MALHAM TARN

A BACKGROUND FOR FRESHWATER BIOLOGISTS

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MALHAM Tarn lies in a small basin with steep limestone cliffs and slopes to the north, at a height of 1,229 ft. above sea level. Its short inflow stream arises from springs near the base of the Great Scar limestone, and presumably not far above the impervious Silurian "slates" which the geological map shows underlying the southern half of the Tarn. Some low morainic hills at this end must once have ponded up the water, which probably overflowed at that time eastwards towards Great Close Mire and Gordale before an outflow was breached through the moraines at the southern corner of the Tarn. The present outflow stream flows overland for about 500 yards before disappearing underground, after crossing the North Craven Fault. Shortly after the Ice Age the level of the water in the Tarn must have been much higher than it is today, as is shown, for example, by the height of the gravel delta on which Miss Hilary's cottage is built. Even after the water level had fallen considerably it must have been nearly twice as large as it is now, so as to include the whole of the area later occupied by the Tarn Moss. The latter is, in fact, a typical raised bog formed in the old western half of the Tarn, and borings through the peat reach ultimately a shelly calcareous mud on top of lake clay. The level of the Tarn was raised artificially in 1791, when the estate was owned by Thomas Lister, who later became the first Lord Ribblesdale; a sluice gate, slipway and embankment were constructed at the southern end which seem to have raised the level about four feet. This raising has caused a rapid cutting back of the peat on the Tarn side of the raised bog, so that the west shore of the Tarn is now a vertical peat bank up to 15 ft. high—an unusual feature to find by a calcareous water. In one place along this shore the cutting back has exposed what may have been a small island of boulder clay, which was eventually buried beneath the peat and is now partly exposed again to give a short stretch of stony shoreline.

The present Tarn is 153 acres in extent and very shallow; the maximum depth so far recorded is 14 ft., while most of the offshore parts are between 6 and 10 ft. deep. It has undoubtedly been much deeper and is now

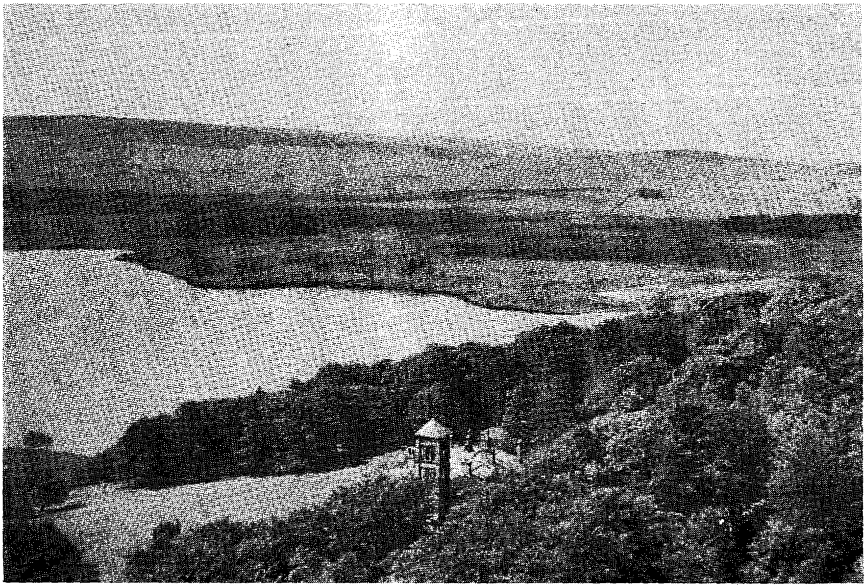

Photo: C. A. SINKER

PLATE I. North-west corner of Malham Tarn, showing the western peat bank, Tarn Moss and inflow stream

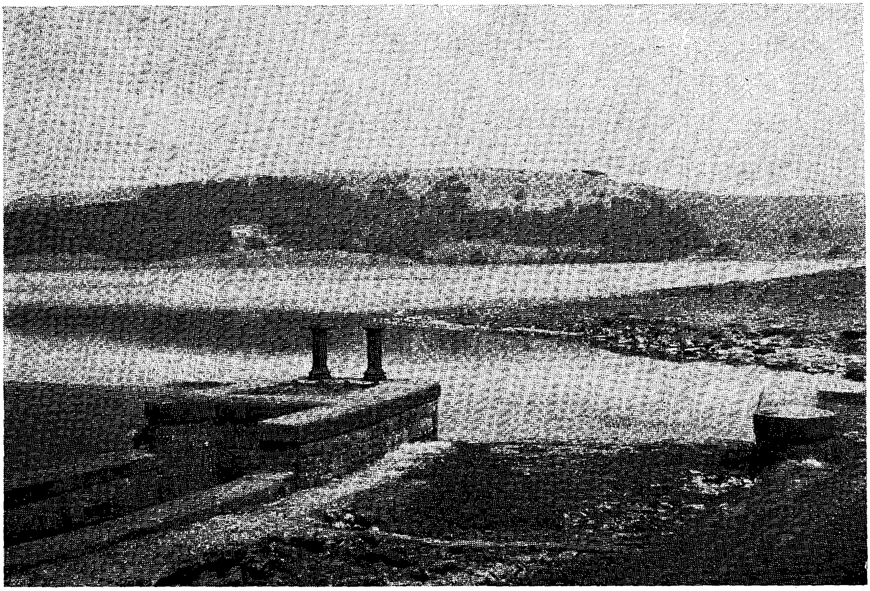

Photo: C. A. SINKER

PLATE II. View of Malham Tarn from the sluice gate and slipway. South-east shore of glacial drift on the right

Photo: Y. M. KERSHAW

PLATE III. Malham Tarn, north shore of stones and boulders

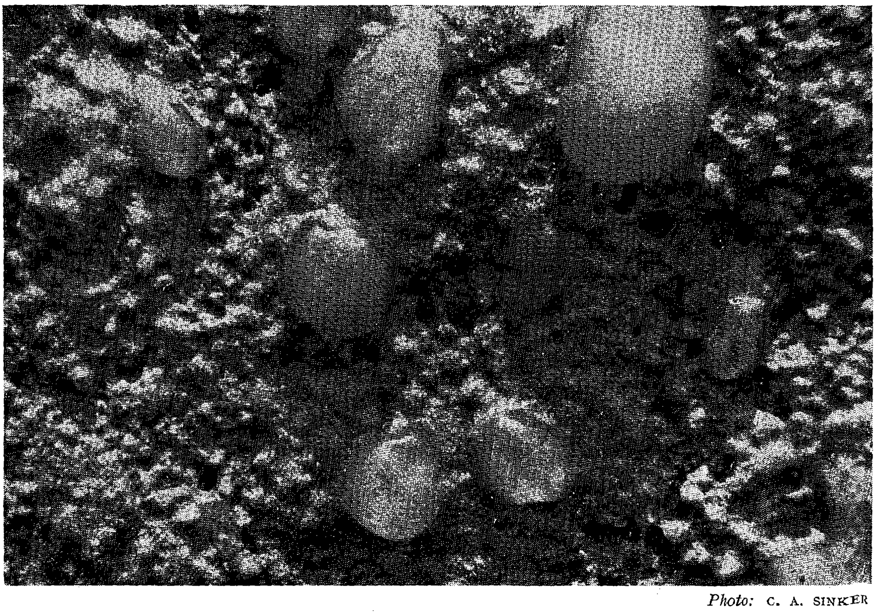

Photo: C. A. SINKER

PLATE IV. Close-up of surface of stone showing colonies of *Ophrydium* (blobs of jelly), irregular incrustation of *Rivularia* and occasional galleries of *Tinodes* rapidly silting up with suspended matter brought down in flood and particularly with organic remains. Owing to the shallowness and the exposed position of the Tarn, there is likely to be thorough mixing of the water by wind at all seasons; no sign of a thermocline, or vertical temperature discontinuity, has ever been detected. Light penetration is adequate for plant growth at all depths, since the plankton never gets really thick.

The shorelines vary according to the nature and gradient of the shore and to the degree of exposure to winds, though the general slope is very gentle in conformity with the shallowness of the basin. Along the north and north-east shores there is limestone not far down, but with a variable depth of drift and scree debris over it; wave action here has produced a mixed shore of large boulders and stones of varying sizes (Plate III). The southern and south-eastern shorelines have been produced by the erosion of glacial drift only, and they vary according to the local nature of that drift: there are two small embayments with sandy shores where the drift is derived from sandstones, and a few patches of shingle, but mostly the shores there are made up of stones of limestone and so do not differ greatly from the north shore. On the western side, as already mentioned, a vertical peat bank forms a marked contrast. All these shores are exposed to the scouring effects of wave action at one time or another, and there are in fact only two small bays sufficiently sheltered from the wind for sediments to accumulate: one is the inflow bay and the other is on the eastern side near Great Close Scar. Here beds of sedges, predominantly *Carex rostrata*, are established, with a zonation of other marsh plants on their landward side.

Where the slope of the ground is neither too steep nor too gentle, a small wave-cut platform has been formed just offshore, which is best developed on parts of the northern side of the Tarn. On these flat areas small stones are mixed with calcareous gravel and mud, or sometimes with clay from the drift. On the offshore side of such a platform, however, lies a wide zone of stones and boulders, which is similar to that of the present-day shore. This zone must represent the pre-1791 shoreline, before the level of the Tarn was raised, and it shelves steeply into deeper water. In times of calm low water the outline of this old shoreline can be clearly seen as a series of big boulders underwater, lying along the edge of the shelf. Where the slope of the shore is steeper, or perhaps where there is less drift, the two shorelines are contiguous, with no platform between them; while along parts of the east shore there is only a very slight slope of the land down to the water's edge and the bottom shelves very gradually away from it. From the western peat bank a fairly level underwater platform of peat, pitted with hollows, extends outwards for some distance, representing the amount that the edge of the Moss has been cut back in the last 165 years.

The effects of high alkalinity on the flora and fauna constitute some of the most interesting aspects of the biology of the Tarn. Regular fortnightly water samples were sent for three years, from 1949 to 1951, and monthly samples for the next two years, to the Freshwater Biological Association at Windermere. A summary of the results of the water analyses, carried out by Mr. F. J. Mackereth, is shown in the following table, compared to similar figures for Windermere; and the outstanding difference can be seen to be the high alkalinity values for the Tarn, estimated as calcium carbonate in milligrams per litre.

	Malham Tarn		Windermere	
	Max. (mg./l.)	Min. (mg./l.)	Max. (mg./l.)	Min. (mg./l.)
Silica	2·6	0·18	2·5	0·2
Nitrate nitrogen	0·36	0·01	0·40	0·04
Phosphate phosphorus ..	0·0025	0·001	0·004	0·001
Alkalinity	142	62	10	6

The concentration of calcium carbonate was found at certain times to be reduced by as much as half between the inflow and outflow streams. There is some doubt about the actual means by which lime is "removed" from the Tarn Water. Precipitation of calcium carbonate is usually brought about by the loss of carbon dioxide: this can occur through a rise in temperature, and the Tarn water in summer is several degrees warmer than the inflow stream. Carbon dioxide is also extracted by living plants: the leaves of *Potamogeton lucens* bear a thin coating of calcite crystals, *Chara* plants are encrusted with lime, and *Rivularia* forms solid knobs of it; probably the phytoplankton, too, plays an important part in the precipitation of lime which accumulates with the organic mud on the bottom.

In the deeper water off the old shoreline, much of the bottom is composed of this black organic mud, derived from the decayed remains of plants and animals. Rooted in the mud are extensive beds of the stonewort *Chara delicatula*, which densely covers perhaps a third of the bottom and forms the most productive animal habitat in the Tarn. Here also are rooted large patches of the emergent *Potamogeton lucens*, which seems to have spread considerably in the last fifty years, and of *Myriophyllum spicatum*. The positions of the *Potamogeton* patches vary surprisingly from year to year, and one supposes that the plants must sometimes be uprooted during high winds before the summer growth has died down; the largest single bed in 1954, in the middle of the Tarn, has for example been quite untraceable during 1955. Other *Potamogeton* species do occur, though in smaller quantities: *P. berchtoldii* mainly on the outer edge of the shelf, *P. perfoliatus* in one or two isolated deep-water beds, and the hybrid *P.* × *nitens* in the inflow bay. Several other species and hybrids have been recorded in the past, but few of them seen in recent years (1). In shallower water, and especially on the wave-cut platforms, a smaller stonewort, *Chara aspera*, is rooted among stones and pebbles, and it also colonizes rather sparsely the peat platform off the west shore. The aquatic moss, *Fontinalis antipyretica*, is frequent on the stones of the shoreline and scattered specimens are found at all depths wherever there are suitable stones for its attachment.

Completely submerged littoral stones are often modified by growths of the Blue-green alga *Rivularia*, which forms considerable incrustations of lime on their upper surfaces, so that they have a knobbly appearance (Plate IV). This breaking up of the smooth surface of a stone has important effects on the fauna, making it possible for a small animal to wedge itself in, and in the Tarn these stones are the usual habitat for the gallery-forming caddis larva of *Tinodes dives*. During the summer months most of the littoral stones become colonized, to a greater or lesser extent, by filamentous green algae of several genera, of which the commonest are *Spirogyra*, *Ulothrix*, *Zygnema*, *Mougeotia* and *Cladophora*. The luxuriance of some of these is strikingly increased where trees overhang the water, as on parts of the north shore; this is probably some kind of manurial effect. An even more convincing case was demonstrated this summer, when a bright green ring of filamentous alga developed round a sheep which had died on the edge of the water. An interesting alga present in the Tarn is *Cladophora sauteri*, which exists in the form of unattached balls of radiating filaments. They rest on the bottom, reaching the size of golf balls, and keep their shape by being gently wafted to and fro in the moving water. In the autumn many of these balls get washed inshore or into the boathouse, where they entangle fallen larch needles and in this way can sometimes reach the size of a grapefruit.

Very characteristic of the Tarn is the spectacular growth of epilithic and epiphytic diatoms on littoral stones and filamentous algae. Early in the spring the stones become brown from the growth of these plants, and later the bright green of fresh filamentous algae is turned to brown in the course of a few days by their rapid multiplication. On the other hand the bottom-living algal flora, on the mud, peat, or calcareous deposits in the Tarn, is poorly developed; this flora has been studied by F. E. Round from samples sent to him during 1949 and 1950 (2). Many species which might be expected from a study of other lakes are absent, and it seems likely that only a restricted number of species are tolerant of the high calcium carbonate concentration which exists. Plankton production is also low, and Round suggests that this development of epilithic and epiphytic communities, at the expense of planktonic and benthic ones, may perhaps be regarded as one of the characteristics of this kind of calcareous water.

The rocky and stony shores of the Tarn provide a great variety of microhabitats for small invertebrate animals to live in, and a correspondingly large number of species can be found here. These shores are exposed to wave action at most times and therefore, except during rare spells of calm weather, most of the fauna will be found only by stone turning (Plate III). Conditions on these shores are similar in some respects, such as water movement and good oxygenation, to those in streams, and this is reflected in certain elements of the fauna which are common to both—Crayfish, Bullheads, River Sponge, River Limpet, *Polycentropus* and *Ecdyonurus* are examples. Conditions for animal life in the sheltered sedge beds are completely different, however, and there is a very distinct fauna there; calm water makes it possible for *Gerris asper* to live on the surface film, while vegetable debris and mud form a soft bottom in which other animals can burrow. Oxygen supplies here may get depleted.

Where the stones of the shore are more uniform or smaller, the number of species which can exist is reduced. The peat bank is a very inhospitable place for animals when the waves beat up against it, and it is not suitable for burrowing types. During calm spells or prolonged periods of westerly winds some invertebrates may migrate on to the peat, and we have seen vast numbers of the minute Corixid *Micronecta poweri* there; but at other times it is difficult to find a single animal.

Away from the shores, animal life is most abundant in the weed beds and the mud underneath them. It is here that most of the Mollusca live, and indeed attain their greatest size. Each type of plant has its own animal community or "facies", though only a few specialized animals are restricted to them; the larvae of the beetle *Macroplea appendiculata* are found only on the roots of *Potamogeton* and *Myriophyllum*, and a leaf-mining fly only on the leaves of *Potamogeton*. The beds of *Chara delicatula* have a very characteristic fauna, which includes large numbers of the bivalve *Sphaerium corneum* and the larvae of two caddis flies (*Phryganea obsoleta* and *Limnophilus politus*), making their cases of *Chara* fragments. The bare mud away from the weed beds, on the other hand, has a fauna of burrowers which is distinctly sparse compared with that of the bottom muds of many other lakes. Rough counts with a Peterson Grab have given populations of between 300 and 450 animals/sq. metre, at a depth of about 10 ft.

In an article of this length it is only possible to mention some of the more interesting features of the fauna. As might be expected in a calcareous water, there is a large Molluscan population: fourteen species of water snails and ten species of small bivalves have been recorded from the Tarn, the fen at the inflow end and the outflow stream, and this is the highest known locality in Britain for quite a number of these. Nine out of the sixteen known British species of pea-mussels (*Pisidium*) have now been identified, two of which were added during the Mollusc course in 1955. An account of the Mollusca of this district, including the Tarn, is due to be published in the Journal of Conchology by Mr. L. W. Stratton. A recent colonizer is the snail *Potamopyrgus* (*Hydrobia*) *jenkinsi*, which apparently reached the Tarn in 1949 or 1950. Since then it has spread rapidly from its original site of colonization in the inflow bay and now extends half way along the stony north shore and the *Chara aspera* zone, where its numbers may reach over 1,000 per sq. ft. There seemed no reason why it should not spread right round the Tarn, but it appeared to be halted at a headland below the house, where the bottom slopes sharply into deep water. In an attempt to find out what in fact was stopping them, 2,000 individuals were "planted" round this headland in 1954 and it remains to be seen how they spread from here.

Caddis flies and their larvae are another striking feature of the Tarn fauna, in both numbers and variety. I have collected over thirty species from the Tarn itself and several of these, such as *Mesophylax impunctatus*, are distinctly rare elsewhere. One peculiar Caddis, *Agrypnetes crassicornis*, had not previously been recorded from Britain, and it has a curious known distribution with records from Finland, N.W. Mongolia, Caucasus and Malham Tarn (3). Mayfly larvae, on the other hand, are very uncommon, with the exception of the silt-dwelling *Caenis honoraria*; there is no *Asellus*, and phantom midge larvae (*Chaeborus*) are absent, though they occur in acid peat pools on the Moss only 300 yards away. Chironomid midges are an important element of the fauna, but their taxonomy is so difficult that little detailed work has been done on them; the most spectacular hatch of the year is of a big *Chironomus* in late May and early June.

Two species of freshwater shrimp occur, the common *Gammarus pulex* and the rare *G. lacustris*. When the latter was first recorded from the Tarn (4) this was its only known locality in England, though it had been found in Scotland and Wales, and it is interesting to have the two species in one water. There seems to be a rough habitat distinction between them, with *pulex* on the shorelines and *lacustris* in deeper and more sheltered water.

Countless colonies of the ciliate protozoan *Ophrydium* appear each year, towards the end of May, as small greenish blobs of jelly attached to stones in about 1 to 2 ft. of water, mainly along the gently shelving parts of the East shore (Plate IV). The colonies grow through the summer, sometimes to the size of a penny, and then in August they get detached from the stones during a strong wind and large numbers are washed inshore. Here the blobs of jelly persist for some time and passers-by think they are freshwater jellyfish.

The only two species of large fish in the Tarn are trout and perch, which have probably been there at any rate since the twelfth century, when "Malewater and the fishing thereof" was granted to the monks of

Fountains Abbey by William de Percy; his daughter Matilda, Countess of Warwick, confirmed in 1175 that "they may fish in Malhewater". Bullhead and stone loach are common on the stony shore, and sticklebacks abundant in some years though scarce in others (1955). Only occasional shoals of minnows are seen, but the individuals are often large, up to 9·8 cm. It is difficult to see how any of these fish could have colonized the Tarn naturally, with the impassable barriers of Malham Cove and Gordale falls, and the large species at any rate must have been introduced by man at some distant time. This also applies to the crayfish which now thrive in the Tarn; these were apparently introduced into the Dales in the sixteenth century from the South of England.

The trout are partly Brown and partly a Loch Leven strain, with which the Tarn has been stocked periodically, and though not numerous nowadays they still reach a good size. I have now collected scales of most of the fish caught during the last seven years, which still await analysis, but the order of growth seems to be about one pound in the first four years. Tarn trout are indifferent risers, there being plenty of bottom food available, and the best rising of the year is at emerging *Chironomus* pupae in early June and emerging Caddis pupae in August and September. All the trout are heavily parasitized with the tapeworm *Eubothrium crassum* in the small intestine and pyloric caecae, and in two summers at least since 1948, dead trout picked up seem to have died from these tapeworms becoming too numerous and producing cysts in the viscera. The Tarn became a famous trout fishing water when it was re-stocked during the nineteenth century and up to 1925. During 1919, which was one of the best years, 74 fish of over 2 lb. and 22 over 3 lb. were caught, and the record fish was one of 6½ lb. in 1924. The trout run up the short inflow streams to spawn where there are unfortunately very restricted stretches of suitable gravel for them to make their redds in. Here it is only too easy for the fish to be poached, as shown in an entry of an Account Book for 1606 (Skipton MSS) which records "P'd to H.H. being at Mawater, watching the well-head for stealing the trouts coming unto this Ritt time, 2s. 6d.".

The perch grow up to 2¾ lbs. and are much more numerous, but their numbers have fluctuated markedly over the last 100 years, as can be seen from the records of fish caught in the old game books, which are now at the Centre. Thus 857 perch were caught in one day in 1911, and 3,357 during the year, but only a single fish in 1905. Large numbers died during the severe spring of 1947 and perch were scarce for the next few years; but there must have been a successful breeding season in 1950 as five-year-olds are now common and the dominant age group.

Phytoplankton samples were sent every two or three weeks to Dr. J. W. G. Lund, at Windermere, from 1949 to 1953, primarily in connection with his studies of the diatom *Asterionella*, and he has kindly provided me with all the data from his work. In each sample Dr. Lund was able to estimate the standing crop of plankton at that time in terms of cells per litre. On the whole, the standing crop of plankton gives a reasonable indication of productivity; thus unproductive lakes do not have large standing crops, while productive ones are bound to do so over a large part of the year. The phytoplankton production in the Tarn during 1949 was extremely small, with the greatest standing crop of the order of 10^5 cells per litre; 1950, on the other hand, was much more productive, with a maximum cell density of about 5×10^7 per litre, though the sample concerned here was exceptional and may not have been a good index of production. During the three succeeding years, production was less than 1950 but greater than 1949, as can be seen from the figures of maximum numbers for the following selected species:

	1949	1950	1951	1952	1953	
Asterionella formosa ..	96	2,563	504	508	322	cells/ml
Cryptomonas spp. ..	146	2,356	1,300	586	472	cells/ml
Anabaena flos-aquae ..	6	7,100	34	71	?	filaments/ml
Dinobryon divergens ..	5	3,310	867	153	426	cells/ml

There is a fairly regular succession of planktonic forms through the year, though numbers can vary enormously. On the whole, the species in the plankton are those typical of a moderately eutrophic type of lake, but their numbers in most years are more those of an oligotrophic one. In addition to those shown above, other species which become common in the Tarn are *Sphaerocystis schroeteri*, *Stephanodiscus hantzschii*, *Ceratium hirundinella*, *Volvox aureus* and *Uroglena* sp.

The Zooplankton is at times moderately thick, with a limited number of different species, and qualitative samples have been taken regularly since 1948. *Diaptomus gracilis* is the dominant planktont over the year as a whole and it is always present in some numbers. *Daphnia hyalina* var.

lacustris and *Bosmina longirostris* each have a marked annual maximum, usually during the summer months, though the exact time varies from year to year. In early 1948 and for seven months in 1949/50, Rotifers became the dominant forms, particularly *Asplanchna priodonta*, at times when the other planktonts were minimal; since 1950, however, they have never reached comparable numbers.

In this article I have attempted to provide a background for students studying mainly the Invertebrate animal groups, but the animals themselves I have purposely dealt with only briefly; detailed faunal and floral lists can be consulted at the Centre. One final point which needs emphasis is that we are only just beginning to understand something of the ecology of the Tarn after seven years here. There is, and always will be, an unlimited number of problems awaiting research.

Many people have provided information which is included in this account, and it could not have been written without their help. I am especially grateful to Charles Sinker for helpful discussion and suggestions.

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GLOSSARY

- PLANKTON: a collective term for all the minute organisms floating in the open water, at the mercy of currents. Animal members are called zoo-plankton, plant members phyto-plankton. One individual organism is called a planktont.
- EUTROPHIC: an eutrophic water is biologically "productive" because of its high content of dissolved inorganic nutrients, e.g. lime, nitrates. The term is used in somewhat different senses by different workers.
- OLIGOTROPHIC: an oligotrophic water is biologically "unproductive"—see eutrophic.
- BENTHIC: living on the bottom.
- EPILITHIC: living attached to the surface of a stone or rock.
- EPIPHYTIC: living attached to the surface of a plant.