INSTITUTE OF FRESHWATER ECOLOGY
The Ferry House, Ambleside, Cumbria LA22 OLP, UK

# Haweswater : a general assessment of environmental and biological features and their susceptibility to change

J.M. Elliott
S.I. Heaney
J.F. Talling (editor)

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Project Leader : J.M. Elliott
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## 1. INTRODUCTION (J.F. Talling)

Haweswater is now one of the larger and deeper Cumbrian lakes, and its drainage basin one of the least populated. These features are not original, but result from a reservoir-dam construction (completed in 1941; described in detail by Taylor 1951) that subsequently deepened the earlier lake by 29 m and flooded the adjacent valley floor. Water storage in the much-enlarged lake is exploited through an aquaduct to the south. Inputs from the immediate catchment are selectively augmented by aquaducts from the water-bodies of Wet Sleddale and (since 1971) Ullswater. Nevertheless very extensive draw-downs still occur in dry summers, and occasion public interest from the exposure of old relics.

Although the lake has not received intensive scientific study, a considerable amount of ecological information exists - chiefly from the records of the Freshwater Biological Association (now Institute of Freshwater Ecology). Such information is summarised in this Report. Particular attention is given to susceptibility to change, that might arise from altered usage of land (e.g. afforestation) or water (e.g. fish-farming), and affect both water supply and conservation interests.

The FBA bibliography compiled by Horne & Horne (1985) gives a useful subject-classified listing of literature on the lake.

## 2. PHYSICAL FEATURES (J.F. Talling)

### 2.1 Geography and bathymetry

The lake occupied a glaciated valley, surrounded by hard mountain rocks of the Borrowdale Volcanic series, in the north-east corner of the Cumbrian Lake District (Fig. 1). Its altitude of 240 m is considerably higher than that of any other major Cumbrian lake (Table 1). The natural drainage area is small relative to the lake area (Table 1), but includes the elevated tarns of Blea Water and Small Water. The inflow becks are short and subject to spates in rainy weather; the natural outflow (Haweswater Beck) soon joins the River Lowther, itself a tributary of the River Eamont and ultimately of the River Eden.

Fig. 2 shows the bathymetry of the original lake, its relation to the present normal shoreline some 29 m higher, and the area-volume relationships of successive depth strata in the original and present lake basins. The rise in level increased the lake's area by a factor of 2.8 and its volume by 6.1. The deepest region (max. 57 m) is nearly central; the sides are generally steeply sloping, but merge into shallows at the southern end.

The reservoir function is further served by three aquaducts (Fig. 3) partly set in tunnels that cross watersheds. That of the draw-off begins at an intake off the eastern shore, and passes southwards down the valley of Longsleddale to the junction at Watchgate near Kendal. Two inflow aquaducts with outfalls near the dam conduct water from the nearby small reservoir of Wet Sleddale and, as required, from the large natural lake of Ullswater. Each has additional minor intakes from becks traversed en route. Further, the tarn of Bleawater in the Haweswater catchment supplies water locally via the small Harper Hills reservoir.

## 2.2 Hydrology

The following outline is assembled from information supplied by North West Water plc, supplemented by estimates from rainfall in the Haweswater catchment.

(a) Input to lake (mean annual values, in $10^6$ $m^3$ $yr^{-1}$)

Haweswater catchment, 1961-84: 72.4 (range 42.0-91.6)
Ullswater abstraction, 1971-87: 10.2 (range 0-33.1)
other sources: Wet Sleddale Res. and beck intakes: approx 56.9 (by difference)

(b) Output from lake (mean annual values, in $10^6$ $m^3$ $yr^{-1}$)

total abstractions, 1973-86: 131.8 (range 108.3 - 143.7)
compensation water release : 7.7
total : 139.5

In this budget, the Haweswater catchment contribution is a little more than would be expected ($53 \times 10^6$ $m^3$ $yr^{-1}$) from considerations of lake and catchment area ($30.5$ $km^2$), mean annual rainfall ($2.16$ m $yr^{-1}$) and probable mean run-off factor (c. 0.8). The generally well-maintained output quantity is clearly very dependent upon piped supplies obtained from outside this catchment. In years with drier summers (e.g. 1973, 1974, 1976, 1978, and 1984) the Ullswater abstraction is increased above $15 \times 10^6$ $m^3$ $yr^{-1}$ (max. $33.1 \times 10^6$ $m^3$ $yr^{-1}$ in 1976). Nevertheless draw-downs of Haweswater can sometimes be extensive, as shown in Fig. 4 for 1974, when normal storage was reduced by c. $50 \times 10^6$ $m^3$.

Despite the additional piped inputs, the average retention time of the lake is not very short. Calculated as the quotient of lake volume to mean annual output, it is 0.66 yr or 7.9 months, similar to that of Windermere North Basin. The compensating factor in Haweswater is the deep lake basin as extended by the dam, and the small natural drainage area.

## 2.3 Temperature stratification

As in other Cumbrian lakes, the annual temperature cycle will induce short irregular periods of inverse winter stratification (<4°C) and regular summer phases of direct stratification (>4°C). The former have not, apparently, been quantitatively documented; the latter have been recorded by the FBA in its spring-to-autumn surveys of 1972, 1973, 1974, 1975, 1976, 1977, 1984 and 1987.

The 1974 series (Fig. 5) provides an example of spring onset, summer maintenance, and autumnal breakdown of such direct temperature/density stratification. In this year the summer thermocline is steep, deep and sharply delimited, the highest recorded surface temperature does not exceed 14°C, and complete vertical mixing re-develops in late-September. All these features are subject to variation between years (Fig. 6). The vertical thermal (and density) gradients can be of lesser slope but more extended vertically; the maximum surface temperature can exceed 17°C (as in 1975-77); and complete vertical mixing ('overturn') can be delayed to at least mid-October (e.g. 1973). The deep-water or hypolimnetic temperature during mid-summer is usually between 9.0 and 9.5°C, although there are exceptional records of c. 10.5°C (1972) and c. 7.5°C (1977).

## 2.4 Light penetration

In the summer of 1952, photo-electric measurements of spectral light penetration were made for comparison with other Cumbrian lakes (Talling 1971). The results (Fig. 7) indicate that Haweswater was then one of the clearer of the intermediate and broadly mesotrophic group of the lakes with a euphotic or photosynthetic zone (to the 1% level of total available light) of c. 14 m. Later information is restricted to measurements of Secchi disc transparency in 1984 and 1987 (Table 2). The higher values of 6.0 and 6.5 m in February and April 1984 are broadly compatible with the 1952 results, and the low value of

3.0 m in July 1984 is probably influenced by exceptional draw -down. However the consistent and fairly low transparency values of 1987 are more similar to those of Windermere North Basin, a markedly more productive water.

## 3. CHEMICAL CHARACTERISTICS (J.F. Talling)

### 3.1 Dissolved oxygen

There is no reliable evidence that the oxygen content of surface water deviates far from 100% saturation, as indicated by measurements in 1972-1987 with electrical temperature-oxygen probes. Markedly lower concentrations do develop in deeper water during summer stratification, as shown in Figs. 5 and 8. However the depletion is not extreme; the minimum levels, reached about August, exceed 60% saturation. When the thermocline is abrupt, as in 1974, it can be accompanied by a sharp oxygen gradient (oxycline) in its later stages. During the earlier phase of stratification, about May and June, the oxygen depletion at depth is relatively small (Fig. 5).

### 3.2 Major ionic composition

The major ionic composition of Haweswater is known most completely from measurements in 1974-5, by which a comparison with other Cumbrian lakes is possible (Table 3). General chemical features are those of a lake at the oligotrophic end of a class with intermediate productivity ('Group 2'). Here the intermediate concentration levels of $Ca^{2+}$ and $HCO_3^-$ (alkalinity) are especially significant, but a similar ranking also results from surveys of light penetration (Fig. 7), algal abundance (Table 7), aquatic macrophytes (original lake - see Section 8), total phosphorus concentration (Table 6 and Jones 1972), and hypolimnetic oxygen depletion (Section 3.1 and Jones 1972). It is noteworthy that over the Cumbrian lakes as a whole the mean concentrations of $Na^+$, $Cl^-$, $SO_4^{2-}$ and $NO_3^-$ have rather small variability. The mean values of pH (6.8 in surface Haweswater) are related to titration alkalinity; marked elevations by photosynthetic $CO_2$-removal are not recorded from Haweswater, and possible depressions by $CO_2$-accumulation in its deep water are not yet investigated.

Some information on long-term variability can be obtained by comparing measurements in 1955-6 and 1974-5 (Table 3), supplemented by a few values (mainly alkalinity) at other times (e.g. Table 6). Mean concentrations of all the cations and anions listed in Table 4 show a small increase (range 4-50%) from 1955-6 to 1974-5. Except possibly for $NO_3^-$ (see Section 3.3 below), changes in atmospheric deposition are unlikely to be responsible, and evidence from other Cumbrian lakes (Sutcliffe et al. 1982) does not support the possibility of increased chemical weathering - unless local leaching of reservoir-flooded valley alluvium is involved. One probable influence is the introductions by pipeline from other waters, including the lake Ullswater with higher concentrations of most major ions.

The few early analyses of the original (natural) lake (Pearsall 1930, Mortimer unpubl.) suggest that the alkalinity was then appreciably lower; the mean value in 1928 was 100 μeq $l^{-1}$ (Pearsall 1930).

In the spring and summer of 1985 surveys were made of tributary becks in the Haweswater catchment, plus the nearby Wet Sleddale reservoir from which water is piped to Haweswater. The results (Table 5) show that some Haweswater tributaries have quite considerable levels of $Ca^{2+}$ and alkalinity (>400 μeq $l^{-1}$), whereas these (and pH) are relatively low in Wet Sleddale reservoir. Chemical inputs to the latter soon after its formation are described by White et al. (1971).

## 3.3 Major plant nutrients

Here forms of the elements N, P and Si are considered (Table 6); the last is chiefly significant in relation to diatom growth (Section 4.1). All values are for surface water.

Inorganic nitrogen is largely in the form of nitrate-nitrogen ($NO_3$-N). Concentrations of ammonium-nitrogen ($NH_4$-N) are not recorded to exceed 10 µg $l^{-1}$, and appreciable concentrations of nitrite-nitrogen would not be expected in the relatively well-oxygenated water. There is some evidence for both long-term and seasonal trends in $NO_3$-N, although the upward correction of the earlier (1949-50) analyses obtained by the phenol disulphonic acid method involves some uncertainty. However the seasonally higher values about February-March show an unequivocal increase, from c. 210 µg $l^{-1}$ in 1949-50 to 330 ± 20 µg $l^{-1}$ in 1984-7. Other information from the region suggests that such increase is widespread and may be due to an increase of concentrations in atmospheric precipitation (Talling & Heaney 1988). For 1949-50 there is evidence of some summer depletion, with a (corrected) concentration as low as 66 µg $l^{-1}$ in August 1949; in 1955 and 1974 (Table 4) and 1984 and 1987 (Table 6) depletion is small or absent. In no year is there a prolonged and severe depletion that would point to a predominant N-limitation of phytoplankton growth.

Phosphorus, by contrast, is present in low to very low concentration in terms of both total phosphorus and soluble reactive phosphorus ($PO_4$-P). Values for total phosphorus, available only since 1974, range from 6.5 to 13.7 µg $l^{-1}$ which is at the lower end of the Cumbrian lakes of moderate productivity (Jones 1972, Gorham et al. 1974). Soluble reactive phosphorus is often below 1 µg $l^{-1}$, and sporadic higher values reach only 3.1 µg $l^{-1}$. Such higher values, recorded since 1974 but not in 1949-50, are possible but inconclusive evidence for some slight enrichment in a probable key nutrient.

Silicon, present as dissolved silicate, is here expressed as the oxide silica ($SiO_2$) in which form it is a major constituent of diatoms. The recorded range is 1.1 - 3.0 mg $SiO_2$ $l^{-1}$, typical for Cumbrian lakes in the absence of a strong seasonal depletion by planktonic diatoms.

There is apparently no information on the nutrient content of deep water.

## 3.4 Implications

There can be little doubt that chemical (nutrient) relationships determine the lake's well-established position at the more unproductive end of the intermediate or Class 2 group of Cumbrian lakes. Further, of measured nutrients, phosphorus is the most likely to be severely limiting on the evidence of concentration levels. The lake is therefore likely to be very susceptible to a large increase of algal productivity, with associated effects like enhanced summer oxygen depletion at depth, from markedly increased inputs of phosphorus. Such response is likely to be enhanced by the relatively adequate base status due to some catchment streams with considerable concentrations of $Ca^{2+}$ and $HCO_3^-$. In the absence of piped sewage and with minimal agricultural activity in the catchment (other than sheep rearing), the main dangers for P-enrichment could come from fish-farming within the lake and afforestation (with preliminary fertilization) in its mountainous catchment.

The available chemical and algal analyses are suggestive of some slight enrichment since impoundment, but are too few for more detailed analysis. Indirect evidence, from trout growth rates (Section 7.2), make it likely that some transient nutrient release and 'trophic upsurge' followed the original flooding after impoundment. It is possible that later major draw-downs may contribute to such release on refilling over exposed sediments, augmented by water transfer from the more productive Ullswater, but adequate analytical evidence is lacking.

## 4. PHYTOPLANKTON (S.I. Heaney)

### 4.1 General survey

Data on the phytoplankton of Haweswater from 1949-51, 1955, and 1961-63 were collected by Dr J.W.G. Lund as described in Gorham et al. (1974). The results of counts of the large algae (retained to some extent by a 65-µm mesh size phytoplankton net) and small or µ-algae are given in Tables 8 and 9 respectively. Table 7 (Gorham et al. 1974) summarizes these results in relation to the phytoplankton of other major lakes in Cumbria.

The large algae (Table 8) were consistently dominated by the diatoms Asterionella formosa and Melosira italica subsp. subarctica (now more correctly Aulacoseira subarctica) with Tabellaria flocculosa var. asterionelloides relatively rare except during 1974. These algae typically increase to maxima about early spring. Species from other algal groups were always present in low numbers except for occasional increases of green algae, cryptomonads and chrysophytes. Blue-green algae were rare.

Small µ-algae, given as green algae, diatoms, chrysophytes and cryptomonads (mainly Rhodomonas lacustris) in Table 9, were only counted from 1955. These algae were always more numerous than the larger species although because of their smaller size they constituted only a small fraction of the total phytoplankton biomass (Table 7). On the basis of these observations, and the derived assessment of a fairly small mean total biomass concentration, Gorham et al. (1974) placed Haweswater in an intermediate group of Cumbrian lakes between those least productive (Wastwater, Thirlmere, Buttermere, Ennerdale Water and Crummock Water) and most productive (Esthwaite Water, Bassenthwaite Lake, Ullswater, Blelham Tarn, Windermere South Basin). This agrees with ranking from some important physical and chemical indices (Sections 2.4, 3.2, 3.3).

Dr R. Mubamba obtained samples from Haweswater during March, June and September 1987. The algal genera he identified and his counts are given in Table 10. The most striking difference between his observations and those of Lund above is the considerable abundance of the blue-green algae Oscillatoria and Gomphosphaeria. The presence of these genera could arise both from growth in situ and from the transfer of water rich in blue-green algae from Ullswater. From their abundance in Haweswater it would appear that appreciable growth must have taken place in the lake even though the inoculum may have been received from Ullswater.

### 4.2 Implications

The observations of Mubamba indicate a significant change in the water quality of Haweswater since the seventies. Although the blue-green algae now present probably have their provenance in Ullswater, their apparent success in Haweswater should cause concern. They indicate that the reservoir is sensitive to change by any further enrichment from whatever source. This is exacerbated by its relatively long retention time.

## 5. ZOOPLANKTON (J.M. Elliott)

### 5.1 General survey

Early records of zooplankton Crustacea in the Cladocera and Copepoda are summarised in two Scientific Publications from the Freshwater Biological Association (Scourfield & Harding 1966; Harding & Smith 1974). The first quantitative study was part of a general survey of zooplankton in Cumbrian lakes during 1961 and 1962 (Smyly 1968). Fig. 9 shows the mean standing populations that he recorded. The major species were the cladocerans Daphnia hyalina, Bosmina coregoni, Leptodora kindti, Bythotrephes longimanus, the copepods Diaptomus gracilis, D. laticeps, Cyclops strenuus and the rotifer

Asplanchna priodonta. Smyly concluded that the zooplankton had changed little since the less intensive survey of Gurney (1923) on the old lake, apart from the loss of the rather erratic cladoceran Diaphanosoma brachyurum.

In March, June and September 1987, zooplankton samples were taken at a site used for gill-netting of fish (Mubamba 1989). In each month, two vertical hauls were taken from near the bottom to the surface, using a conical plankton net. The predominant planktonic Crustacea (not identified below genera) were Eudiaptomus, cyclopoids, Daphnia and Bosmina, and the predominant rotifers were Asplanchna, Kellicottia and Conochilus (Table 11). All these groups were most abundant in the June sample. These results are similar to those of earlier workers.

### 5.2 Implications

The zooplankton populations do not appear to have changed greatly in the last seventy years. There is no reason to consider that they are likely to change significantly in future in the absence of strong eutrophication or alteration in the management of the reservoir for water-supply purposes. The success of the zooplankton is likely to be related to that of the phytoplankton. As the zooplankton is an important food for charr and schelly, it should be monitored in the future.

## 6. BOTTOM FAUNA (J.M. Elliott)

### 1. General survey

The lake level was raised 29 m by the construction of a dam. Before the dam was completed in 1941, records of the animal benthos were restricted to the following taxa found in fish stomachs : shrimp Gammarus pulex, midge larvae and pupae (Chironomidae), larvae of stoneflies (Plecoptera), mayflies (Ephemeroptera), caddis-flies (Trichoptera) and dragon-flies (Odonata), water-bugs (Corixidae), larval and adult water beetles (Coleoptera), and gastropod snails (Gastropoda) (Swynnerton & Worthington 1940). Many species of Protozoa were also recorded from the lake (Brown 1931).

Since 1941, only three publications have dealt with the benthos of Haweswater. The freshwater limpet Ancylus fluviatilis was found on the shore in 1952/53 (Geldiay 1956), the worm Limnodrilus hoffmeisteri was taken from the bed of the lake at a water depth of 10 m (Brinkhurst 1964), and the ostracod Cypria opthalmica and the benthic copepods Cyclops fimbriatus and C. viridis were found in the deeper parts of the lake (Smyly 1968).

In an unpublished thesis, Reynoldson (1983) recorded four species of worms, Stylodrilus heringianus, Ilyodrilus templetoni, Peloscolex ferox and Uncinais uncinata, all from the deepest part of the lake. This latter study was part of a general survey of oligochaetes (worms) in the profundal zone of sixteen lakes in the English Lake District. Results for Haweswater were closest to those for Ennerdale with three of the four species in each lake common to both lakes.

Some rather inconclusive information on the benthos is given in an unpublished thesis by Mubamba (1989). Samples taken with an Ekman grab in three months contained only flatworms and bryozoan statoblasts in March, Daphnia ephippia in June, and chironomid larvae and Daphnia ephippia in September.

## 5.2 Implications

The general conclusion is that very little qualitative, and virtually no quantitative, information exists for the bottom fauna of Haweswater. As the benthos must provide large quantities of food for the fish of the lake, there is an urgent need for at least a thorough qualitative survey, especially if any changes in the use of the lake are contemplated in the near future.

## 7. FISH (J.M. Elliott)

### 7.1 Introduction

The fish species recorded from Haweswater are brown trout (Salmo trutta L.), eels (Anguilla anguilla L.), charr (Salvelinus alpinus (L.)), schelly (Coregonus lavaretus (L.)), perch (Perca fluviatilis (L.)), minnows (Phoxinus phoxinus (L.)) and sticklebacks (Gasterosteus aculeatus L.). Samples collected by gill nets in November 1986 and March, June and September 1987 showed that schelly were predominant (44.9%) in the deeper water, followed by charr (31.6%), brown trout (14.1%) and perch (9.4%), but seasonal changes in abundance could not be detected because of the small number of samples (Mubamba 1989).

The food and growth of some of these species were studied by Swynnerton & Worthington (1939, 1940; also Worthington & Swynnerton 1939) who used a seine net to sample fish in July 1938, i.e. before the lake became a reservoir.

### 7.2 Trout

The total catch of 101 trout in the survey of July 1938 showed that their growth was similar to that of trout in Lough Atarick in Ireland but poorer than that of trout in Ullswater and Windermere in the Lake District and Lough Derg in Ireland (Fig. 10). An additional sample of trout was taken by seine netting and fly fishing in May 1941 whilst the reservoir was filling and two years after filling commenced (Frost 1956). This sample showed that there had been a marked improvement in trout growth (Fig. 11). The enhanced growth was attributed to an increased food supply brought about by the inundation of the land. Although no further samples of trout were taken after the filling was completed in December 1941, Frost (1956) reports that since 1949 the trout fishing has deteriorated and therefore the initial enhancement of growth was probably not sustained. The total number of trout (36 fish) caught in the gill-net surveys from November 1986 to September 1987 was too small to provide representative age-distribution data (Mubamba 1989). Fish sizes in the catch ranged from a three-year-old with a length of 14.3 cm and wet weight of 30.0 g to a seven-year-old with a length of 29.1 cm and weight of 281.0 g. Stomach analyses indicated a mixed diet of planktonic Crustacea and benthic invertebrates (Table 12). It is notable that the largest trout in the samples (29.1 cm) was about the same size as that recorded by Frost (cf. Fig. 11). The pre-reservoir sample in July 1938 showed that the trout were feeding chiefly on benthic invertebrates, with larger trout also taking sticklebacks and minnows.

### 7.3 Perch

The pre-reservoir sample also showed that small perch fed chiefly on planktonic Crustacea, those of intermediate size on benthic invertebrates and the largest on other fish. The total number of perch (24 fish) caught in the gill-net surveys from November 1986 to September 1987 was too small to provide representative age-distribution data (Mubamba 1989). Fish sizes in the catch ranged from a two-year-old male with a length of 15.1 cm and wet weight of 40.3 g to a ten-year-old female with a length of 25.2 cm and wet weight of 187.0 g. Perch in Haweswater appear to be longer lived and slower growing than those in other lakes in the district, possibly because of the absence of pike. There is some evidence that perch grow faster in lakes containing pike (McCormack 1965). Stomach analyses of perch taken in the gill-net samples indicated a diet of chiefly benthic invertebrates with some planktonic Crustacea that were mainly Bythotrephes and cyclopoids (Table 12).

### 7.4 Charr

The pre-reservoir sample in July 1938 also provided the first information on the food of charr and schelly. Both species fed predominantly on planktonic Crustacea with benthic invertebrates providing the rest of the diet. This conclusion was confirmed for charr by samples taken at later dates (Frost

1977). The spawning time for charr in Haweswater appears to be late January; spawning probably occurs in deep water (Frost 1965). The gill-net surveys from November 1986 to September 1987 caught 81 charr ranging in size from 8.1 cm to 29.0 cm (Mubamba 1989). Mean fork-length was estimated to be 9.57 ± 1.39 cm at an age of one year, 12.18 ± 1.85 cm at two years, 21.00 ± 4.30 cm at three years, 24.66 ± 1.51 cm at four years, 26.00 ± 0.86 cm at six years and 27.60 cm at seven years (no five-year-olds were found). Analyses of stomach contents confirmed that their diet was chiefly planktonic Crustacea (Table 12).

### 7.5 Schelly

Haweswater contains one of only six populations of schelly in the British Isles. Elsewhere, this species is known as the powan (two populations in Scotland) and Gwyniad (one population in North Wales). The two remaining populations occur in Ullswater and Red Tarn in the Lake District with perhaps a seventh population in Brotherswater. Apart from Loch Eck in Scotland (Maitland 1985), Haweswater is the only lake known to contain both charr and schelly. These species both occurred in Ullswater but the charr are now extinct in that lake.

There are several brief notes on the schelly of Haweswater and Ullswater (Swynnerton & Worthington 1940; Bagenal 1966; Ellison 1966; Ellison & Cooper 1967), but the first detailed account is that by Bagenal (1970). He obtained samples from Ullswater by gill-netting but all the schelly from Haweswater were caught at the end of an aquaduct from the reservoir (total catch was 188 from January 1965 to 1967). Males matured when three-years-old and females when four-years-old, but the spawning grounds were not found. As the main breeding season for schelly is probably from mid-January to mid-February and most of the fish moving down the aquaduct were taken over the same period, it was concluded that the spawning grounds could be near the southern bay of the old lake. The oldest fish was nine-years-old and information was obtained on mean sizes and growth rates for males and females.

The gill-net surveys from November 1986 to September 1987 caught 115 schelly; 69 fish in November 1986, 23 fish in March 1987, only 7 fish in June 1987 and 16 fish in September 1987 (Mubamba 1989). A comparison of morphometric and meristic characters showed that schelly in Haweswater were significantly longer and heavier with more lateral scales than those in Ullswater. An electrophoretic analysis also suggested some differences in allele frequencies between the two populations but sample sizes were too small for statistical tests. There were ten age-groups of males with group 7 dominant, and eleven age-groups of females with groups 8 and 9 dominant (Fig. 12).

Growth curves derived from the data were similar for both sexes with markedly reduced growth in the older fish (Fig. 13). Bagenal (1970) found that growth rates of schelly were similar in Ullswater and Haweswater, but the data from Mubamba (1989) show that this is no longer the case, Haweswater growth rates being clearly superior (Fig. 14). This discrepancy was due to a decline in growth rates in Ullswater and no decline in Haweswater; growth rates in the two studies were similar for the latter lake (Fig. 15).

Stomach analyses confirmed the conclusions of earlier workers that Haweswater schelly feed chiefly on planktonic Crustacea and benthic invertebrates (Fig. 16). Although samples were available from only November, March, June and September, they suggest that the fish fed little in winter, especially before and soon after spawning. Benthic invertebrates predominated in the diet in November and plankton predominated in June and September. In March, schelly fed chiefly on their eggs (38.8% occurrence in diet) and benthic invertebrates.

## 7.6 Implications

It can be concluded that, of the fish species in Haweswater, nothing is known about the ecology of eels, minnows and sticklebacks in the reservoir and very little is known about the brown trout, charr and perch. Samples of trout before (July 1938) and during (May 1941) filling of the reservoir and long after (November 1986 to September 1987) provide useful information on size and growth.

The detailed study of Bagenal (1970) and the unpublished thesis by Mubamba (1989) provide a large amount of information on the schelly but only for the periods January 1965 to 1967 and November 1986 to September 1987. There is no evidence to suggest that there has been any marked decline in the growth rates, sizes and density of Haweswater schelly. This is in marked contrast to the situation in Ullswater. Charr have already disappeared from Ullswater, possibly because their spawning grounds in Glenridding Beck were polluted by suspended solids and lead from mine washings. There is no evidence to suggest that any recent pollution is responsible for the decline of growth rates in schelly in Ullswater, and the chief reason may be the marked increase in population density since the late 1960's. If food resources are limited, then food intake per fish would be reduced, and hence growth rates and sizes would have declined.

Such a hypothesis is only speculative at present but indicates the potential fragility of the populations of schelly and charr in Haweswater, especially if changes in the reservoir affected their spawning grounds or food supply. Fortunately, schelly received legal protection in November 1987 under the Wildlife and Countryside Act, making it illegal to "take from the wild, injure, kill or destroy" them. Such a ruling is presumably applicable to any schelly removed from the lake during water abstraction (we assume the water authority is aware of this).

There is clearly a need to protect the unique schelly of Haweswater. Haweswater is one of only two lakes in the British Isles, and the only reservoir, in which schelly and charr co-exist. This rare combination is therefore of great scientific interest (Maitland 1985), especially because Haweswater is liable to considerable fluctuations in water level. Having lost one example of a schelly/charr lake (Ullswater), it would be tragic to lose a second.

## 8. AQUATIC MACROPHYTES (J.M. Elliott)

The lake level was raised 29 m by the construction of a dam. Before the dam was completed in 1941, the following plants were recorded by Pearsall (1921, 1949) at water depths below 2 m (with percentage occurrence in parenthesis): quillwort Isoetes lacustris (5%), algae Nitella opaca/flexilis (65%) and Chara globularis (6%), bulbous rush Juncus bulbosus f. fluitans (1%), starwort Callitriche hamulata (4%), pondweed Potamogetum spp. (5%), water-milfoil Myriophyllum spp. (13%), moss Fontinalis antipyretica (1%). The same survey also recorded the following plants in shallow water (<2 m deep) around the shore of the lake : shoreweed Littorella uniflora, water-milfoil Myriophyllum spicatum, pond-weed Potamogeton natans, reed Phragmites communis and beaked sedge Carex rostrata.

The lake was abnormal in its high proportion of Nitella and scarcity of Isoetes. This discrepancy was due to the high proportion of the shore that was silted; as silting increases, Isoetes is replaced by Nitella. Pearsall concluded that vigorous erosion in the past apparently washed large quantities of sand and gravel into the lake and the sand facilitated the silting-up of the shores. On the basis of its vegetation, Pearsall placed Haweswater towards the middle of the lakes series, close to Derwentwater and just after the four unproductive lakes (Wastwater, Ennerdale, Buttermere, Crummock Water).

Since the lake became a reservoir, twenty-four species have been recorded (Stokoe 1983) from three surveys in 1973, 1975 and 1980: milfoil Achillea millefolium, the grass Agrostis stolonifera, starworts Callitriche hamulata and C. stagnalis, sedge Carex demissa, chickweed willow-herb Epilobium alsinifolium, marsh bedstraw Galium palustre, marsh cudweed Gnaphalium uliginosum, the rushes Juncus articulatus, J. bufonius, J. bulbosus f. fluitans and J. effusus, shoreweed Littorella uniflora, blinks Montia fontana, water forget-me-not Myosotis caespitosa, water purslane Peplis portula, great plantain Plantago major, the pondweeds Polygonum hydropiper and P. persicaria, common tormentil Potentilla erecta, lesser spearwort Ranunculus flammula, yellow-cress Rorippa palustris, corn spurrey Spergula arvensis and the alga Nitella opaca.

Many of these species occur only at the lake margin and would not be classed as truly aquatic plants by most authors. Here colonization by normally terrestrial plants would be favoured by the periodic draw-down of water level. A comparison with the earlier survey shows that few species recorded earlier are absent from the later survey. Exceptions are the quillwort Isoetes lacustris, water-milfoil Myriophyllum spp. and the moss Fontinalis antipyretica. Their absence could be simply due to the fact that they occurred at water depths greater than those sampled in the later surveys. It is not therefore known if these species are now absent from the lake. There is clearly a need for a thorough survey of the aquatic macrophytes to record not only the species but also their distribution throughout the lake.

## 9. NUTRIENT INPUTS (S.I. Heaney)

### 9.1 Actual and critical levels

With the exception of Haweswater Hotel (whose sewage is piped beyond) there is little human habitation within the catchment of the lake. There is also little cultivated land or forestry and it follows that direct anthropogenic inputs of plant nutrients into the lake are likely to be small. For phosphorus this is borne out in the winter concentrations of $PO_4$-P ($< 3$ $\mu g\ P\ l^{-1}$, see Section 3.3). Winter concentrations of $NO_3$-N however are relatively high ($>200$ $\mu g\ N\ l^{-1}$, see Section 3.3) and probably reflect inputs in rainfall. Concentrations in inflow becks are considerable, as are those of $Ca^{2+}$ and $HCO^-_3$ (alkalinity) in some becks. Phosphorus concentrations have not been measured on inflows.

An indirect estimate of the input to Haweswater of phosphorus, probably the most critical nutrient (Section 3.4), has been calculated using a value for the annual export of total phosphorus from a grazed granitic upland catchment of 19.9 kg P $km^{-2}$ obtained for Dartmoor by Rigler (1979). Although Rigler pointed out that the methods used in obtaining his value can seriously underestimate true export, applied to the Haweswater catchment of 26.6 $km^2$ it would apply an annual input to the lake of 530 kg or an annual loading per unit lake area for total phosphorus of 0.14 g P $m^{-2}yr^{-1}$. This would increase to 0.27 g P $m^{-2}yr^{-1}$ if the additional loading due to water introduced by aqueducts from nearby upland catchments is considered as proportional to the input volumes.

For phosphorus controlled lakes, the critical loading of total phosphorus which determines the transition between oligotrophy and eutrophy has been examined by Vollenweider (1976), taking into account both the mean depth and the residence time of the water. He deduced that the critical loading value can be described by equation (1):

$$L_c = (10 \text{ to } 20).q_s \ (1+\sqrt{\bar{z}/q_s}) \qquad (1)$$

Where $L_c$ = critical specific loading (mg $m^{-2}yr^{-1}$

$\bar{z}$ = mean depth (m)

$q_s$ = hydraulic load (m $yr^{-1}$ = $Q_y/A_o$)

where $Q_y$ = total yearly discharge ($m^3$ $yr^{-1}$)

$A_o$ = lake surface area ($m^2$)

Using the values for Haweswater in Table 13 where total yearly discharge is the mean value between 1973 and 1986 (Section 2.2), the range of critical loading of total phosphorus with the reservoir full is 650-1300 mg P $m^{-2}$ $yr^{-1}$. This range would be lowered under conditions of drought and marked draw-down (i.e. reduced $\bar{z}$ and $q_s$). However the lower limit of the critical loading is over twice as great as the annual loading of total phosphorus of 270 mg P $m^{-2}yr^{-1}$ estimated above. On the basis of this calculation and other evidence within this report, Haweswater can be considered oligotrophic or mesotrophic with low productivity, although higher than that of some other lakes in Cumbria (Gorham et al. 1974).

### 9.2 Implications

The observational records indicate that additions of P rather than N are likely to be crucial for lake enrichment, with potentially unfavourable consequences for survival of charr and schelly. A very rough estimate of the magnitude of the critical annual P addition is the difference between the indirect estimates of the critical loading ($L_c$) and current loading; this is 0.61 - 1.29 g P $m^{-2}yr^{-1}$.

## 10. POTENTIAL INFLUENCE OF FISH-CAGE CULTURE (J. F. Talling)

In 1989, plans were submitted for a project to install salmon rearing cages in Haweswater. This project did not proceed for several reasons, but aroused opposition on conservation grounds from two official bodies (Appendix ). Reasons given included undesirable nutrient enrichment from food pellets and waste, modification of bottom-sediments used as spawning grounds by schelly and charr, possible introduction of fish disease, and competition by escaped fish to the native stocks. The last danger is noted in Section 7, where the schelly-charr combination in Haweswater is emphasized as unique in Cumbrian lakes following the recent loss of charr from Ullswater.

Fish farming must increase the inputs of nitrogen and phosphorus to the lake, in amounts dependent upon the density of fish stocking. The main impact is likely to be that of additional phosphorus (see Section 3.4), and will be greatest during summer, to early autumn when reservoir draw-down is typically greatest and the conditions of light, temperature and water retention are most favourable for algal growth. At this season the reduced oxygen content of deep water is also most pronounced (Section 3.1), and would be expected to decrease further if phytoplankton production were increased by additional nutrient inputs. Such increase is qualitatively likely from considerations of the present low P loading (Section 9), the present low P status of the lake water (Section 3.3), the moderate base status (Section 3.2), and the evidence for a marked increase in blue-green algae in recent decades (Section 4.2).

On all grounds noted above, there is a strong danger to conservation interests from any development of fish farming in Haweswater on a commercially viable scale.

For further general information on environmental consequences of cage fish-farming, reference may be made to Phillips et al. (1985) and Maitland (1986, 1987, 1989).

## 11. PROPOSALS FOR FUTURE RESEARCH

### 11.1 Nutrient balance (J.F. Talling)

There is a need to monitor the lake at wide intervals to test for possible long-term change, and also to test for altered regimes of seasonal depletion and re-supply. In the absence of new usage of lake or catchment, years of roughly monthly sampling separated by 4 year intervals would be appropriate, and could be combined with corresponding measurement of $O_2$-depth profiles and sampling of plankton (Section 10.2 below). More frequent (e.g. weekly) sampling, especially in summer, would be needed to assess the consequences of major new inputs, such as from fish-farming, or possible relationships to exceptionally low drawdown and subsequent re-flooding. An experimental approach, as by laboratory nutrient bioassays using algal culture technique, would then be very desirable.

### 11.2 Plankton (S.I. Heaney)

This report indicates changes in algal quality and probably quantity since 1974. The increase of the blue-green algae Oscillatoria and Gomphosphaeria are likely to be mainly the result of water transfers from Ullswater. Any further enrichment of Haweswater from potential fish-farming activities will almost certainly lead to a deterioration of water quality and the possibility of algal blooms during dry summers.

In the absence of fish-farming activities or other significant perturbations to Haweswater and its catchment, a programme of samples collected from the 0-5 m layer during the four seasons should be sufficient to detect major changes of phytoplankton composition and abundance. Any commencement of fish farming in the lake should be accompanied by a seasonal sampling at monthly intervals increasing to biweekly during summer. Provision should be made for opportunistic sampling at times of severe drought or for unseen special circumstances such as land-use changes within the catchment. Vertical net hauls for zooplankton counts or sedimented volumes should be collected at the same time that phytoplankton samples are obtained.

### 11.3 Fish (J.M. Elliott)

There is a need to obtain more information on the ecology of the schelly, especially the location of their spawning grounds, the life history of the early stages (larvae and juveniles), their population density fluctuations and their relationships with other fish species in the reservoir, especially the charr.

Regarding trout, detailed work is clearly required on an analysis of the three existing data sets and on obtaining future sets at more frequent intervals. Such work would be essential if ever proposals were made to rear rainbow trout or brown trout in the lake. The inevitable escape of captured trout would obviously lead to changes in the resident trout population, as well as indirectly affecting other species in the reservoir through competition for food and space.

### 11.4 Other biota (J.M. Elliott)

The desirability of further work on the very poorly known communities of the bottom fauna (Section 6) and aquatic macrophytes (Section 8) has already been noted. Little is known about the variable relative contributions of benthic invertebrates and zooplankton as food for the fish.

## 12. SUMMARY (J.F. Talling)

1. Haweswater, now one of the larger (3.9 $km^2$) and deeper (max. 57 m) Cumbrian lakes, was extended from a small original lake by a dam completed in 1941. Besides the dam-outlet, it supplies water by offtake pipeline to the south; water input from its largely mountainous drainage basin is augmented by piped transfers from Wet Sleddale reservoir, the lake Ullswater, and adjacent uplands. Draw-down can be extensive during and after summer droughts.

2. The hydrology is complex. The average annual input from the original catchment ($72.4 \times 10^6$ $m^3$ $yr^{-1}$) falls far short of the output by abstraction ($131.8 \times 10^6$ $m^3$ $yr^{-1}$) plus compensation water release ($7.7 \times 10^6$ $m^3$ $yr^{-1}$). The difference is made up by the piped transfers, of which the Ullswater component is used mainly in drought conditions, plus draw-down of stored water during droughts. The mean retention time is 7.9 months.

Temperature (density) stratification is probably irregular during winter and of fairly regular incidence - usually May to September - during summer. The summer deep water (hypolimnion) is typically at 9.0-9.5°C, but the degree of surface warming and the vertical extent of the thermocline region vary considerably in relation to weather.

Light penetration and transparency are variable, but generally place the lake as one of the clearest in the Cumbrian group of intermediate production.

3. Of chemical constituents, the seasonal oxygen regime and the mean concentration of major ions and total phosphorus are consistent with expectations for a Cumbrian lake of low to intermediate production. Even at depth, below a well-marked summer thermocline, oxygen % saturation levels do not fall below 60% of the surface values. The base status ($Ca^{2+}$, alkalinity) is moderate due to not inconsiderable concentrations in some catchment streams. Concentrations of total and soluble reactive phosphorus are low, and suggest a predominant limitation of algal production by this element. Nitrogen as nitrate typically appears in more ample supply, with variable summer depletion and a long-term upward trend of concentration that may reflect increased atmospheric inputs. There is no record of pronounced silicon depletion by diatom growth. Some evidence exists for long-term but small upward trends in most major ions and, less conclusively, for seasonal maxima in phosphate-phosphorus. Possible influences here include water transfers (esp. from Ullswater) and episodic flooding of exposed sediments after drought.

4. In the two decades after reservoir filling, the phytoplankton was generally dominated by large diatoms and its total biomass concentration was fairly small, indicative of a Cumbrian lake of intermediate production. The last feature was also supported by estimations of chlorophyll a concentration in 1987, but by then blue-green algae - rare in earlier records - appeared in moderate abundance. This change may have been due to introduced inoculum quantities from Ullswater followed by growth in Haweswater.

5. The zooplankton is known - largely for Crustacea - from qualitative records in the pre-reservoir period and quantitative estimations on a few dates in 1961-62 and 1987. There appear to be few significant changes between the earlier and later periods. The species recorded are generally of common and widespread distribution.

6. A general faunistic survey of the bottom fauna has never been made, and the available information is uneven. That from fish stomachs confirms an importance as fish food. The fauna of oligochaete worms from deep water is most similar to that of the unproductive Ennerdale Water among Cumbrian lakes.

7. In the fish fauna, seven species are represented - brown trout, perch, charr, schelly, eels, minnows and sticklebacks. The ecology here of the last three is not known. For the others there is information on food, with variable contributions from zooplankton (predominant for charr plus young perch and seasonally for schelly) and from bottom-living invertebrates, other fish and fish eggs. In some instances comparison is possible with the late pre-reservoir period, and can sometimes be extended to growth rates and other fish stocks. Thus there are indications that the growth rate of brown trout showed transient increase after reservoir filling, perhaps from food resources offered by inundated land; that of the schelly was recently (1987) greater than in the Ullswater population, after a possibly density-dependent decline in the latter's growth rate. Pike, a master-predator, is absent. For most species the age-distributions are not well known, due to insufficient samples; an exception is the 1965-67 and 1987 work on the schelly. In 1987 this fish was numerically predominant in gill-net catches. Losses elsewhere point to the need for conservation of the rare association with charr, taking into account the unfavourable influence of marked eutrophication and the possible influence of large draw -downs. Conservation must also take spawning characteristics into account; the charr appears to spawn in late-January, probably in deep water, whereas the main breeding season for schelly is probably mid-January to mid-February, with spawning grounds uncertain but possibly near the present water offtake. The schelly is now legally protected and should not be removed during water abstraction.

8. The aquatic macrophytes of the impounded (post-1941) lake are known chiefly from surveys in 1973-80 which emphasized the shore vegetation, but recorded the totally submerged Littorella uniflora, Callitriche spp. and the alga Nitella opaca. Much earlier, for the original lake, additional submerged aquatics were recorded; these included Isoetes lacustris, the alga Chara globularis, Potamogeton spp., Juncus bulbosus f. fluitans, Myriophyllum spp., and the moss Fontinalis antipyretica. At least some of these may still be present, in deeper water. Horizontal distributions are uncharted.

9. There is evidence that inputs of N are considerable and those of P probably small, consistent with analyses of atmospheric precipitation and (for $NO_3$-N) inflow becks within a largely unpopulated catchment. A very rough indirect estimate of the probable magnitude of P-loading per unit lake area was 0.27 g P $m^{-2}$ $yr^{-1}$, less than one-half of the loading (c.1.0 ± 0.35 g P $m^{-2}$ $yr^{-1}$) calculated as the likely threshold level for eutrophic conditions to develop.

10. In 1989 plans were submitted for a project to install salmon-rearing cages in the lake but later withdrawn. Such fish-farming could potentially alter the environment and its biota by nutrient enrichment, modification of bottom spawning grounds, introduction of fish disease, and competition by escaped fish. The ecological master-factor is nutrient enrichment. The present Report indicates that P-enrichment could be decisive for further eutrophication unfavourable to the rare schelly-charr combination, and that the lake is susceptible to changes in phytoplankton and possibly in the oxygen content of deep water.

11. Proposals for future research are made, having regard to possible long-term changes, the impact of short-term episodes (e.g. draw-down), and changes of

catchment or lake usage. They concern chemical conditions, plankton, fish, the bottom fauna and aquatic macrophytes. Special attention should be given to the schelly population and the circumstances governing its survival.

## 12. ACKNOWLEDGEMENTS

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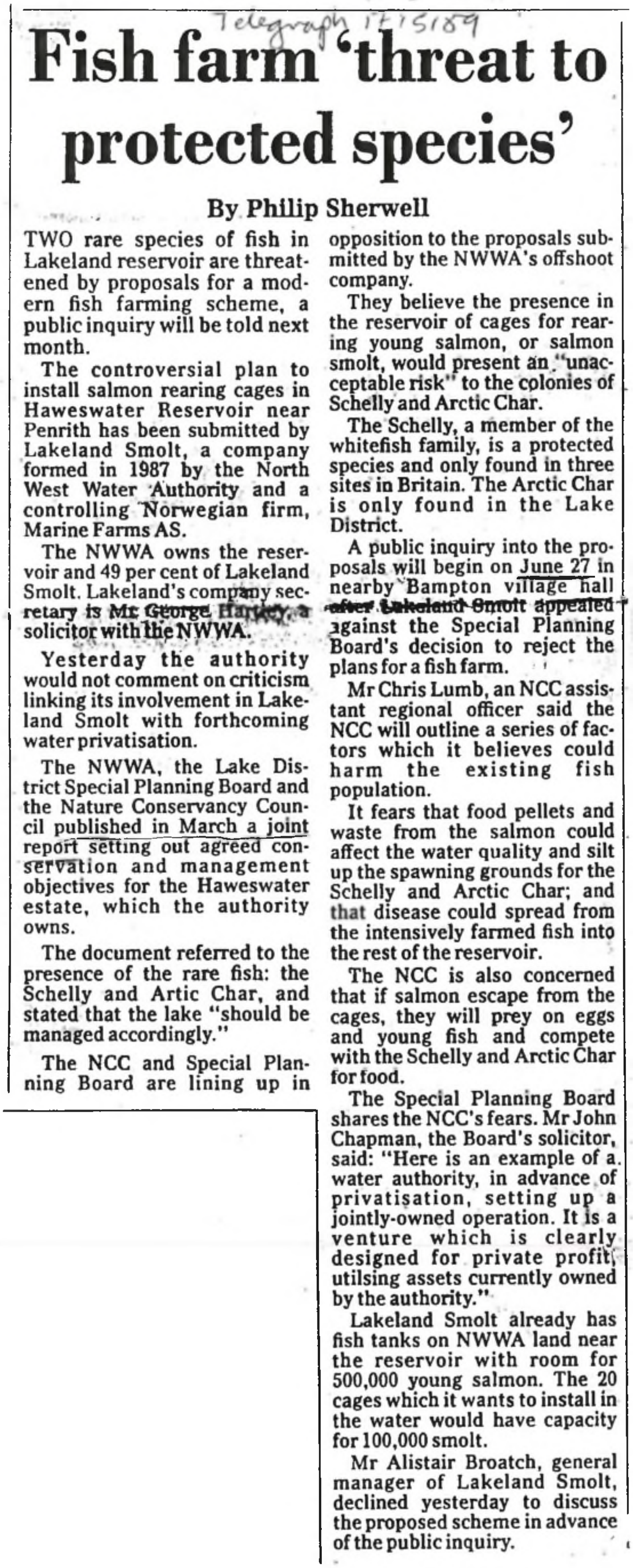
Appendix. Extract from the Daily Telegraph, 17 May 1989, relating to proposals for fish farming in Haweswater.



Telegraph 17/5/89

# Fish farm 'threat to protected species'

**By Philip Sherwell**

TWO rare species of fish in Lakeland reservoir are threatened by proposals for a modern fish farming scheme, a public inquiry will be told next month.

The controversial plan to install salmon rearing cages in Haweswater Reservoir near Penrith has been submitted by Lakeland Smolt, a company formed in 1987 by the North West Water Authority and a controlling Norwegian firm, Marine Farms AS.

The NWWA owns the reservoir and 49 per cent of Lakeland Smolt. Lakeland's company secretary is Mr George Hartley, a solicitor with the NWWA.

Yesterday the authority would not comment on criticism linking its involvement in Lakeland Smolt with forthcoming water privatisation.

The NWWA, the Lake District Special Planning Board and the Nature Conservancy Council published in March a joint report setting out agreed conservation and management objectives for the Haweswater estate, which the authority owns.

The document referred to the presence of the rare fish: the Schelly and Artic Char, and stated that the lake "should be managed accordingly."

The NCC and Special Planning Board are lining up in opposition to the proposals submitted by the NWWA's offshoot company.

They believe the presence in the reservoir of cages for rearing young salmon, or salmon smolt, would present an "unacceptable risk" to the colonies of Schelly and Arctic Char.

The Schelly, a member of the whitefish family, is a protected species and only found in three sites in Britain. The Arctic Char is only found in the Lake District.

A public inquiry into the proposals will begin on June 27 in nearby Bampton village hall ~~after Lakeland Smolt appealed~~ against the Special Planning Board's decision to reject the plans for a fish farm.

Mr Chris Lumb, an NCC assistant regional officer said the NCC will outline a series of factors which it believes could harm the existing fish population.

It fears that food pellets and waste from the salmon could affect the water quality and silt up the spawning grounds for the Schelly and Arctic Char; and that disease could spread from the intensively farmed fish into the rest of the reservoir.

The NCC is also concerned that if salmon escape from the cages, they will prey on eggs and young fish and compete with the Schelly and Arctic Char for food.

The Special Planning Board shares the NCC's fears. Mr John Chapman, the Board's solicitor, said: "Here is an example of a water authority, in advance of privatisation, setting up a jointly-owned operation. It is a venture which is clearly designed for private profit, utilising assets currently owned by the authority."

Lakeland Smolt already has fish tanks on NWWA land near the reservoir with room for 500,000 young salmon. The 20 cages which it wants to install in the water would have capacity for 100,000 smolt.

Mr Alistair Broatch, general manager of Lakeland Smolt, declined yesterday to discuss the proposed scheme in advance of the public inquiry.

TABLE 1

TABLE 1. Physical characteristics of Haweswater, before and after impoundment, in relation to other Cumbrian Lakes. (Ramsbottom 1976)

## LAKES COVERED BY THE 1937 ECHO-SOUNDING SURVEY

### GENERAL DATA ON THE LAKES

| | *Level above O.D. at time of survey* | | *Length* | *Max. depth* | *Mean depth* | *Area* | *Volume* | *Area of drainage basin* |
|---|---|---|---|---|---|---|---|---|
| | ft | m | km | m | m | $km^2$ | $m^3 \times 10^6$ | $km^2$ |
| Windermere | 129·0 | 39·3 | 17·0 | 64 | 21·30 | 14·764 | 314·546 | 230·5 |
| Wastwater | 200·2 | 61·0 | 4·8 | 76 | 39·73 | 2·910 | 115·622 | 48·5 |
| Ennerdale Water | 368·4 | 112·3 | 3·8 | 42 | 17·76 | 2·999 | 53·249 | 44·1 |
| Thirlmere | 587·7 | 179·1 | 6·0 | 46 | 16·08 | 3·267 | 52·537 | 29·3 |
| Bassenthwaite Lake | 225·6 | 68·8 | 6·2 | 19 | 5·28 | 5·284 | 27·900 | 237·9 |
| Esthwaite Water | 214·5 | 65·4 | 2·5 | 15·5 | 6·42 | 1·004 | 6·444 | 17·1 |
| Loweswater | 398·4 | 121·4 | 1·8 | 16 | 8·37 | 0·643 | 5·379 | 8·9 |
| Grasmere | 202·5 | 61·7 | 1·6 | 21·5 | 7·74 | 0·644 | 4·987 | 27·9 |
| Haweswater (Natural Lake) | 692·6 | 210·9 | 3·7 | 28 | 10·87 | 1·380 | 5·510 | 29·1 |
| Haweswater (Present Lake) | 787·6 | 239·8 | 6·9 | 57 | 23·43 | 3·909 | 76·585 | 26·6 |
| Blelham Tarn | 136·0 | 41·5 | 0·67 | 14·5 | 6·79 | 0·102 | 0·693 | 4·3 |

TABLE 2. Records of transparency by Secchi disc in Haweswater, 1984 and 1987.

| Date | Transparency (m) | Source |
|---|---|---|
| 29 Feb 1984 | 6.5 | FBA unpublished |
| 30 Apr 1984 | 6.0 | " |
| 18 Jul 1984 | 3.0 | " |
| 30 Mar 1987 | 4.25 | Mubamba 1989 |
| 29 Jun 1987 | 4.25 | " |

# TABLE 3

TABLE 3. Mean concentrations (µequiv. $l^{-1}$) of major ions in surface waters of twenty-four lakes and tarns, 1974–78. *n* is the range of the number of determinations on individual ions (Sutcliffe et al. 1982)

| | Lake | Total anions* | Total cations† | pH | $Na^+$ | $Cl^-$ | $Ca^{2+}$ | $Mg^{2+}$ | $K^+$ | Alk | $SO_4^{2-}$ + $NO_3^-$ | $SO_4^{2-}$ | $NO_3^-$ | Sampling period | *n* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Group 1* | | | | | | | | | | | | | | | |
| 1. | Levers Water | 275 | 264 | 4.7 | 135 | 153 | 43 | 57 | 9 | −168 | 138 | 101 | 30 | Aug 74–Mar 78 | 44–64 |
| 2. | Buttermere | 342 | 336 | 6.2 | 160 | 192 | 118 | 51 | 7 | 48 | 102 | 91 | 9 | Apr 74–Jul 76 | 25–29 |
| 3. | Blea Tarn | 348 | 340 | 6.3 | 145 | 154 | 142 | 46 | 7 | 57 | 137 | 123 | 7 | May 74–Jan 78 | 82–131 |
| 4. | Thirlmere | 356 | 357 | 6.5 | 159 | 175 | 148 | 42 | 8 | 50 | 131 | 112 | 13 | May 74–Jul 76 | 24–28 |
| 5. | Wastwater | 357 | 358 | 6.7 | 172 | 186 | 114 | 62 | 10 | 50 | 121 | 101 | 18 | Apr 74–Jul 76 | 28–32 |
| 6. | Ennerdale Water | 368 | 369 | 6.5 | 187 | 208 | 100 | 72 | 10 | 42 | 118 | 102 | 15 | Apr 74–Jul 76 | 26–30 |
| 7. | Crummock Water | 379 | 389 | 6.6 | 181 | 215 | 126 | 73 | 9 | 43 | 121 | 106 | 13 | Jan 75–Jul 76 | 15–17 |
| 8. | Goats Water | 392 | 383 | 6.4 | 167 | 190 | 127 | 78 | 11 | 34 | 168 | 128 | 34 | May 74–Apr 76 | 17–19 |
| *Group 2* | | | | | | | | | | | | | | | |
| 9. | Haweswater | 485 | 487 | 6.8 | 148 | 155 | 249 | 78 | 12 | 175 | 155 | 142 | 15 | May 74–Nov 75 | 18–21 |
| 10. | Grasmere | 487 | 487 | 6.8 | 184 | 191 | 237 | 56 | 10 | 141 | 155 | 138 | 17 | Jun 74–Feb 78 | 77–119 |
| 11. | Rydal Water | 505 | 505 | 6.8 | 193 | 200 | 240 | 60 | 12 | 156 | 149 | 135 | 13 | Apr 74–Jun 76 | 47–85 |
| 12. | Derwentwater | 511 | 520 | 6.7 | 220 | 298 | 236 | 55 | 9 | 98 | 115 | 109 | 8 | Apr 74–Jul 76 | 25–28 |
| 13. | Brotherswater | 550 | 548 | 6.7 | 195 | 197 | 276 | 68 | 9 | 188 | 165 | 157 | 12 | Jul 74–Jul 76 | 22–24 |
| 14. | Ullswater | 555 | 564 | 7.0 | 172 | 178 | 293 | 87 | 12 | 231 | 146 | 136 | 11 | May 74–Jul 76 | 26–30 |
| 15. | Windermere (N) | 608 | 611 | 7.0 | 202 | 222 | 314 | 81 | 14 | 204 | 182 | 157 | 24 | Apr 74–Mar 78 | 79–122 |
| 16. | Coniston Water | 640 | 644 | 6.9 | 220 | 259 | 318 | 91 | 15 | 178 | 203 | 183 | 22 | May 74–Jul 76 | 27–31 |
| *Group 3* | | | | | | | | | | | | | | | |
| 17. | Windermere (S) | 677 | 683 | 7.1 | 219 | 242 | 355 | 92 | 17 | 236 | 199 | 171 | 25 | Apr 74–Feb 78 | 84–123 |
| 18. | Bassenthwaite Lake | 681 | 690 | 6.9 | 251 | 309 | 310 | 111 | 18 | 189 | 183 | 147 | 16 | Apr 74–Jul 76 | 22–25 |
| 19. | Loweswater | 693 | 708 | 6.9 | 266 | 321 | 291 | 130 | 21 | 175 | 197 | 171 | 30 | Apr 74–Jul 76 | 25–29 |
| 20. | Blelham Tarn | 930 | 926 | 7.0 | 222 | 248 | 542 | 136 | 26 | 403 | 279 | 242 | 34 | May 74–Mar 78 | 64–90 |
| 21. | Esthwaite Water | 933 | 923 | 7.1 | 249 | 282 | 526 | 123 | 25 | 386 | 265 | 231 | 31 | May 74–Feb 78 | 67–93 |
| *Tarns on Claife Heights* | | | | | | | | | | | | | | | |
| 22. | Hodsons | 650 | 650 | 6.7 | 251 | 295 | 276 | 113 | 10 | 122 | 233 | — | — | Sep 74–Nov 75 | 11–15 |
| 23. | Wise Een | 652 | 641 | 6.9 | 210 | 245 | 328 | 91 | 12 | 197 | 210 | — | — | Aug 74–Nov 75 | 12–16 |
| 24. | Wraymires | 654 | 658 | 6.8 | 213 | 248 | 337 | 96 | 12 | 202 | 204 | — | — | Aug 74–Nov 75 | 12–16 |

*Sum of means for $Cl^-$, $SO_4^{2-}$ + $NO_3^-$ and Alk.

†Sum of means for $Na^+$, $K^+$, $Ca^{2+}$ and $Mg^{2+}$ (and 20 µequiv. $l^{-1}$ $H^+$ for Levers Water).

Table 4. Concentrations of major ions, nitrate, and pH in near-surface water of Haweswater, 1953-6 and 1974-5. n, number of analyses; C.L., 95% confidence limits; C.V, coefficient of variation; S.A., total anions of strong acids ($SO_4^{2-}$ + $Cl^-$ + $NO_3^-$). (Carrick & Sutcliffe 1982) Concentrations in μeq $l^{-1}$.

| Date | Na | Ca | Mg | K | Alk | S.A. | Cl | $NO_3$ | $SO_4$ | pH |
|---|---|---|---|---|---|---|---|---|---|---|
| 24.4.53 | (126) | (238) | (63) | (5) | 154 | 274 | 151 | | | |
| 6.5.55 | (135) | (252) | (46) | (9) | 144 | 284 | 136 | 7 | 141 | |
| 10.6.55 | (126) | (222) | (57) | (8) | 154 | 272 | 142 | 6 | 124 | |
| 8.7.55 | (130) | (210) | (77) | (9) | 170 | 262 | 132 | 8 | 122 | |
| 17.10.55 | (122) | (229) | (59) | (8) | 157 | 264 | 174 | | | |
| 9.11.55 | (126) | (235) | (86) | (6) | 158 | 278 | 184 | 17 | 77 | |
| 20.12.55 | (135) | (250) | (60) | (6) | 151 | 295 | 147 | 13 | 135 | |
| 5.1.56 | (135) | (240) | (61) | (6) | 147 | 275 | 141 | 6 | 128 | |
| 15.3.56 | (131) | (264) | (31) | (9) | 160 | 272 | 132 | 13 | 127 | |
| Period: 6.5.55 - 15.3.56 | | | | | | | | | | |
| n | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 7 | 7 | |
| mean | 130 | 238 | 60 | 8 | 155 | 275 | 149 | 10 | 122 | |
| C.L. | 4 | 15 | 14 | 1 | 7 | 9 | 16 | 4 | 19 | |
| C.V. | 4 | 7 | 28 | 18 | 5 | 4 | 13 | 43 | 19 | |
| 3.5.74 | 153 | 230 | 80 | 12.5 | 158 | 300 | 162 | 18 | 120 | |
| 23.5.74 | 156 | 240 | 76 | 12.5 | 150 | 305 | 169 | 16 | 120 | |
| 21.6.74 | 160 | 260 | 72 | 14.5 | 163 | 330 | 175 | 18 | 137 | |
| 3.7.74 | 149 | 260 | 92 | 10.5 | 171 | 310 | 164 | 15 | 131 | 7.6 |
| 27.7.74 | 149 | 260 | 36 | 12 | 170 | 310 | 154 | 15 | 141 | 7.2 |
| 15.8.74 | 153 | 240 | 80 | 12 | 144 | 330 | 159 | 17 | 154 | 6.3 |
| 12.9.74 | 146 | 240 | 80 | 10.5 | 176 | 305 | 152 | 14 | 139 | 7.2 |
| 30.10.74 | 153 | 280 | 92 | 16.5 | 206 | 305 | 164 | | | 6.9 |
| 29.11.74 | 146 | 250 | 60 | 12 | 168 | 300 | 159 | | | 6.2 |
| 23.1.75 | 144 | 230 | 70 | 11.5 | 145 | 305 | 155 | | | 7.0 |
| 20.2.75 | 150 | 220 | 70 | 14.5 | 144 | 305 | 168 | | | 6.9 |
| 27.3.75 | 144 | 220 | 90 | 9.5 | 148 | | 155 | | | 6.7 |
| 16.5.75 | 157 | 230 | 60 | 10 | 163 | 336 | 166 | 12 | 158 | 7.0 |
| 4.6.75 | 142 | 240 | 90 | 9.5 | 170 | 314 | 152 | 13 | 149 | 7.1 |
| 30.6.75 | 150 | 250 | 100 | 12.5 | 195 | 327 | 149 | 11 | 167 | 7.1 |
| 23.7.75 | 148 | 260 | 84 | 13.5 | 204 | | 152 | | | 7.0 |
| 11.8.75 | 153 | 260 | 80 | 15 | 207 | | 154 | | | 7.1 |
| 28.8.75 | 144 | 270 | 70 | 10.5 | 215 | | 145 | | | 6.8 |
| 12.9.75 | 144 | 260 | 70 | 10 | 201 | | 147 | | | 6.8 |
| 23.10.75 | 135 | 260 | 100 | 9 | 180 | 292 | 107 | | | 6.7 |
| 25.11.75 | 137 | 260 | 88 | 8.5 | 190 | 299 | 144 | | | 7.0 |
| Period: 3.5.74 - 25.11.75 | | | | | | | | | | |
| n | 21 | 21 | 21 | 21 | 21 | 16 | 21 | 10 | 10 | 18 |
| mean | 148 | 249 | 78 | 12 | 175 | 311 | 155 | 15 | 142 | 6.8 |
| C.L. | 3 | 8 | 7 | 1 | 11 | 7 | 6 | 2 | 11 | - |
| C.V. | 4 | 7 | 19 | 18 | 13 | 4 | 9 | 16 | 11 | - |

TABLE 5

Table 5. Concentrations of major ions, nitrate and pH in tributary becks within the natural catchment of Haweswater (see Fig. 1) plus one beck (site 12) with offtake diverted to the lake. Sampling was in spring and summer of 1985 under wet or spate conditions. (Sutcliffe & Carrick, unpubl.).

| Site No. | Name & date | $Na^+$ | $Cl^-$ | $K^+$ | $Ca^{2+}$ | $Mg^{2+}$ | $SO4^{2-}$ | $NO3^-$ | pH | Alk |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | μeq $l^{-1}$ | | | | | | |
| 1 | 3/4/85 (wet) | 147 | 131 | 6 | 160 | 51 | 157 | 5 | 6.4 | 52 |
| | 13/8/85 [spate] | 116 | 77 | 1 | 343 | 65 | 113 | 2 | 7.2 | 321 |
| 2 | Guerness Gill | | | | | | | | | |
| | 3/4/85 (wet) | 137 | 124 | 6 | 170 | 49 | 147 | 10 | 6.6 | 62 |
| | 13/8/85 [spate] | 98 | 72 | 1 | 184 | 49 | 91 | 1 | 6.8 | 152 |
| 3 | Hopgill Beck | | | | | | | | | |
| | 3/4/85 (wet) | 134 | 124 | 6 | 192 | 68 | 129 | 50 | 6.6 | 68 |
| | 13/8/85 [spate] | 91 | 70 | 1 | 230 | 68 | 86 | 3 | 7.2 | 202 |
| 4 | Gatescarth Beck | | | | | | | | | |
| | 3/4/85 (wet) | 129 | 132 | 13 | 225 | 75 | 123 | 54 | 6.8 | 109 |
| | 13/8/85 [spate] | 111 | 93 | 2 | 264 | 76 | 93 | 9 | 7.0 | 246 |
| 5 | Mardale Beck | | | | | | | | | |
| | 3/4/85 (wet) | 134 | 130 | 5 | 125 | 50 | 104 | 48 | 5.8 | 12 |
| | 13/8/85 [spate] | 95 | 82 | 2 | 154 | 40 | 82 | 10 | 6.6 | 85 |
| 6 | Riggindale Beck | | | | | | | | | |
| | 3/4/85 (wet) | 134 | 136 | 7 | 172 | 50 | 104 | 28 | 6.6 | 67 |
| | 13/8/85 [spate] | 109 | 95 | 2 | 273 | 52 | 86 | 6 | 7.0 | 234 |
| 7 | Randale Beck | | | | | | | | | |
| | 3/4/85 (wet) | 127 | 119 | 5 | 120 | 41 | 100 | 29 | 6.2 | 32 |
| | 13/8/85 [spate] | 102 | 85 | 1 | 227 | 39 | 66 | 4 | 7.1 | 182 |
| 8 | Whelter Beck | | | | | | | | | |
| | 3/4/85 (wet) | 130 | 128 | 7 | 185 | 48 | 106 | 22 | 6.8 | 101 |
| 9 | Pultsgill Beck | | | | | | | | | |
| | 3/4/85 (wet) | 150 | 151 | 6 | 303 | 67 | 133 | 37 | 7.1 | 182 |
| 10 | Measand Beck | | | | | | | | | |
| | 3/4/85 (wet) | 140 | 139 | 9 | 225 | 78 | 90 | 26 | 7.1 | 170 |
| 11 | Birkhouse Beck | | | | | | | | | |
| | 3/4/85 (wet) | 168 | 169 | 9 | 774 | 209 | 219 | 10 | 7.7 | 758 |
| 12 | Naddle Beck | | | | | | | | | |
| | 3/4/85 (wet) | 226 | 262 | 43 | 695 | 139 | 223 | 196 | 7.2 | 405 |
| | 13/8/85 [spate] | 130 | 82 | 6 | 341 | 75 | 119 | 13 | 6.9 | 312 |
| 13 | Wet Sleddale Res. | | | | | | | | | |
| | 26/3/85 | 167 | 169 | 12 | 175 | 76 | 164 | 21 | 6.0 | 47 |
| | 7/6/85 | 138 | 132 | 8 | 163 | 70 | 157 | 10 | 6.5 | 81 |
| | 9/7/85 | 133 | 114 | 7 | 171 | 72 | 175 | 7 | 6.7 | 98 |
| | 13/8/85 [swollen] | 86 | 51 | 3 | 146 | 45 | 197 | 2 | 5.7 | 57 |
| | 12/9/85 | 85 | 65 | 3 | 113 | 45 | 147 | 2 | 6.2 | 65 |

**TABLE 6**

Table 6. Long-term variation of plant nutrients in Haweswater, 1949-1987. Sources : 1949-50, Lund unpubl.; 1974, Heron & Rigg unpubl.; 1977, Godhino unpubl.; 1984, Heaney unpubl.; 1987, Mubamba 1989. All analyses performed by the FBA Analytical Laboratory. The 1949-50 values for alkalinity are corrected by subtraction of 20 μeq l$^{-1}$ (Sutcliffe *et al*., 1982). The 1949-50 values for NO$_3$-N (x) are corrected by the relationship y = 1.20 x + 30, based on tests of the phenol disulphonic acid method on Windermere water.

| Date | alk (HCO$_3^-$) μeq l$^{-1}$ (mg CaCO$_3$/l x 20) | NO$_3$-N μg l$^{-1}$ orig. (x) | corr. (y) | NH$_4$-N μg l$^{-1}$ | PO$_4$-P μg l$^{-1}$ | Total P μg l$^{-1}$ | SiO$_2$ mgl$^{-1}$ |
|---|---|---|---|---|---|---|---|
| 1949: | | | | | | | |
| 3 Feb | 144 | 100 | 150 | - | <1 | - | 1.6 |
| 14 | 180 | 150 | 210 | - | <1 | - | 1.8 |
| 3 Mar | 172 | 100 | 150 | - | - | - | 2.2 |
| 17 | - | 90 | 138 | - | - | - | - |
| 30 | - | 130 | 186 | - | - | - | - |
| 12 Apr | 144 | 120 | 174 | - | - | - | 2.0 |
| 28 | - | 160 | 222 | - | <1 | - | 3.0 |
| 11 May | 152 | 110 | 162 | - | <1 | - | 2.6 |
| 7 June | 144 | 90 | 138 | - | - | - | 2.4 |
| 20 June | 152 | 90 | 138 | - | - | - | 2.2 |
| 28 July | 150 | 60 | 102 | - | - | - | 1.3 |
| 3 Aug | 164 | <30 | <66 | - | <1 | - | 1.7 |
| 14 | 166 | 55 | 96 | - | - | - | 1.4 |
| 30 | 160 | 30 | 66 | - | - | - | 2.0 |
| 12 Sept | | 70 | 114 | - | 1 | - | 1.1 |
| 28 | 172 | 90 | 138 | - | 1 | - | 1.2 |
| 10 Oct | 178 | 80 | 126 | - | <1 | - | 1.2 |
| 22 | 164 | 90 | 138 | - | - | - | 1.5 |
| 7 Nov | 160 | 100 | 150 | - | 1 | - | 2.1 |
| 22 | 152 | 150 | 210 | - | <1 | - | 1.6 |
| 3 Dec | 156 | - | | - | <1 | - | 1.3 |
| 1950: | | | | | | | |
| 3 Jan | 146 | - | | - | 1 | - | 1.8 |
| 15 | 142 | 150 | 210 | - | - | - | 1.4 |
| 6 Feb | 138 | - | | - | - | - | 1.3 |
| 14 | 134 | 150 | 210 | - | - | - | 1.2 |
| 27 | 144 | 150 | 210 | - | <1 | - | 1.4 |
| 11 Mar | 132 | 150 | 210 | - | 1 | - | 1.6 |
| 22 | 130 | 160 | 222 | - | <1 | - | 1.3 |
| 11 Apr | 128 | 130 | 186 | - | | - | 1.1 |
| 24 | 132 | 140 | 198 | - | <1 | - | 1.2 |
| 18 May | 156 | 110 | 162 | - | <1 | - | 1.3 |
| 1974: | | | | | | | |
| 7 Feb | - | 165 | | 6 | 1.9 | 13 | 1.73 |
| 1977: | | | | | | | |
| 26 Oct | - | 261 | | 9 | <0.6 | - | - |
| 1984: | | | | | | | |
| 18 Feb | - | 347 | | - | <3 | 6.8 | 2.10 |
| 30 Apr | - | 331 | | - | <3 | 6.5 | 1.63 |
| 19 July | - | 322 | | - | <0.6 | - | 1.41 |
| 25 Oct | - | 298 | | - | 2.2 | 7.2 | 1.62 |
| 1987: | | | | | | | |
| 30 Mar | 94 | 315 | | <5 | <0.6 | 11.0 | 1.66 |
| 29 Jun | 122 | 302 | | 5 | 3.1 | 8.4 | 1.31 |
| 30 Sept | 173 | 228 | | <5 | 0.6 | 13.7 | 1.34 |

TABLE 11

Table 11. Seasonal distribution of zooplankters (No. $m^{-3}$) in March, June and September 1989. (Mubamba 1989)

| Organism | Mar | Jun | Sep |
|---|---|---|---|
| *Eudiaptomus* | 238 | 2258 | 484 |
| Cyclopoids | | 746 | 143 |
| *Daphnia* | 40 | 503 | 368 |
| *Diaphanosoma* | | 10 | |
| *Leptodora* | | | 5 |
| *Bosmina* | 59 | 157 | 10 |
| Crustacean nauplii | 4 | 20 | 21 |
| Crustacean eggs | 53 | 27 | 32 |
| *Asplanchna* | | 27 | |
| *Keratella* | | 7 | 5 |
| *Kellicottia* | | 55 | |
| *Conochilus* | | 51 | |
| Ostracoda | 2 | | |
| Chironomidae | 2 | | 10 |

TABLE 12

Table 12. Stomach contents of perch, trout and charr from Haweswater, 1986-87. (Mubamba 1989)

|  | Perch |  | Trout |  |  | Charr |  |  |
|---|---|---|---|---|---|---|---|---|
| Month | Jun | Sep | Nov | Jun | Sep | Nov | Jun | Sep |
| No.of fish examined | 6 | 8 | 10 | 10 | 11 | 28 | 15 | 20 |
| Empty stomachs | 0 | 1 | 2 | 2 | 1 | 25 | 0 | 6 |
| % Occurrence of prey |  |  |  |  |  |  |  |  |
| *Daphnia* | 8.3 |  |  |  |  | 67.0 | 11.1 | 18.2 |
| *Gammarus* | 33.4 | 33.3 | 6.7 | 5.9 | 15.0 |  |  |  |
| Ephemeroptera | 8.3 |  |  |  |  |  |  |  |
| Plecoptera | 16.7 |  |  | 5.9 |  |  |  |  |
| Trichoptera | 16.7 |  | 13.3 | 11.8 |  |  |  |  |
| Coleoptera | 8.3 |  | 46.7 | 11.8 | 5.0 |  |  |  |
| Fish fry | 8.3 | 6.7 |  |  |  |  |  |  |
| Chironomid larvae |  | 13.3 | 6.7 |  |  |  |  | 3.0 |
| Chironomid pupae |  | 26.7 |  | 5.9 | 20.0 |  |  | 3.0 |
| *Bythotrephes* |  | 6.7 |  | 5.9 | 20.0 | 33.0 | 38.9 | 42.5 |
| Cyclopoids |  | 6.7 |  |  |  |  |  |  |
| Lumbricidae |  | 6.7 |  |  |  |  |  |  |
| Plant remains |  |  | 6.7 | 17.6 |  |  |  |  |
| Air-borne insects |  |  | 6.7 | 17.5 |  |  |  | 3.0 |
| Other insect larvae |  |  | 6.7 | 11.8 | 10.0 |  |  |  |
| *Pisidium* |  |  | 6.7 |  | 5.0 |  |  |  |
| Salmonid fingerling |  |  |  | 5.9 |  |  |  |  |
| *Bosmina* |  |  |  |  | 5.0 |  | 36.1 | 3.0 |
| *Planorbis* (Gastropoda) |  |  |  |  | 5.0 |  |  |  |
| *Leptodora* |  |  |  |  | 10.0 |  | 5.6 | 15.2 |
| *Eudiaptomus* |  |  |  |  |  |  | 8.3 | 9.1 |
| *Diaphanosoma* |  |  |  |  |  |  |  | 3.0 |

TABLE 13

Table 13. Range of critical loadings of total phosphorus ($L_c$) for Haweswater. This is calculated from the mean annual inflows (1961-1984) using the equation of Vollenweider (1976), $L_c = (10 \text{ to } 20) \, . \, q_s \, (1 + \sqrt{\bar{z}/q_s})$ where $L_c$ = critical total phosphorus loading (mg $m^{-2}$ $yr^{-1}$), $\bar{z}$ = mean depth (m), and $q_s$ = hydraulic load defined as $Q_y/A_o$ where $Q_y$ = total yearly discharge ($m^3$ $yr^{-1}$) and $A_o$ = lake surface area ($m^2$).

| | |
|---|---|
| $\bar{z}$ | 23.4 (m) |
| $A_o$ | $3.90 \times 10^6$ ($m^2$) |
| $Q_y$ | $72.4 \times 10^6$ (m $yr^{-1}$) |
| $q_s$ | 35.8 (m $yr^{-1}$) |
| $L_c$ | 394 - 789 (mg P $m^{-2}$ $yr^{-1}$) |

FIG. 1

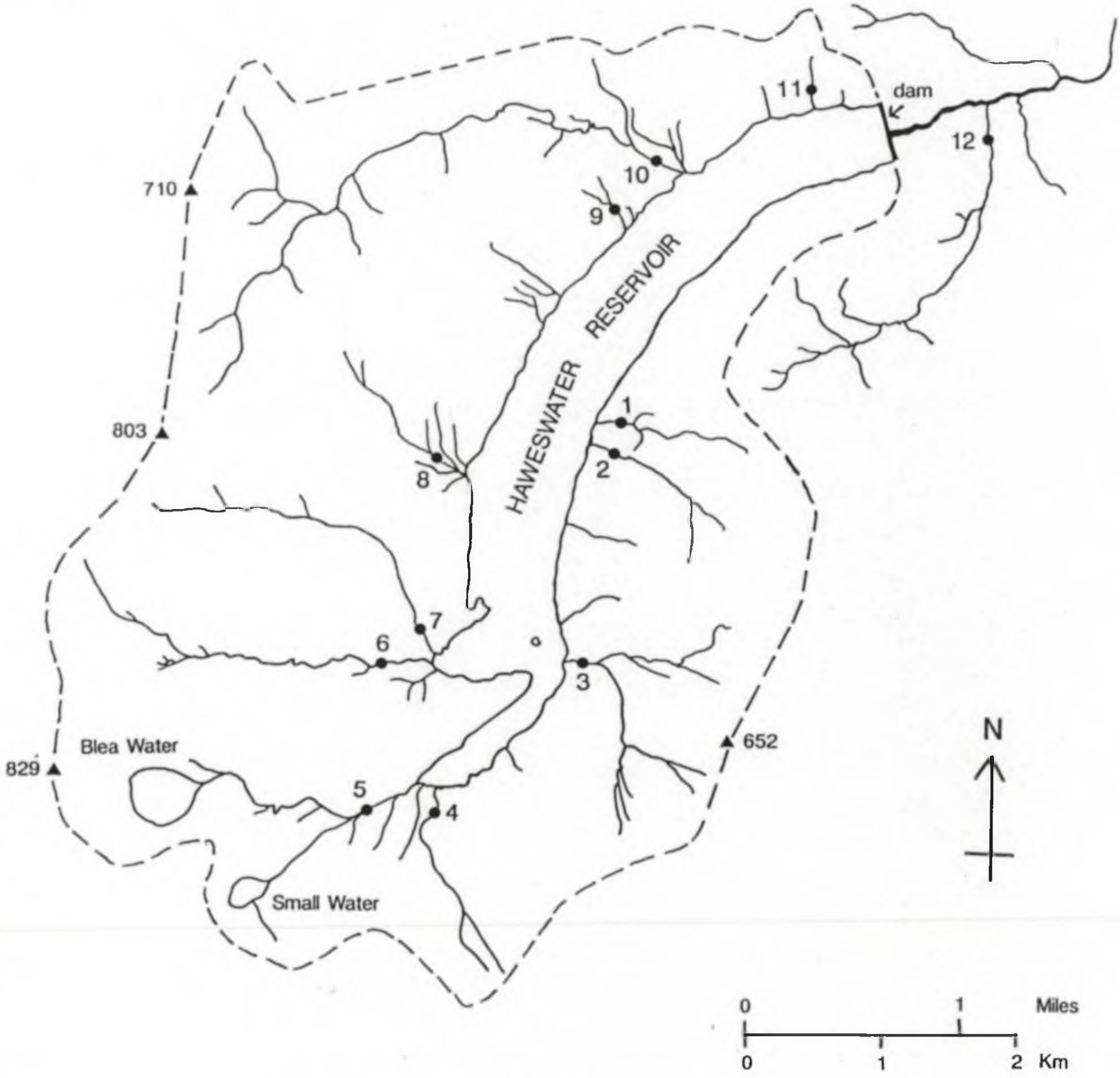
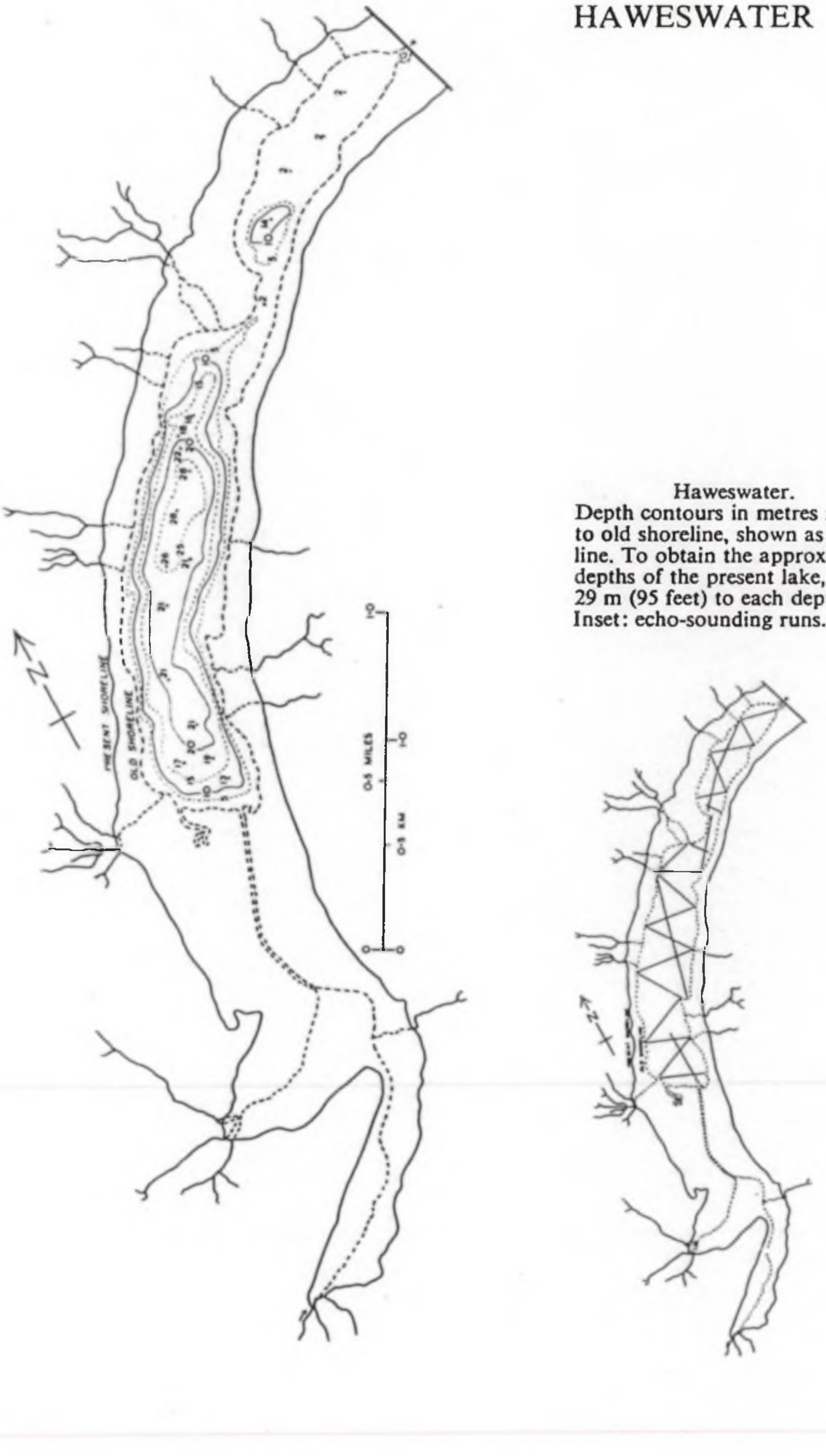


Fig. 1. Map of Haweswater and surrounding region. Limits of the natural catchment, including heights in metres, are marked by a broken line; filled circles indicate stations for beck samples numbered as in Table 5.

FIG.2 (a)


HAWESWATER

Haweswater.
Depth contours in metres refer to old shoreline, shown as a broken line. To obtain the approximate depths of the present lake, add 29 m (95 feet) to each depth.
Inset: echo-sounding runs.

Fig. 2. Bathymetric features of Haweswater, showing (a) depth contours (in m) of the old natural lake in relation to the present shoreline, (b) depth - area - volume relationships of the natural and present lake basins. From Ramsbottom (1976).

# HAWESWATER

The data for Haweswater require an explanatory note. The echo-survey was carried out before the level of the lake was raised 29 metres (95 feet) by the construction of the dam, which was completed in 1941. Data are given for the old lake basin (Table i ) computed from the echo-soundings. The data for the present lake basin (Table ii ), are arbitrary, and obtained by the addition of 29 metres (95 feet) to the old depths; consequently there are no soundings for the region from the present shoreline down to 29 metres.

TABLE i HAWESWATER (NATURAL LAKE BASIN)

| *Depth of contour* m | *Area enclosed by contour* km² | % | *Layer* m | *Volume of layer* m³×10⁶ | % |
|---|---|---|---|---|---|
| 0 | 1·380 | 100 | 0-5 | 5·510 | 37 |
| 5 | 0·824 | 60 | 5-10 | 3·730 | 25 |
| 10 | 0·668 | 48 | 10-15 | 2·875 | 19 |
| 15 | 0·482 | 35 | 15-20 | 1·908 | 13 |
| 20 | 0·281 | 20 | 20-25 | 0·875 | 6 |
| 25 | 0·069 | 5 | 25-28 | 0·104 | 0·7 |
| 28 (bottom) | | | | | |

Max. depth: 28·0 m Mean depth: 10·9 m Total Volume: 15·0 $m^3 \times 10^6$

TABLE ii HAWESWATER (PRESENT LAKE BASIN)

| *Corresponding old contour* m | *Depth of contour* m | *Area enclosed by contour* km² | % | *Layer* m | *Volume of layer* m³×10⁶ | % |
|---|---|---|---|---|---|---|
| | 0 | 3·909 | 100 | 0-29 | 76·585 | 84 |
| 0 | 29 | 1·380 | 35 | 29-34 | 5·510 | 6 |
| 5 | 34 | 0·824 | 21 | 34-39 | 3·730 | 4 |
| 10 | 39 | 0·668 | 17 | 39-44 | 2·875 | 3 |
| 15 | 44 | 0·482 | 12 | 44-49 | 1·908 | 2 |
| 20 | 49 | 0·281 | 7 | 49-54 | 0·875 | 1 |
| 25 | 54 | 0·069 | 0·2 | 54-57 | 0·104 | 0·1 |
| 28 (bottom) | 57 (bottom) | | | | | |

Max. depth: 57·0 m Mean depth: 23·4 m Total Volume: 91·6 $m^3 \times 10^6$

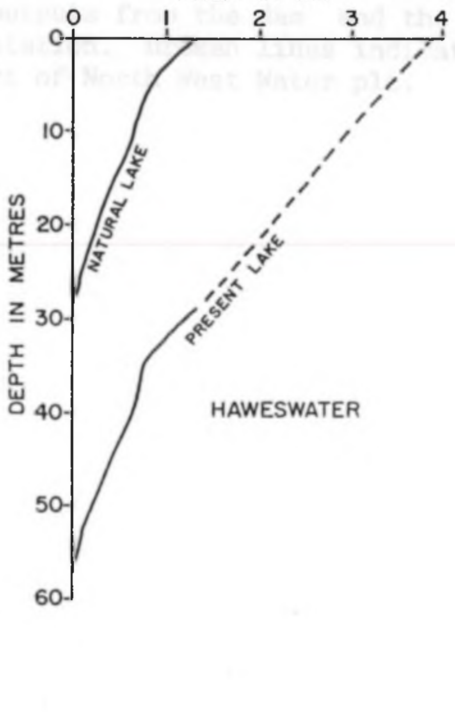


FIG.8

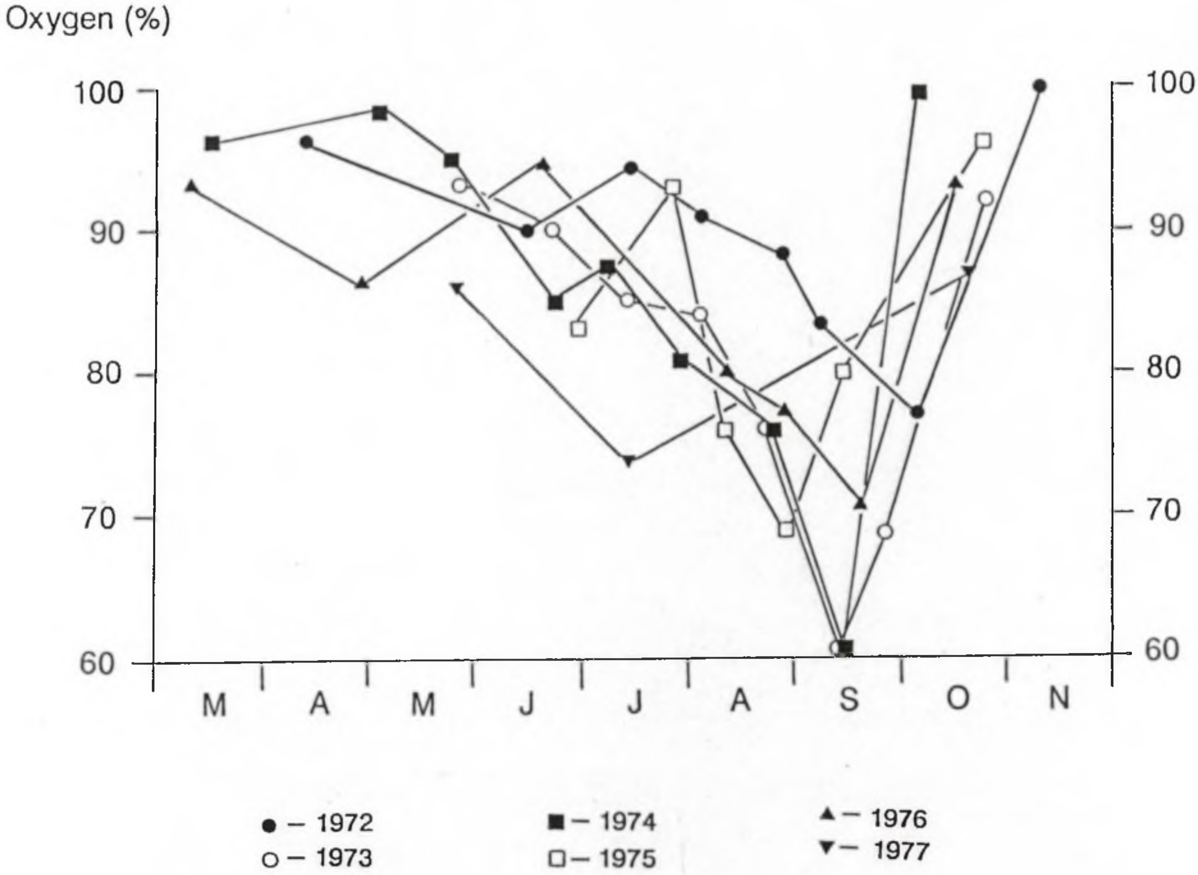


Fig. 8. Seasonal change in the relative oxygen saturation of near-bottom water during the years 1972-77. Oxygen saturation values are referred to 100% in surface water; the depths involved are in the range 34-50 m.

FIG.9

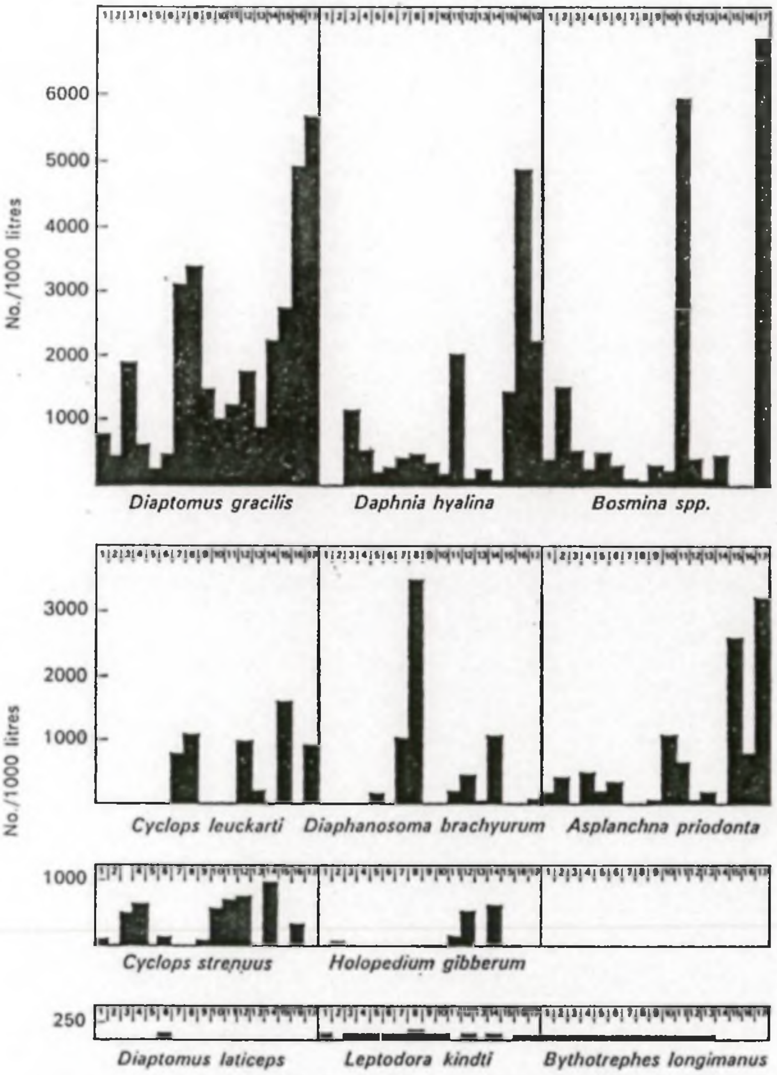
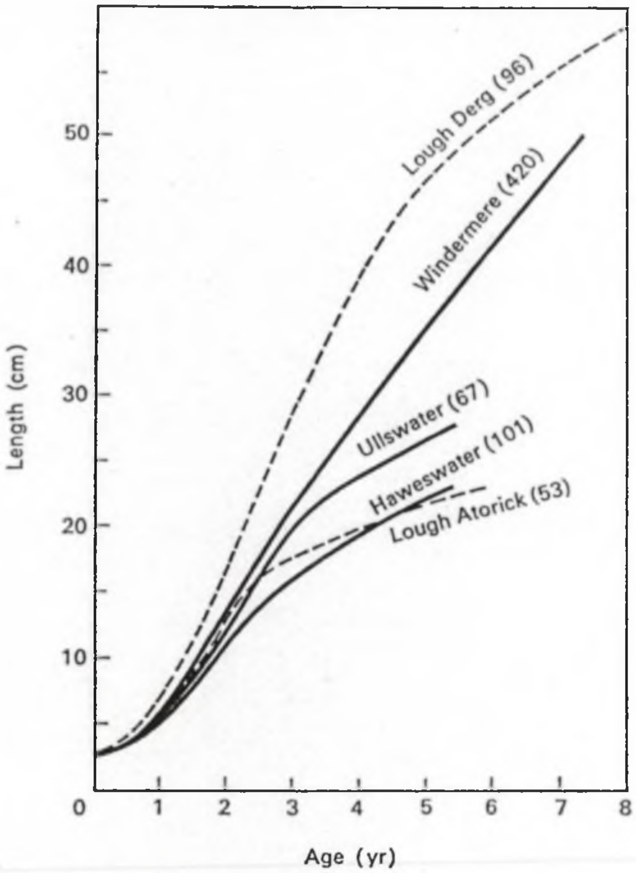


Fig. 9. Mean numbers per 1000 litres of eleven common planktonic Crustacea caught in the lakes of the Lake District in vertical net hauls in 1961 and 1962.

1. Wastwater
2. Ennerdale
3. Buttermere
4. Crummock Water
5. Thirlmere
6. Haweswater
7. Derwentwater
8. Bassenthwaite Lake
9. Coniston Water
10. Ullswater
11. Brothers Water
12. Rydal Water
13. Elterwater
14. Grasmere
15. Blelham Tarn
16. Loweswater
17. Esthwaite Water

(Smyly, W. J. P. (1968), *J. Anim. Ecol.* 37).

FIG.10



No. of fish examined ( )

Fig. 10. The average growth rates of brown trout in lakes (Swynnerton, G. H. and Worthington, E. B. (1939), From Macan 1970.

FIG.11

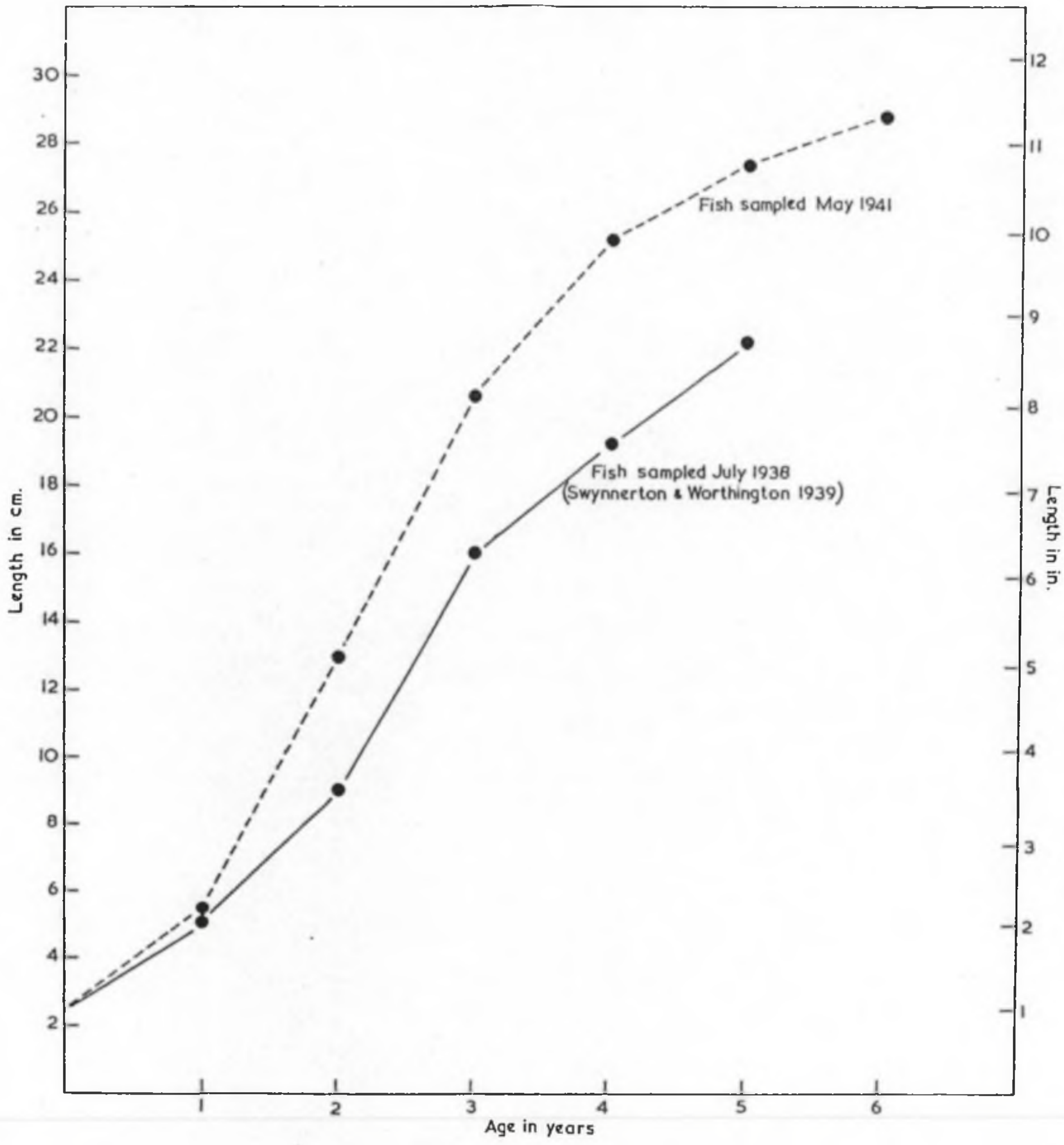


Fig. 11-Growth of brown trout in Haweswater before (fish sampled July 1938) and after (fish sampled May 1941) the raising of the level of the lake. From Frost 1956.

FIG.12

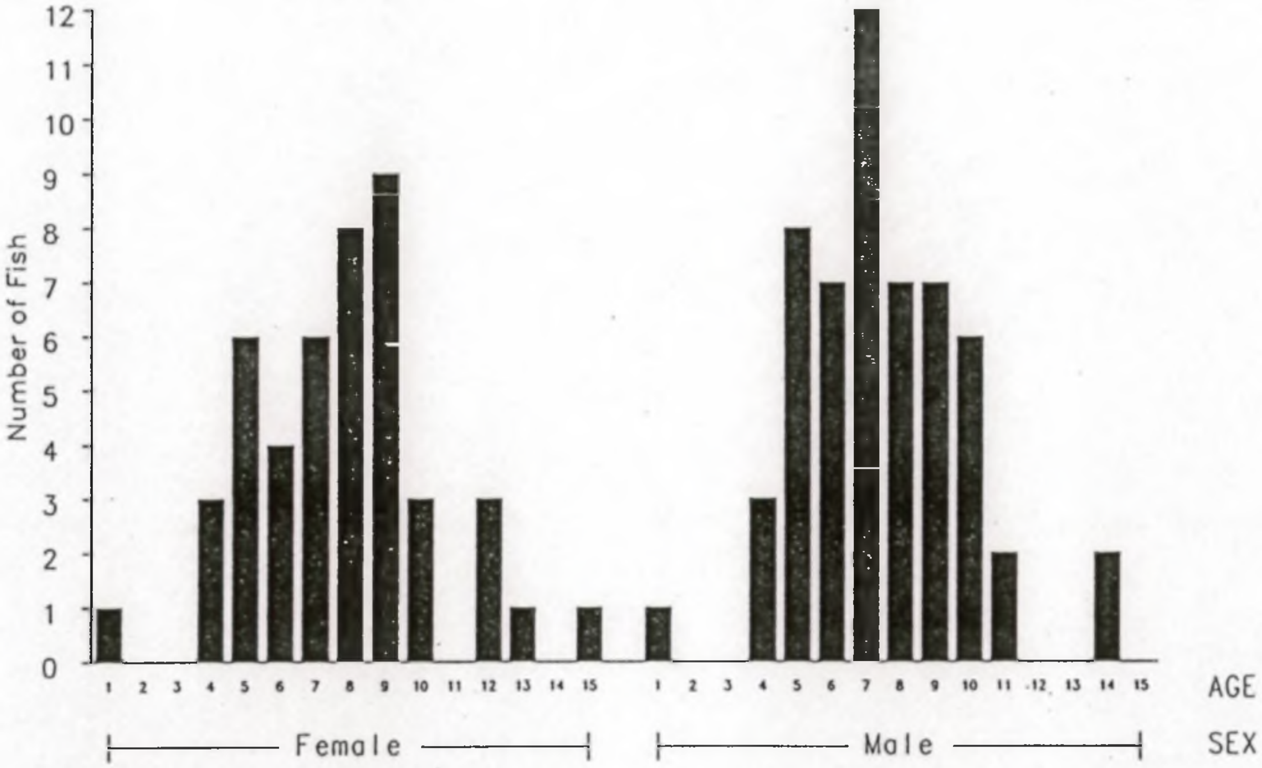


Fig. 12. Age composition of schelly from Haweswater, Nov 1986 - Sept 1987. From Mubamba 1989.

FIG.13

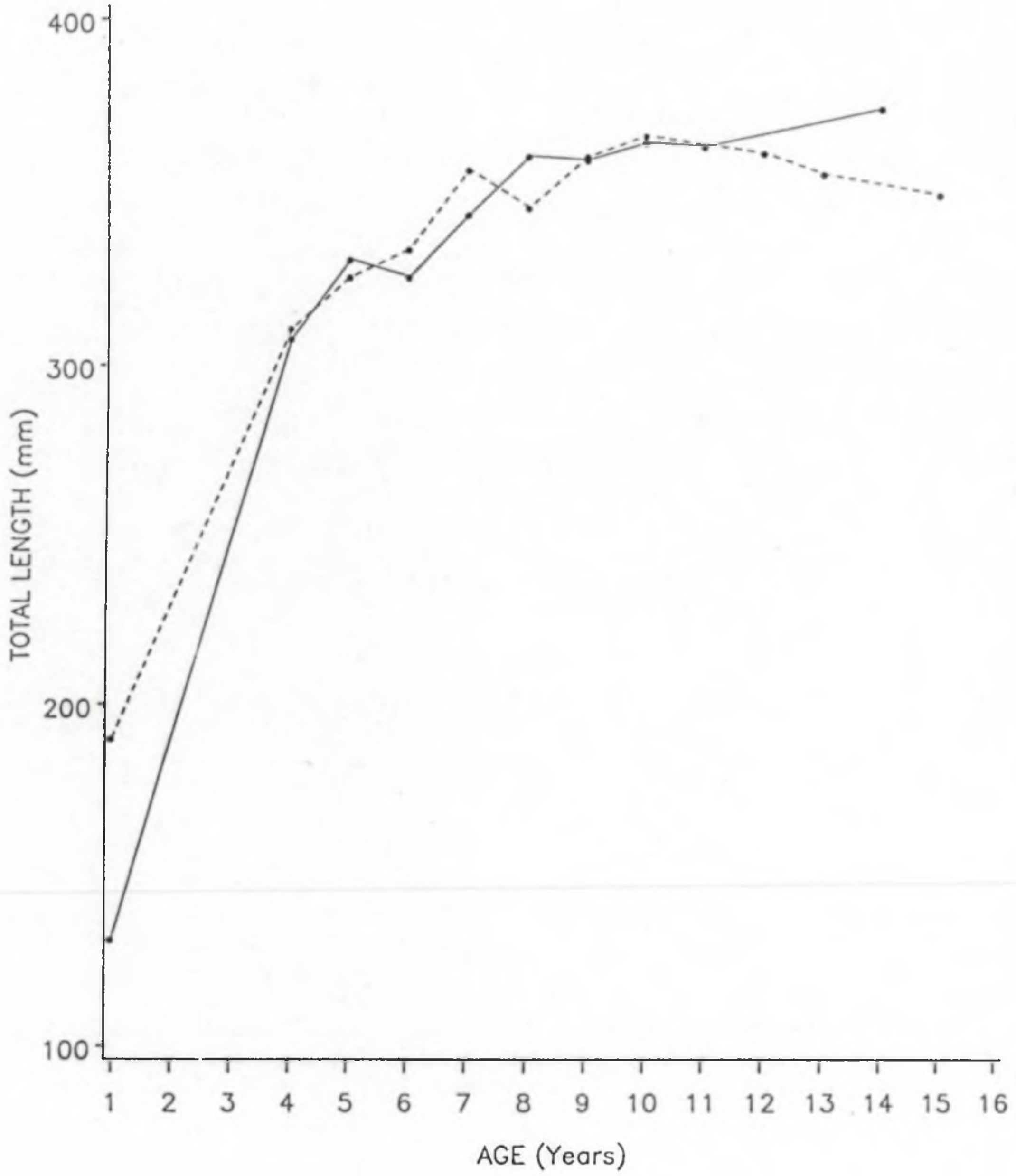


Fig. 13. Growth of male and female schelly in Haweswater in 1987

Solid line = males, Dashed line = females

From Mubamba 1989.

FIG.14

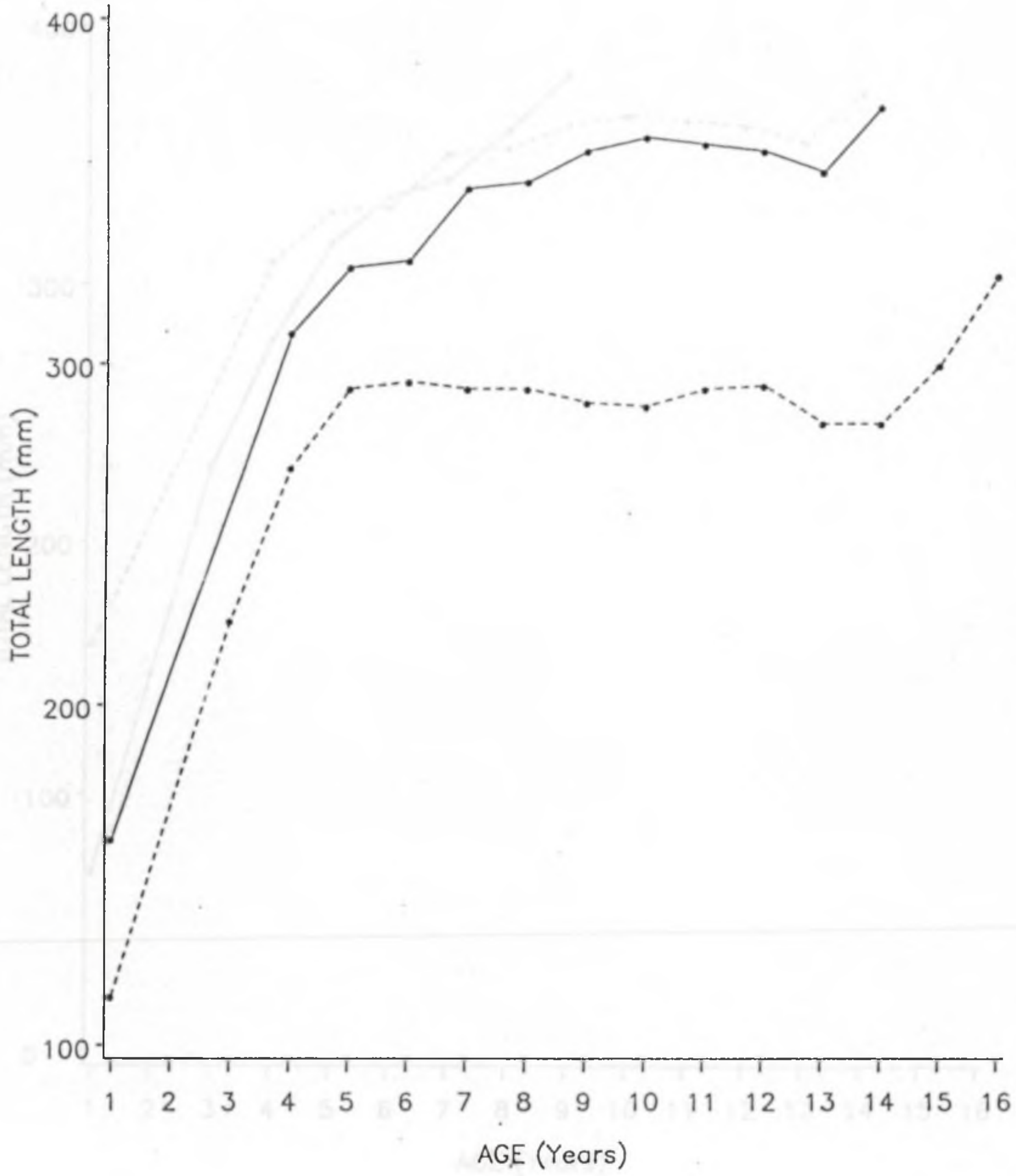


Fig. 14. Growth of schelly in Haweswater and Ullswater in 1987

Solid line = Haweswater , Dashed line = Ullswater

From Mubamba 1989.

FIG.16

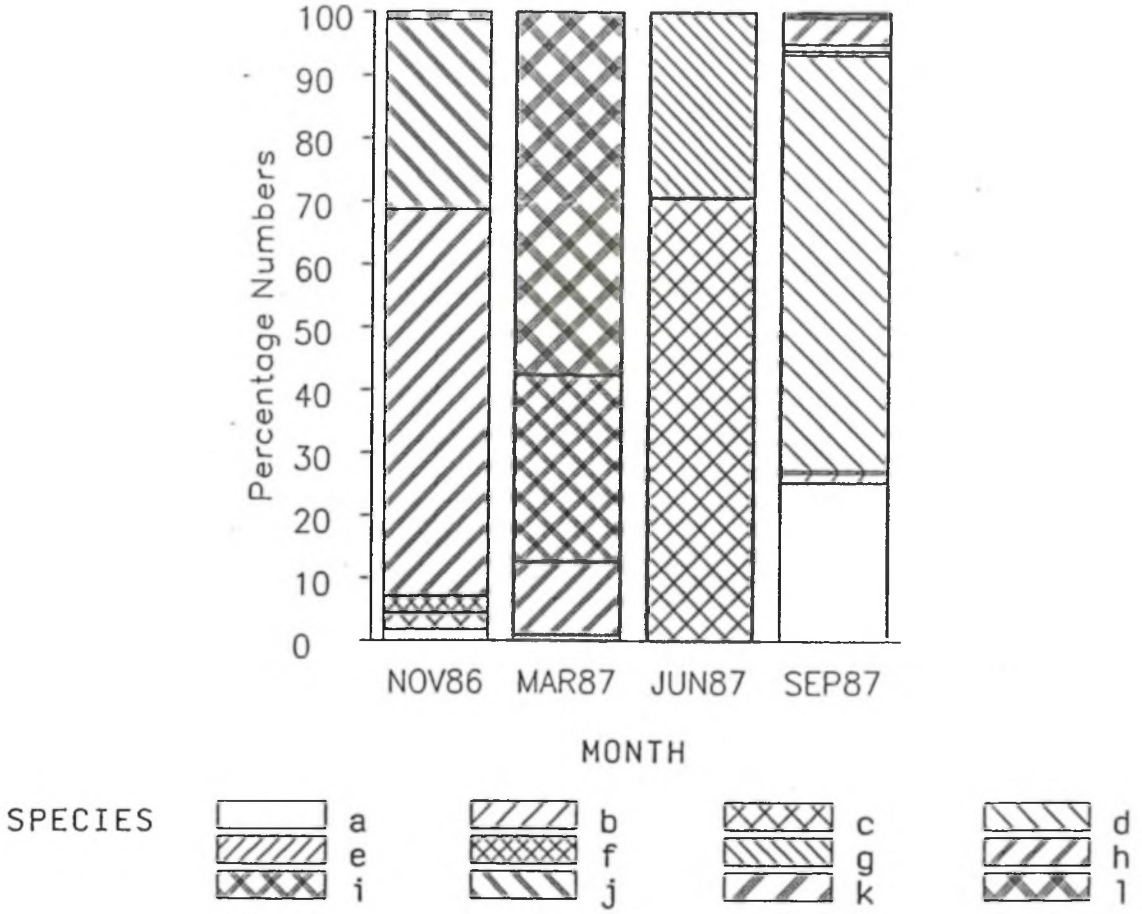


Fig. 16. Seasonal variation of food organisms in the schelly of Haweswater, 1986-87. From Mubamba 1989.

a = Daphnia
b = Leptodora
c = Bosmina
d = Bythotrephes
e = other Cladocera
f = cyclopoid Copepoda
g = Eudiaptomus
h = chironomids
i = Gammarus
j = Pisidium
k = cocoons
l = other organisms