalls or pools.

Visiting a stream

ESCURSION

8. In groups, survey three or four stream stretches (or on the same one, to compare them later); mark analysed stretch on cartographic map and direction of flow with regard to north.
9. Photograph stretches and identify points from which photos were taken and length of stretch.
10. Collect other unexpected data: possible presence or traces of animals, waste or dumped substances, influence of human intervention, etc..
11. Analyse stream waters: temperature, pH and conductivity (with specific instruments) and hardness, chloride and phosphate contents with appropriate kits.

FURTHER CLASS WORK

12. Compare data and prepare a report describing the analysed stream. Both report and photographs should give a precise description of the stream at a particular moment in time.

SECOND EXCURSION

13. This should be organized, if possible, in a season characterized by different water flow, or after floods or intense rainfall.
14. Repeat group survey.
15. Compare data and analyses, particularly as regards flow, regime, accumulation or deposits on topographic maps.
16. Photographs should be taken in exactly the same spots as the previous time.

CONCLUSION

17.Prepare a conclusive report. Identify factors which determine variations in the environment, such as climate, more or less erodible substrates, man's intervention, landslides or natural barriers, etc..

18.Discuss the need to protect the integrity of the environment for future generations, considering that a certain number of variations are due to the natural evolution of that same environment, which changes constantly.

NOTES

If this study is carried out over a long period (more than one year), it will yield better results. However, even the study of minor aspects carried out over one school year is more effective and interesting for students, who must work harder over a shorter period of time.

Map of a mountain area, in which straight stretches of a stream are determined by the tectonic of the zone

Streams are essential characteristics of mountain landscapes

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Glossary

> Accessory pigments: pigments which absorb energy from light and transfer it to chlorophyll, which uses it for photosynthesis.

> Allopatric: two species are called allopatric when their areas of distribution do not overlap.

> Allochthonous: an extraneous organism, originating from a place different from the one in which it is found; the terms “alien” and “exotic” are often used as synonyms.

> Anther: the upper part of stamens, where pollen granules form.

> Autochthonous: originating in a particular place; “indigenous” and “local” are often used as synonyms.

> Catkin: spiciform inflorescence which may be variably dense, hanging or erect. Its very small, unisexual flowers are arranged on delicate filaments and have small, involucral organs. Seeds are generally carried by the wind.

> Crenobe: an organism exclusively found in the sspring environment, e.g., many watermites and microcrustaceans.

> Detrivore: organism which feeds on debris, i.e., fine or coarse organic matter derived from other dead animal or vegetal organisms.

> Endemic: a species is endemic when it is distributed in a restricted area; endemic species are highly important for the protection of regional fauna.

> Hygrophilous: organisms which live in damp environments.

> Macroinvertebrates: invertebrates which are usually larger than 1 mm and are trapped by a 0.5-mm net.

> Nitrogen fixation: a biochemical process by means of which certain bacteria and cyanobacteria use molecular nitrogen from the atmosphere, assimilating it into organic compounds.

> Orophilous: mountain-loving organisms.

> Oxygenic photosynthesis: a kind of photosynthesis which characterizes cyanobacteria and all eukaryotic plants. It uses water as hydrogen donor and releases oxygen.

> Ozonosphere: ozone-rich layer of the atmosphere between 15 and 50 km above the Earth's surface, which absorbs UV radiation.

> Photoprotective pigment: a coloured substance capable of shielding organisms from potentially harmful components of light (particularly UV-A and UV-B rays).

> Phreatic water animals/Phreatic: stygobitic organisms (see stygobites) exclusive to interstitial water environments, where they spend all their life-cycle; among their particular adaptations they have no eyes, are depigmented, with worm-shaped bodies and highly developed senses.

> Phreatobites: organisms which are frequently found but are not exclusive to interstitial environments where they reproduce; many insect larvae are phreatobytic during their juvenile stages; a few organisms feature adaptations to life in these environments (euphreatophyles).

> Phreatoxene: an organism only occasionally found in interstitial waters.

> Primary production: the total amount of energy in plant tissues.

> Sympatric: two species are called sympatric when they live together in portions of their areas of distribution; if the two species are collected together at the same sampling station, they are called “syntopic”.

> Stygobites: organisms which typically live in subterranean waters and thus contrive special adaptations to dark environments with few resources (depigmented, they have no eyes but enhanced senses).

> Thallus (thallose and thallophyte): a plant, the structure of which is not divided into roots, stem and leaves.

> Taxon (pl. taxa): any formal taxonomic category (e.g., class, order, family, genus, species, subspecies, etc.).

> Vascular plant: a superior plant (like ferns and plants producing seeds), with well-differentiated vascular tissues.

List of species

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