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Bassenthwaite Lake: a general assessment of environmental and biological features and their susceptibility to change

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1. INTRODUCTION (J.F. Talling)

Bassenthwaite (Lake) is one of the larger Cumbrian lakes, certainly one of the most distinctive, and of considerable conservation and amenity value. Although its shores lack sizeable settlements, its main inflow receives sewage effluent from a major tourist centre (Keswick) and is subject to episodic floods. These influences, the growing development of leisure activities at the lake (e.g. sailing, time-share units), and recent road-construction, have led to past appraisals of ecological impacts (Jones et al. 1982) and lake management (Lake District Special Planning Board 1980).

Until 1979 the lake belonged to the Egremont family. Following the death of Lord Egremont, the lake and extensive commons were made over to the nation in settlement of estate duty and the freehold transferred to the Lake District Special Planning Board (LDSPB, 1980). In 1983 Bassenthwaite was notified as a Site of Special Scientific Interest (SSSI) by the Nature Conservancy Council under the provisions of the Wildlife and Countryside Act of 1981. The reasons for notification (Appendix 1) relate to emergent and submerged vegetation (Section 8.1) and the presence of the rare vendace fish (Section 7).

The lake has not been the subject of intense and long-term ecological study, but much scattered information exists that is relevant to future management decisions. In the present Report, commissioned by North West Water, such information - published and unpublished - is surveyed. Especial attention is given to evidence bearing on susceptibility to change, affecting the lake environment and its biota or species of conservation interest. Extensive use has been made of the results of a recent (1986-7) seasonal survey by the FBA. The FBA bibliography compiled by Horne & Horne (1985) has also been of great value.

2. PHYSICAL FEATURES (J.F. Talling)

Bassenthwaite Lake lies in the extreme north-east of the Lake District (**Fig. 1**), partly in a broad alluvial valley between mountain-masses of relatively soft rocks (Skiddaw Slates). Drainage is predominantly from valleys to the south and south-east. In one, a short distance upstream, is the large lake of Derwentwater. An eastern tributary (the River Greta) brings water from the reservoir Thirlmere, but in relatively small volume. By contrast the short R. Derwent inflow from Derwentwater is subject to high flood discharges after episodes of heavy rainfall in the Borrowdale region (older examples in Hudleston 1935). Sediment was also transported on a large scale and much is deposited around the southern end of the lake. This, and a shallow shore topography on the eastern side (Hay 1928), have favoured a considerable development of reedswamp. The entire drainage basin, omitting that of Thirlmere, is the largest of the English Lakes (**Table 1**).

Bathymetric information is given in **Fig. 2** and **Table 1**. The lake basin is an unusual combination of a fairly deep central third (maximum 19-20 m) with two large terminal areas less than 5 m deep. Because of the latter the mean depth is only 5.3 m; some 75% of the bottom area and 64% of the lake volume lie above a depth of 5 m. There are two shallow bays on the eastern shoreline.

The combination of relatively large drainage basin (with high rainfall) and shallow mean depth implies a short mean retention time. This can be calculated from an estimated mean annual lake discharge of 420 x 10^6 m^3 , based on a mean annual rainfall of 2.2 m and fractional run-off factor of 0.8 in a catchment of 238 km^2 , as 24 days.

Table 1 also gives information enabling comparison with other lakes of the district. Only Derwentwater is similar in both lake area and volume. However Bassenthwaite is outstanding in its high ratio of lake + drainage area to lake volume, which - assuming similar rainfall and fractional run-off - is inversely proportional to retention time.

The seasonal variation of water level can be considerable, with records of an annual range of 2 m and floodwater-induced rises of 1 m (Stokoe 1980). It causes conspicuous horizontal excursions on the areas of shallow-shelving shore, of local significance for littoral vegetation and animal communities.

Water temperature varies seasonally and with depth, as shown by the single year-long series for 1987-8 (**Table 2**). For most of the year the surface temperature is similar to that in a deep lake, Windermere, but additional surface cooling in shallow water further depresses the winter minimum in Bassenthwaite. Thus in mid-January 1987 (a very cold winter) the water mass is c. 0.8°C in Bassenthwaite and 4-5 °C in Windermere. In Bassenthwaite the summer temperature / density stratification develops comparatively late, the vertical temperature range is comparatively small, and there is evidence of additional summer mixing to deep water (cf. a temporary warming there in August 1987). These three features imply a weaker stratification with a reduced isolation of the deep layer or hypolimnion. The summer temperature stratification in 7 earlier years is summarized in **Fig. 4**. Large year-to-year differences exist in the onset and termination of stratification, and in the magnitude of the vertical temperature interval. However the duration of stratification is typically short, as in 1987.

Underwater light penetration is very limited, due to both coloured humic material and suspended silt. This is indicated by the rare photoelectric measurements in various spectral bands (**Fig. 3**) and by the visual Secchi disc transparency. During 1957 the latter did not exceed 1.6 m and values under 1.0 m were not infrequent (**Table 7**). Lower values are likely to result mainly from a high particulate content induced by inflow flood water and by the disturbance of shallow sediments by wind-action - a feature widespread in shallow lakes.

3. CHEMICAL INFORMATION (J.F. Talling)

3.1 Historical

Older (pre-1985) analyses of surface water are reproduced in **Tables 3-6**. They include conductivity, major ions, pH, and major plant nutrients (NO,-N, NH_4-N, PO_4,-P, total P, Si as SiO_2). Except for dissolved oxygen (**Fig. 5**), measurements for deep water are almost lacking. Those of Mortimer (unpublished notebooks) for October 1939 and February 1940 show little variation with depth, but are from seasons without pronounced thermal/density stratification.

Major ions are particularly well-documented for the years 1955-6 and 1974-6, although the record for alkalinity (here virtually equivalent to HCO_3-) extends back to 1928. **Table 3** shows that in general ionic composition Bassenthwaite belongs to the group of most productive or most eutrophic lakes in the Lake District. On a country-wide or world-wide basis it is of fairly low ionic content (cf. cation sum, anion sum, conductivity) and base-poor (cf. Ca^{2+} , alkalinity), although in these features it is relatively high in the Cumbrian lake series. Local sub-surface sources of Cl^- , some involving seepage from below the lake bed of Derwentwater (Hamilton-Taylor et al 1988), account for a relatively high concentration of this ion. The mean pH value of 6.9 is that expected from the alkalinity or HCO_3^- content; summer elevations of pH by photosynthetic activity, known in other productive Cumbrian lakes, here appear minor, although there is a single record of pH 9.0 in July 1974 (**Table 5**). The pre-1974 records of conductivity and alkalinity (**Tables 5**, **7a**,**b**, **8**) indicate a slight long-term increase, of about 15-20%, which (from alkalinity) probably occurred mainly between 1949 and 1974. Such increases have occurred in other productive Cumbrian lakes (Sutcliffe et al. 1982).

Major plant nutrients undergo large seasonal variations, as documented for 1928 and 1949 (**Table 7**). Analyses for Si (**Table 7**) confirm that periodic depletions well below the probable inflow levels do occur, presumably by diatom growth. The more abundant data for NO_3-N (**Tables 3**, **5**. **7**), show, in all series, a trend to lower concentrations in summer than in winter. The mean annual values for 1954-6 and 1974-6 are similar (**Table 4**), of a magnitude commonly found in the Cumbrian lakes (**Table 3**), but much greater than those applicable to 1928 (data of Pearsall 1932) and 1949. There is evidence, therefore, of a long-term trend of nitrate enrichment. For phosphorus (**Tables 7**, **8**) use can be made of the few analyses of total phosphorus content, inclusive of the particulate fraction, and soluble reactive phosphorus (PO_4-P). For both fluctuations within any year are likely to be considerable, due especially to resuspended silt (total P) and algal uptake (PO_4-P). Consequently it is difficult to establish long-term trends, but total P has probably increased and its recent mean concentration is suggestive of a moderately productive lake in the Cumbrian series - for which Jones (1972) presents this and other indices.

From occasional measurements over many years, it was known that the dissolved oxygen content of deep water was liable to be strongly depleted during summer stratification (e.g. Jones 1972, Collins 1977), although not necessarily always so (e.g. 29 July 1963 - Macan 1970 Fig 30). The variable incidence of such depletion during eight years since 1968 is illustrated in **Fig. 4** and discussed in the following section.

3.2 Detailed study of 1987-8

This study, by R. Mubamba, enables a better seasonal resolution of chemical change and concurrent comparison of variables. Influential factors also include the depth-time aspects of temperature and thermal/density stratification (**Table 2**) and the seasonal change of Phytoplankton abundance (**Tables 11**, **12**).

Dissolved oxygen (**Table 6**) shows no remarkable seasonal variation in surface water, the absolute concentrations varying with temperature but never far from air-equilibrium. As differences within the 0-5 m layer are small, such conditions also apply to about two-thirds of the lake volume. Only in the months July and August, when surface temperature had risen considerably (> 17°C) and thermal/density stratification was pronounced (**Table 2**), did oxygen concentrations in deep water fall well below *50%* saturation. Such depletion was clearly lessened in August 1987 by downward water transfer, evidenced by a short-lived temperature rise below (see Section 2 above). This behaviour is broadly representative of patterns of oxygen change in seven other years within the period 1968-197 , shown in relation to concurrent temperature stratification in **Fig. 4**. However there are important variations from year to year, especially in the timing of the onset and termination of stratification, and in the extent of oxygen depletion at depth (**Fig. 5**). The latter is generally greater in warmer summers with stronger temperature stratification after June. Its elimination often occurs as early as August, before surface cooling is appreciable, and is probably influenced by episodes of stronger wind and also possibly flood-water.

Regarding <u>plant nutrients</u> (**Table 7**). the analyses of surface water indicate considerable seasonal changes in concentrations of N (as NO_3-N, NH_4-N), P (as total P, PO_4-P), and Si in much of the water-mass. During summer N03-N fell to roughly half of its winter concentration, a net depletion probably due to denitrification and plant uptake and expected from general experience, although less extreme than in many productive lakes. The limited variation of NH4-N suggests that uptake preponderates over release plus net influx during most of the spring and summer; the high August value may indicate some vertical mixing (cf. temperature) from accumulations likely to develop in stratified deep water. Soluble reactive phosphorus (PO_4-P) also showed the expected spring-summer depletion, although the August concentration again showed increase and in only 2 months did values fall below 1 µg ^{1} . These last features may reflect the relatively weak summer stratification and the extensive contact between shallow-water sediment and the main water-mass. By contrast, total-P rose to higher concentrations in spring and summer, abruptly so from March to April. These changes may be partly induced by wind-disturbance of sediments, although there is no simple relationship with the Secchi disc transparency (**Table 7**). Nor is there a correlation with another particulate fraction, the phytoplankton biomass as measured by chlorophyll a concentration (**Table 12**). However increments in the latter during winter to summer are generally related to decreases in Si content (**Table 7**), consistent with the abundance of diatoms in the phytoplankton and possibly (Round 1957a,b) on the shallow sediments. Thus some nine-tenths of the winter Si concentration is lost in the February to June period when there was a major seasonal increase of chlorophyll a concentration and probably (Round 1960) of bottom-living diatoms.

The <u>major ionic concentration</u> shows some variability (**Table 7**). although this is less for the total ionic content measured by conductivity (range 63-81 μS cm) than for the principal anion, HCO_3^-, measured by alkalinity (128-245 μeq 1^{-1}) . Both external and internal sources of HCO_3^- may contribute to its considerable summer increase.

The interpretation of changes in many constituents is limited by deficiency of information on the inflows, of potential importance given the low retention time of the lake. However the contribution from Derwentwater - and hence the Borrowdale catchment - can be gauged from concurrent analyses on this lake. From these, and older analyses for major ions (Carrick & Sutcliffe 1982), it appears that only Si among the nutrients measured is present in similar mean concentrations in the two lakes. Nitrate-N and ammonium-N are slightly lower in Derwentwater; PO_4-P and total P are much lower, the former generally below the limit of detection (0.6 μg 1). Alkalinity, and therefore HC03- , is in Derwentwater a fraction 0.45 ± 0.07 of the Bassenthwaite levels, with parallel variation in the two lakes. Clearly, therefore, other inputs than Derwentwater are quantitatively important for the nutrient supply to Bassenthwaite. From the general topography of the drainage basin, attention focuses on inputs to lowland drainage near the lake -including that from Keswick. Thirlmere, as a nutrient-poor reservoir (**Table 3**. and unpublished FBA analyses of P fractions) of low river discharge, can be discounted.

Regarding the question of possible long-term trends, the 1987-8 information extends that from 1928, 1939-40, 1949, 1954-6, 1971, 1974-6 and 1984 (**Table 8**). Despite uncertainties introduced by altered analytical methods and seasonal variability, earlier indications (section 3.1) are confirmed for a small increase in conductivity and alkalinity, and a larger one throughout the series in $N0_3$-N. The last is likely to be influenced by increase of nitrate in atmospheric precipitation as well as by surface additions such as agricultural fertilisers. The total phosphorus concentration has almost certainly increased markedly since 1971. There is no evidence of long-term change in mean pH or Si concentration.

3.3 Implications

The following conclusions can be drawn bearing on the susceptibility of the lake to change.

(a) There is some evidence for long-term change in recent decades (in total ionic content, HCO_3- , $N0_3$-N, total P), but only that deduced for total P is likely to be influential in significantly promoting algal production.

(b) From the character of the drainage basin and analyses of a major inflow drainage (Derwentwater), chemical enrichment is likely to derive mainly from lowland sources (including one town) near the lake.

(c) Because of the extensive areas of shallow-water sediment, with liability to wind-disturbance, this source may provide much short-term, internal loading of nutrients and so promote seasonal algal maxima.

(d) The significance of nutrient stocks in the water-mass for future algal production, as by carry-over on an annual or seasonal basis, is lessened by the short retention time and by the small volume with short duration of deep stratified water.

(e) The short retention time will be expected to greatly reduce the lake's susceptibility to change in relation to external nutrient loading.

(f) Although oxygen depletion in deep water during summer stratification is apparently of usually short duration, it (and probably other chemical stratification relevant for fish and bottom-living animals) is variable from year to year because of variable temperature/density stratification. Exceptional and in part biologically unfavourable years may therefore occur, most probably those with hot dry summers.

4. PHYTOPLANKTON (S.I. Heaney)

4.1 Historical

Early observations on the periodicity and species composition of the phytoplankton of Bassenthwaite (and other Cumbrian lakes) were made by Pearsall & Pearsall (1925) between August 1920 and November 1922. In this pioneering study the diatom *Asterionella formosa* (*gracillima*) and the green alga *Mougeotia elegantula* were the dominant species with the diatom *Tabellaria fenestrate* and var. as sub-dominant. W.H. Pearsall (jun.) made a further study during 1928 (Pearsall 1932) with emphasis on the seasonal periodicity and its controlling factors. Diatoms and green algae were found to be dominant throughout the year except during summer when the blue-green alga *Oscillatoria tenuis* was important.

Following the work of the Pearsalls, the next studies were intermittent observations from 1949 to the seventies by J.W.G. Lund who has provided data on the principal diatoms given in **Table 9**. He has also (in Gorham et al. 1974 -

see **Table 10**) made an assessment of numbers and approximate biomass of the phytoplankton and its constituent groups in 1949-51 and 1961-3. Compared with values for other Cumbrian lakes, the mean algal concentration was clearly high. The flora continued to consist mainly of diatoms which can, unusually for Cumbrian lakes, form maxima during the summer months. A fourth diatom, Melosira italica subsp. subarctica, was also recorded in moderate numbers during 1973-4 but not earlier. The counts suggest that in the whole period there was no significant trend of biomass, and numbers of blue-green algae remained very low.

Water samples were collected during 1984 and the phytoplankton counted by C.S. Reynolds. In this year the algae showed no appreciable qualitative or quantitative changes from before. Blue-green algae were not observed during the particularly dry summer of this year.

4.2 Study of 1987-8

From January 1987 to January 1988 water samples were obtained from the 0-5 m layer of the lake at monthly intervals and algal species counted after sedimentation by R. Mubamba. The seasonal succession of the phytoplankton is presented as broad groupings in **Fig.6** and **Table 11**. The dominance of diatoms and green algae, and low numbers of blue-green algae still persists in the most recent work. The main difference from the Pearsalls' studies is the large numbers of cryptomonads during summer and winter months. These small algae, if present in the twenties, would mostly have passed through the net (60 meshes to the centimeter) then used. Another change is the increase in importance of the green algae Sphaerocystis and Gemellicystis. Although the algae which dominate the phytoplankton include many which grow relatively quickly and are thus more resistant to being washed out, the slow-growing Ceratium is also represented. Its persistence in conditions of high lake flushing may result from its ability to form resting stages and overwinter on the sediments. This ability to form resting stages is also likely to be significant for other species, including zooplankters, making the sediments an important source of the plankton in this lake.

Chlorophyll a (**Table 12**) was also measured in the same water samples from which the counts of phytoplankton were obtained. The mean value for 1987 was 15.3 µg chl a l^{-1} . After a strong rise in spring, concentrations were high from April onwards, with a maximum of 31.2 µg l^{-1} during October when the green alga Gemellicystis was dominant. The only other determinations of chlorophyll a for Bassenthwaite were 6.6 µg l^{-1} during August 1971 (Jones 1972) and 14.7 during the following month (Jones, unpublished). The first is far lower than the corresponding value for August 1987 (21.4 ug l^{-1}), but is possibly reduced by washout after recent heavy rain. Further, the data are too scanty to be evidence of a long-term trend. The similar and relatively high estimates of biomass dry weight in 1949-51 and 1961-3 by Lund (**Table 10**) suggest a mean chlorophyll a content of about 20-40 µg l^{-1} (at 0.5 - 1% dry weight), not less than the 1987 measurements.

4.3. Implications

There is no reliable indication of significant change in the quality or quantity of the phytoplankton of the lake from the twenties to the present; this can be no cause for concern. That the lake does not reflect the enrichment indicated in Section 9 in quality or quantity of phytoplankton is without doubt a result of its very short retention time. This feature, and associated washout, has the effect of repressing increase of slow-growing algae more than that of faster growing species. The former include bloom-forming blue-green algae which have characterized the lake's plankton from the twenties to present. Greatest change would be brought about by increasing significantly the retention time of the lake, as through a diversion of water input or a change of climate to drier weather.

5. ZOOPLANKTON (S.I. Heaney)

5.1 Historical

The first quantitative study of seasonal changes of the crustacean zooplankton of Bassenthwaite was made as part of a study of Cumbrian lakes during 1961 and 1962 by Smyly (1968). **Fig. 7** shows the mean standing populations that he recorded. The major species were the cladocerans *Diaphanosoma brachyurum* and *Daphnia hyalina* and the copepods *Diaptomus* (*Eudiaptomus*) *gracilis* and *Cyclops leuckarti*. Smyly considered that the zooplankton of the lake had not changed since the less intensive study of Gurney (1923) some forty years earlier.

5.2 Study of 1986-8

A recent seasonal study of the zooplankters was made by R. Mubamba between December 1986 and January 1988, with an additional sample during August 1988. **Table 13** lists the taxa identified and gives their changing abundance throughout the study period. During August 1987 there was a large population of *Daphnia* (25971 animals m^{-3}), although the following August these animals were quite scarce being replaced by a large population of *Eudiaptomus* (3860 animals m^{-3}). In contrast, the cladoceran *Bosmina* was absent during summer. The rotifers *Asplanchna* and *Kellicottia* both had brief maxima, the former reaching 5669 animals m^{-3} during May. Compared to Smyly's study some 25 years earlier, numbers of *Daphnia* and *Bosmina* appear to have increased and those of *Eudiaptomus* and *Diaphanosoma* decreased. Nevertheless, the data in these two studies alone should not be taken as conclusive evidence of change of structure of the zooplankton populations within the lake.

5.3 Implications

Populations of zooplankton do not appear to have changed greatly this century. There is no reason to consider that they are likely to change appreciably in future in the absence of strong eutrophication or alteration to the short retention time of the lake. These animals may reduce the likelihood of loss from the latter feature through taking advantage of slack-water areas, vertical migration behaviour and overwintering in the sediments as resting stages. The success of the zooplankton is likely to be related to that of the phytoplankton.

6. BOTTOM FAUNA (J.M. Elliott)

6.1 Historical

Between 1940 and 1969. only six publications dealt with the animal benthos of Bassenthwaite (Macan 1940, 1950, 1955. 1962, 1965; Brinkhurst 1964).

The most detailed work, on the invertebrates living on the shore in shallow water (depth < 60 cm), is summarised in the book by Macan (1970). Macan sampled at 50 sites around the lake (see **Fig. 8**) between November 1966 and January 1967. He found 34 invertebrate species, which are listed in **Table 1** together with their frequency of occurrence and relative abundance. The following species are not included in **Table 14** but were recorded on the shore in earlier studies (see Macan 1970): flatworm *Polycelis tenuis*, leech *Glossiphonia heterochita*, water-bug *Sigara scotti*, gastropod molluscs *Planorbis* leucostoma, *Lymnaea truncatula*. The water-bug *Aphelocheirus montandoni*, rare in northern England, was once found on the stony shore of the lake but was absent from more recent surveys (Macan 1965).

Notable members of the shore fauna are the freshwater shrimp *Crangonyx pseudogracilis*, a recent immigrant from North America (see also Williams 1972), and the water-louse Asellus meridianus which is being replaced in other lakes by A. aquaticus (Moon 1957). The button ramshorn snail, Planorbis leucostoma, is particularly abundant in Bassenthwaite as is also the mayfly, Ephemera danica. Surprising absentees are mayflies, Ecdyonurus dispar and Heptagenia lateralis, which occur on the stony shores of most lakes in the Lake District (see Table 37 in Macan 1970) . The abundance of E. danica and absence of E. dispar and H. lateralis may be due to the substratum which is frequently sand and gravel rather than large stones, especially on the east shore and around the inflow delta. Macan (1970) concludes from his extensive survey that the shore fauna of Bassenthwaite is close to that of Esthwaite Water and the South Basin of Windermere, the major differences being the presence of Asellus aquaticus, Ecdyonurus dispar and Heptagenia lateralis in the two latter water-bodies but not in Bassenthwaite.

Until recently, there was a paucity of information on the bottom fauna at water depths greater than about 1 m. Brinkhurst (1964) recorded two species of worms, Limnodrilus hoffmeisteri and Aulodrilus pluriseta, on the bed of the lake at water depths of 5 m and 12 m, with Peloscolex ferox also present at 5 m. Reynoldson (1983) later recorded the first two species together with Limnodrilus claparedeanus, Tubifex tubifex, T. ignotus and Ilyodrilus templetoni, all from the deepest part of the lake. The 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 Bassenthwaite and Loweswater were similar with large numbers of worms and a relatively high number of species, including L. claparedeanus which was found in only these two lakes.

6.2 Study of 1986-8

A recent survey provides the first quantitative information on the profundal bottom fauna (Mubamba 1989). Monthly samples were taken from December 1986 to December 1987 at depths between 12 m and 18 m. Relatively few taxa were found, the dominant groups being larvae of chironomid midges, tubificid worms and pea-mussels (Pisidium spp.) (**Table 15).** The rough orders of magnitude (mean ± range) of seasonal maxima for tubificid worms (5000 ± 100 animals m^{-2}) and chironomid larvae (8000 ± 4000 animals m^{-2}) indicate a productive lake. Large numbers of Daphnia ephippia (resting eggs) were also found throughout the year. There were no marked seasonal changes in the profundal benthos but chironomid larvae were generally most abundant in autumn and winter. Some differences associated with depth were seen in a single comparison in February 1987 (**Table 16).** More taxa were taken at a depth of 4 m than at 18 m, pea-mussels were more abundant at 4 m, chironomid larvae were the dominant group at 4 m whilst tubificid worms dominated at 18 m. Apart from the one survey at 4 m, there is no information on the sub-littoral benthos, i.e. invertebrates living on the shore at water depths between 1 m and 10 m. As about 80% of the bed of the lake lies between these depths, this is a major deficiency in our knowledge of the bottom fauna.

6.3 Implications

The general conclusion from this brief survey is that species lists and some qualitative information are available, but little quantitative information exists for the bottom fauna of Bassenthwaite. There is little information on the profundal benthos and especially on the sub-littoral benthos, both of which must provide large quantities of food for the fish of the lake.

7. FISH (C.A. Mills)

7.1 Historical

The most distinctive, and probably the quantitatively predominant, fish in Bassenthwaite is the vendace. Many late Victorian and Edwardian texts on the fishes of the British Isles contain short, and usually similar, accounts of this fish in Britain. Most however only mention the populations in two lochs near Lochmaben, Dumfriesshire which, unhappily, are probably extinct. However Regan (1906, 1908) gives taxonomic details, based on a small sample of Derwentwater fish. Watson (1925) comments that Bassenthwaite vendace are rarely taken by anglers "and even then at long intervals". In a note to Nature Maitland (1966a) describes the netting of 225 vendace from Bassenthwaite in 1965 (and of 84 from Derwentwater) though no scientific information on these specimens is given.

The origin of the four British vendace populations and a review of their taxonomy is given by Maitland (1970). It is now generally accepted that they do not form one (or more) endemic species but are part of the Coregonus albula group. This is still widespread in Scandinavia where heavy commercial netting is common. However all the remaining populations in Central Europe are listed as endangered through eutrophication of their environments (Lelek 1987).

What information there is on the other fish species in Bassenthwaite comes mainly from angling guides. Watson (1925) lists the species present as trout, pike, perch, vendace, eels and migrating salmon. Though large trout were present only small specimens would rise to the fly. Perch were "exceedingly small", averaging less than 4 oz though some individuals could reach up to 3 lb. The pike population is said to have declined due to partial destruction of the eggs by water from lead mines though weights ranged up to 16 lb. Earlier large fish weighed 17 and 25 lb and a preserved head in Keswick museum was labelled "Caught in Bassenthwaite by trolling, July 12th, 1861, weight 34 lbs." There were also eel-coops (traps), on the River Derwent, catching descending eels up to 6 lb in weight. A recent angling guide (Holgate & Parkinson 1987) gives very similar information for the present day. However the average perch is now said to weigh 8 to 12 oz, though large specimens up to 2½ or 3 lb remain. The typical pike weighs 7 to 9 lb though 20 lb fish are taken from time to time.

The only scientific information available gives a histogram of the ages of 246 adult perch caught in traps. The oldest was aged 10 but the vast majority were aged 4 from the strong 1949 year class {Le Cren 1955).

7.2 Detailed Study of 1987

7.2.1 Vendace

7.2.1.a Introduction

Initial work confirmed earlier experience that the Cumbrian vendace can only be caught from dusk onwards and that the nets should be lifted swiftly to avoid damage to the catch by eels. Thus in this study the vendace were caught at night in gill nets containing a range of mesh sizes. The principal net used was 6.5 m deep and 33.5 m long at the float line and comprised 6 panels bearing 30, 16.5, 38, 22, 12.5 and 45 mm bar mesh sizes. The nets were set on the bottom in deep water (15-20 m) approximately 200 m east of the launch point. This was on the western shore of the lake, 2.4 km from its southern tip (NGR 215285) • They were set about one hour before dusk and lifted some four or five hours later. A total of 495 vendace were caught in 14 fishings. Of these 33% were taken in the 30 mm bar mesh and 29% in the 22 mm mesh. On most occasions the majority were caught in the lower half of the net and were usually wedged in the net, rather than gilled. Catches were higher in winter (20-123 fish) than in summer (15-51 fish). From July to September a floating, but otherwise identical net, was also set above deep water, thus fishing the top 6.5 m of the water column. This net caught far fewer vendace (0-9) but the fish that were caught tended to be younger (2 or 3 years old) and as small as 114 mm (fork length). On several occasions echo-surveys were also made using a lightweight portable Furuno machine (see 6.2.1.e).

7.2.1.b Age and growth

The age composition of vendace catches from Bassenthwaite contained an extremely high proportion of 6 year old fish from the 1981 spawning (**Fig....9**).

A parallel study of Derwentwater vendace caught large numbers of fish aged 3, 4, 6 and 7. so the Bassenthwaite result seems more likely to be derived from the occurrence of a single particularly strong year class than from net selectivity or from the behaviour of the fishes. However the tiny catches of fish less than 3 years old (in both lakes) corresponds with the results of studies elsewhere which indicate that young C. albula are difficult to catch in gill nets and often occupy different areas of lakes than the older fish.

At age 3 and 4 male vendace were longer than females (though the numbers were small). Thereafter female fish were longest and continued to grow in length until they reached a mean of around 230 mm at age 8. In contrast males showed little growth after reaching age 5 and also had a shorter life-span (**Table 17**, **Fig. 10**). Von Bertalanffy growth curves fitted to the data gave asymptotic lengths (L_∞) of 211 mm for males and 238 mm for females. These were substantially higher than the equivalent values for Derwentwater vendace (183 and 199 mm). Comparison of the Cumbrian vendace (sexes combined) with data from other European C. albula populations shows that the Bassenthwaite fish are relatively fast growing (**Fig. 11**). Note that for comparative purposes total lengths are used in this figure (to the tip of the tail) rather than the fork lengths given elsewhere. The Cumbrian fish are much longer-lived than these other populations. This is probably because the Cumbrian populations are pristine, unharvested this century. Most European populations are heavily exploited for food, usually by intensive netting, and consequently survival is low.

The relationship between $\log_{10}$ transformed fish length (L) and total fish weight (W) by sex (all seasons pooled) can be described by the following regression equations:

Male fish log W = 3.14 log L - 5.26 r^2 = 84.7% n = 155

Female fish log W = 3.57 log L - 6.23 r^2 = 80.9% n = 297

Pooled log W = 3.49 log L - 6.04 r^2 = 82.9% n = 453

Thus on average a 200 mm male fish weighed 92 g and a female fish 97 g. At the asymptotic (maximum) lengths predicted by the growth curve males would weigh 109 g and females 178 g. Seasonal variation in weight is examined in the following section.

7.2.1.C Feeding and condition

Examination of stomach fullness shows that the feeding season lasted only 5 months from April to August though during this period the great majority of stomachs were full (**Table..18**). In April the stomachs contained chironomids and other benthic organisms indicating that the fish were not feeding in the water column but from the bottom. In this month the density of planktonic organisms was low except for the relatively "evasive" Cyclopoids which they avoided (**Table .19).** For the rest of the feeding season the diet was dominated by zooplankton. In May Eudiaptomus was favoured over the equally abundant Daphnia. However during summer Daphnia formed between 54.8 and 94.5% of the diet and Eudiaptomus was very strongly avoided (**Table. 19** and **Fig. 12**). The 'other' cladoceran component comprised mainly large taxa such as Bythotrephes and Leptodora. Cyclopoids were only an important component (25.9%) of the diet in July.

The annual cycle of condition in the fish closely reflects this feeding data. Condition is a measure of the "fatness" of fish derived from dividing weight by length cubed. Total condition refers to condition derived from total weight and somatic condition is derived from total weight less gonad weight. Total condition of both sexes rose rapidly between April and June from around 1.05 to 1.40 with female condition rising further to 1.52 in July. This was followed by gentle declines to September with a steeper decline thereafter

(**Fig. 13**). From July to November female fish were substantially "fatter" than the males. **Fig. 14** shows that from August onwards a substantial and increasing gap opens between female somatic and total condition due to transfer to resources to the developing gonads. Thus after spawning female condition actually falls below that of the males (**Fig. 13**) which have far smaller gonads.

The Bassenthwaite vendace were always in better condition than Derwentwater fish. **Fig. 15** shows this for female fish but the pattern was similar for males.

7.2.1.d Fecundity and reproduction

When sampling started on 11 December 1986, 39 of the females caught were in an advanced state of ripeness and one had already spawned. The 4 males caught were all ripe. By 15 January 1987 45 females had spawned and one was still shedding eggs. There then followed several months with little gonad development. By October and November the fish had reached an advanced state of ripeness and on 14 December 1987 9 ripe males and 2 females which were both shedding eggs were captured. It seems probable that the bulk of spawning occurs in December though it may extend into January.

Fig. 16 shows the changes in gonad weight (GW) over the year for both sexes, following standardization for fish length (L) to give the gonadosomatic index (GSI) for each sex (GSI = GW (g)/L (mm)^3 x 10^6 for females and x10^7 males due to their smaller gonads). Egg development followed a very similar pattern to that of the female GSI with mean egg diameters in the gonads increasing only from around 0.4 to 0.6 mm between January and July followed by rapid development to the spawning size of around 1.4 mm by November (**Fig. 17**).

The youngest fish caught in Bassenthwaite were 2 years old (114-175 mm in length) and at this age all fish of both sexes had attained maturity. Amongst 2, 3 and 4 year old fish there was no significant difference in the proportion of male and female fish captured but from age 5 onwards females predominated with 2.01 females per male rising to 3.8 to 1 amongst fish over 7 years old. This clearly indicates a higher death rate amongst males.

Fecundity (F) and gonad weight (GW) were both positively correlated with increasing length (L), somatic weight (SWT) and age. A series of regressions can be used to describe these relationships:

$\mathrm{Log}_{10}\ F = 0.0094L + 2.05$ $r^2 = 0.77$, $n = 29$ eq 1
$\mathrm{Log}_{10}\ F = 0.096AGE + 3.56$ $r^2 = 0.54$, $n = 28$ eq 2
$F = 110SWT - 91$ $r^2 = 0.70$, $n = 29$ eq 3
$GW = 0.455L - 65.30$ $r^2 = 0.68$, $n = 19$ eq 4
$GW = 5.65AGE + 3.08$ $r^2 = 0.42$, $n = 19$ eq 5

Thus from equation 5 a 200 mm vendace would, on average, contain 8 511 eggs in a gonad weighing 25.7 g (equation 4) whilst a large 250 mm fish would contain 25 119 eggs. In terms of age a 5-year old would contain on average 10 965 eggs and an 8-year old would contain 21 281 (equation 2).

In February 1987 a series of grab samples were collected and examined for vendace eggs in an attempt to locate spawning sites. One was found 20-30 m offshore from the launch point at depths ranging from 3-5 m. The bottom consisted of decaying vegetation overlying soft sediment. The diameter of the eggs was between 2.2 and 2.4 mm. They were incubated at 4°C in the laboratory and hatched on 4-5-87. The following 14 December eggs were stripped, artificially fertilized, and incubated at a range of temperatures from 2°C to 10°C. Survival was generally good except at 100C where only 40% survived to hatching. Both the size and weight of hatching larvae declined with increasing temperature from 8.96 mm and 3.44 mg at 2°C to 7.82 mm and 2.84 mg at 10°C. Mean times from fertilization to hatching ranged from 172 days at 2°C down to 53 days at 10°C. Eggs incubated in water drawn from Windermere (5.2 to 8.2°C) took 98 days to hatch. Some larvae were successfully reared to a length of 40-50 mm using natural zooplankton as food.

7.2.1.e Distribution and abundance

Fig. 18 shows a sequence of echo-sounder traces taken between the launch point on the west shore of the lake and the netting site some 200 m eastwards in the deep (19-20 m maximum) trough that runs down the lake. Few echo traces were evident at 15-25 hours though the "rough" appearance of the bottom may indicate the presence of fish there. At 16.00 hours (sunset was at 16.15 hours) several traces are present and shortly after dark (16.45 hours) the density has increased greatly though most traces are below 10 m. In examining these traces it must be borne in mind that the echo-sounder beam spreads out at a constant angle (8.4° in this case) from the surface; thus if the fish were evenly dispersed more traces would appear in deeper water. One echo in the top 5 m is equivalent to 3 between 5 and 10 m, 5 between 10 and 15 m and 7 between 15 and 20 m. However despite this bias it is clear that most fish are in deep water and on this evening remained so at 17.20 hours and in subsequent traces. It is likely that the fish giving these relatively large traces are vendace because their presence coincided with times when vendace were catchable and because vendace comprised over 90% of all net catches.

Further confirmation of the vendace's nocturnal activity is shown in **Fig. 19** where the three daylight traces taken around 18.00 hours show only a handful of large traces. The three taken later in the year in darkness at around the same time show many traces, almost all at or below 10 m. The small "point" traces usually towards the surface (see also **Fig. 20)** tended to indicate high zooplankton concentrations. They may also indicate small vendace, perch or other species though, as mentioned in the introduction, few were caught in surface gill nets.

Of particular importance is the possible effect of low dissolved oxygen concentrations on vendace distribution. On 9 July 1987 vendace first appeared in numbers at just above 10 m soon after dark. An oxygen and temperature profile taken just before dark showed a strong stratification and low oxygen levels (< 3.7 mg l^{-1}) below 12 m and < 2.1 mg l^{-1} below 16 m. Few, very scattered echos were seen at 22.30 hours but an hour later the fish were back in deeper water, mainly between 10 and 15 m, with a dense band of smaller echos around 4 m. This distribution persisted at 04.00 hours (**Fig. 20**). Unfortunately no later oxygen profile was made to determine whether an internal seiche had increased the concentrations at these depths or whether the vendace were tolerating such low levels of oxygen. A more striking example of the effect of low oxygen concentration is available from the neighbouring Derwentwater population on 6 August (**Fig. 21**). In this case there appears to be a depth cut-off to the vertical distribution at 16-17 m over successive traces. When measured around 18.00 hours the oxygen concentrations (mg l^{-1}) were 14 m - 5.5, 15 m - 2.6, 16 m - 2.0, 17 m - 1.6, 18 m - 1.1, 19 m - 0.0.

Crude population estimates can be made even from a simple echo-sounder where output is only to a paper trace provided the distance travelled is recorded. The volume of water surveyed at a series of depth intervals can then be determined, allowing for the angle at which the beam spreads (8.4 ° in this case) and comparing the number of echos in these volumes with the total volume of the lake in this layer (Ramsbottom 1976). Because only a tiny volume is surveyed near the surface, and because of the possible presence there of small perch (or vendace) and some shoals of fish (possibly also perch), the traces from the 0-5 m layer were not included in the calculations. In the remaining deeper water (5-19 m) net catches indicate that 90% of the traces are likely to be vendace.

The first estimate was made from a 630 m transect eastwards across the lake made some 80 minutes before dusk on 4 August 1988 in overcast conditions. The traces were well dispersed and concentrated between 5 and 10 m (**Fig. 22**). This gave an estimate of 80 000 vendace in the lake. A second much longer survey (1630 m) was conducted later the same evening (**Fig. 23**), this time northwards up the lake. This gave an higher estimate of 172 000 vendace. The big unknown is whether this figure relates only to the size-classes of fish we captured or whether the young vendace were actually present and contributing to these pelagic echos. The fish we actually caught had an average weight of around 100 g. If this is an accurate reflection of the fish surveyed it would imply a biomass of between 8 and 17 tonnes of adult fish or 15-32 kg ha^{-1} . The last value is moderately high for freshwater fish populations. Only the use of a more sophisticated computer-linked echo-sounder would provide detailed size structures for the fish surveyed. Nevertheless it is reasonable to conclude that Bassenthwaite does contain a large population of vendace.

7.2.2 Other fish species

In addition to vendace the gill nets caught 43 perch (7.9% of the total catch), 8 roach (1.5%) and one specimen each of brown trout, pike and eel (each 0.16%). Shoals of minnows, Phoxinus phoxinus, were also observed in the lake margins.

Two of the roach and 25 of the perch were caught in deep water during the winter. The remaining fish (apart from the eel) were caught in the surface gill net set over deep water. Only two perch were caught between May and August. The smallest perch was 46 mm long and aged one year. The largest was 288 mm long and 7 years old. The frequency distribution and lengths-at-age are given in **Table 20**. A standard von Bertalanffy growth curve fitted to these data gave a predicted maximum length (L_w) of 364 mm, consistent with the reported presence of large perch in the lake. The first males matured at age two and the first females at age 3. Older fish were all mature. Of the 24 perch stomachs examined from winter and spring, 17 contained food. Chironomid larvae followed by Gammarus and cocoons (probably of oligochaetes) were the dominant food items.

The roach were between 130 and 210 mm fork length and aged between 3 and 5. All were adult fish. They contained a wide range of food organisms including Pisidium, ostracods, chironomid larvae and, in July, zooplankton, phytoplankton (Melosira) and aerial insects. The sole trout was caught in May. It was a very slow-growing fish (140 mm, 5 years old) which had presumably spent much of its life in a small stream. It contained Gammarus and chironomid larvae and pupae.

7.3 Implications

There is no doubt that at present Bassenthwaite contains a large population of vendace, certainly several tens of thousands of fish. It is also evident that this species is vulnerable to eutrophication of its habitats (Lelek 1987) and that elsewhere in Europe, due to its commercial importance, many populations are maintained only through artificial propagation and stocking (Bninska 1985a, b).

Bassenthwaite receives considerable inputs of phosphate and nitrate of anthropogenic origin. It is more eutrophic than Derwentwater and probably more eutrophic now than at any time in the history of the lake. Consequently it is of particular importance to review the Bassenthwaite population and its habitat in the light of what is known of the Dumfriesshire lochs that once held the other British populations of the species.

Castle Loch has a maximum depth of only 5 m and an area of 78 ha. It is highly enriched by discharges of effluent from Lochmaben sewage works. This generates massive blooms of phytoplankton. Bream, Abramis brama, have long been common in the loch, along with roach, pike, perch, eels and vendace (Maitland 1966b). The latter probably became extinct soon after the sewage works came into operation around 1911 (Maitland 1979). Mill Loch is much smaller (13 ha) but more similar in topography to Bassenthwaite with a deep basin down to 16.8 m. It was less grossly eutrophic than Castle Loch, contained no bream and the other species reached smaller sizes (Maitland 1966b). Vendace were caught there in the mid 1960's but subsequently there was further eutrophication and loch-side development, and subsequent nettings in the 1970's failed to obtain any vendace (Maitland 1979). Maitland (1985) lists the Mill Loch population as possibly extinct.

The behaviour of the Mill Loch vendace showed considerable similarity to that of the Bassenthwaite population. "In summer they remain in the lowest depths, during the warmer weather, but on dull or cold days, or rather the evenings of such days they will rise higher in the water" (Service 1906). Maitland (1967) found a similar pattern of behaviour using an echo-sounder though at night the fish came right up to the surface, something not noted in Bassenthwaite. During the day (in August) the fish retreated to deeper water rather than the bottom. This could be an indication of deoxygenation of the deeper water. Maitland also attempted to estimate the population size and found at least 1500-30 000 fish. Bassenthwaite has over 31 times the surface area of Mill Loch and after standardizing the estimates by total lake area the estimates bear a remarkable similarity. Mill Loch 89-179 fish ha^{-1} , Bassenthwaite 151-325 fish ha^{-1} .

If Bassenthwaite continues to become more eutrophic it will have the following implications for the vendace.

a) Increasing deep water anoxia will disturb the fishes normal behaviour patterns and may force them into water they would normally avoid due to its high temperature.

b) Populations of cyprinids are likely to increase (the roach may be a recent addition to the Bassenthwaite fish fauna as their presence is not reported in the existing texts). These would tend to compete with the vendace for zooplankton. However eutrophication will in itself tend to increase the availability of zooplankton - hence the faster growth rates in Bassenthwaite. Cyprinids might also prey on vendace eggs.

c) The most serious effect is likely to be failure in reproduction. Lelek (1987) suggests that this is caused by silting of spawning sites. In

Bassenthwaite the shading out of submerged vegetation, amongst which the vendace eggs were found, by phytoplankton blooms might be crucial.

All the evidence suggests that continued increases in nutrient loading to the lake will lead inexorably to the extinction of this population of Britain's rarest species of freshwater fish.

8. OTHER BIOTA

8.1 Macrophytes (S.I. Heaney)

In a study of the aquatic vegetation in the English lakes, Pearsall (1921) records twenty species of macrophytes from Bassenthwaite. These include the shallow-water forms Littorella lacustris, Myriophyllum spicatum. Ranunculus peltatus, Potamogeton natans, Nymphaea lutea, Castalia alba, Phragmites communis, Scirpus lacustris, Equisetum limosum, Carex inflata and the off-shore species Isoetes lacustris, Nitella opaca, N. flexilis, Juncus bulbosus, Callitriche intermedia, Potamogeton pusillus. Myriophyllum spicatum. Fontinalis antipyretica, Ranunculus spp., and Sparganium minimum. The next known extensive survey of the lake was between 1976 and 1979 by Stokoe (1980), who recorded over fifty taxa (**Table 21**). Amongst the reasons for notification of the lake as an SSSI (Appendix 1) is the richness of the lake in aquatic vegetation as a result of its shallowness and high through-flow of nutrient-rich water.

Stokoe (1980) considered the following species deserved special comment. Callitriche hermaphroditica, a scarce plant in Cumbria but common off Dubwath; Elatine hexandra, unknown in the Lake District until 1976 but now with a flourishing colony off Redness Point; Juncus filiformis, the most important littoral species and rare outside Cumbria; the presence of Potamogeton alpinus, P. gramineus and P. pusillus, more restricted and less robust species of Potamogeton; Ranunculus peltatus, the precise taxonomy of this species uncertain in Bassenthwaite; and Carex aquatilis a northern sedge, rare in Cumbria but reported from the Redness area.

Implications

The greatest dangers to the macrophytes within the lake are eutrophication or localized pollution in bays from nearby houses, farms and caravan sites; also from any significant and sustained lowering of lake level (Stokoe 1980).

8.2 Birds (K.M. Atkinson)

Bassenthwaite Lake supports a good diversity of wintering and summer-breeding birds. Its importance for birds is recognised by the Lake District National Park Authority, which has established a nature reserve (no boating) area over the southern sector of the lake, and which operates a close control and containment of recreational activities on the lake.

Bassenthwaite regularly has a peak winter count of over 1000 wildfowl and is the second most important site in the National Park for winter duck (after Windermere). Regular counts have been made as part of the National Wildfowl Census organised by The Wildfowl Trust. September to March monthly counts show both considerable species diversity and numbers. The latter fluctuate widely in part due to water levels - high water levels and flooding causing the dispersal of duck onto the area between Bassenthwaite and Derwentwater.

From the 1985/86, 1986/87 and 1987/88 winter counts the mean annual maximum figures for the most numerous species were: mallard (Anas platyrhynchos) 653. wigeon (Anas penelope) 281, tufted duck (Aythya fuligula) 304, goldeneye (Bucephala clangula) 105, greylag goose (Anser anser) 298, coot (Fulica atra) 347. It is the only lake in the National Park where wigeon are regularly seen. Owen et al. (1986) comment that the greylag geese are mainly feral birds, and that the majority of the estimated north Cumbria total of about 200 birds are centred on the marshland at the southern end of

Bassenthwaite - but that a few wild greylag may occur, giving temporary peak counts of up to 350.

The areas of the lake most frequented by wintering duck are North Scarness Bay and Bowness Bay on the east side and the nature reserve area at the south of the lake. Not surprisingly these areas, together with Dubwath Bay, the locality favoured by coot, coincide with the areas of greatest diversity and richness of aquatic plants.

However it is for its summer breeding waterbirds, and its post-breeding and moulting flock of wildfowl, that Bassenthwaite is even more important. A summer breeding survey undertaken in 1981 by the National Park Authority lists 8 species of waterbirds and 17 other species nesting in the wetland areas around the lake (Lake District Special Planning Board - unpublished report 1981), Bowness Bay and the marshlands at the southern end of the lake being the most important areas. In July and August breeding tufted duck are joined by post-breeding birds from other localities which remain to moult, as do some pochard. Nevertheless August numbers for both species are usually lower than the count for September, which in many winters is the peak-count month.

9. NUTRIENT INPUTS (S.I. Heaney)

9.1 Historical

There is no known quantitative assessment of nutrient inputs to the lake. Nevertheless, several considerations point to their increase over the past 40 years. These include increased population within the catchment especially during summer, improved sewage treatment facilities, introduction of phosphorus detergents during the fifties, improved pasture through fertilizer application (particularly nitrates), and increased nitrogen in precipitation.

9.2 Current

As far as can be ascertained there are no current, direct measurements of nutrient inputs to Bassenthwaite. Phosphorus is generally considered the main element likely to limit phytoplankton production in Cumbrian lakes. Rough indirect calculations are given in **Table 22** for the contribution of sewage-borne soluble reactive phosphorus (PO_4-P) and for the total phosphorus input from all sources entering Bassenthwaite. These estimates are based upon:

(1) Calculated contributions of P04-P from the resident populations of Keswick and Braithwaite connected to sewage treatment plants (North West Water) and an estimated 1.8 g phosphorus per person-day (Alexander & Stevens 1977) into the sewage system. Estimates for holiday residents and day-visitors are based on numbers obtained from Keswick Town Council and the Lake District Special Planning Board, with the daily phosphorus contribution per capita reduced to 50% of that of a normal resident. The figures for holiday residents, considered to be conservative, are based upon a 60% bed-occupancy between April and October.

(2) Calculated inputs from the catchment excluding Keswick and Braithwaite. In the absence of direct measurement estimates have been made using (a) values of PO_4-P and total P loading obtained by North West Water (Agar et al. 1988) for the catchment of Esthwaite Water and adjusted to take account of the 14-fold increase in catchment of Bassenthwaite and (b) using a value of annual export of total phosphorus from a grazed granitic upland catchment of Dartmoor (Rigler 1979). The values thus obtained by (a) are likely to be overestimates for the Bassenthwaite catchment due to (i) a greater proportion of upland mountain area compared to that of Esthwaite Water and (ii) a probable net removal of phosphorus in Derwentwater due to uptake by phytoplankton and sedimentation. Further, in discussing the phosphate export for the Dartmoor catchment, Rigler (1979) pointed out that the methods used can seriously underestimate true export.

Table 22 gives the loading of PO4-P to Bassenthwaite per unit lake area as 1.65 g P m^{-2} yr^{-1}. This value is very large, although for reasons given above the actual value is probably somewhat lower, but unlikely to be less than 1 g P m^{-2} yr^{-1}. Nevertheless, this lower value still represents a high value of phosphorus loading for such a shallow lake. It can be compared with values derived in a similar manner for Esthwaite Water of 0.48 g g P m^{-2} yr^{-1} (Talling & Heaney 1983) and for the North and South Basins of Windermere of 0.28 and 0.91 g P m^{-2} yr^{-1} respectively (Atkinson et al. 1986). The

estimates for total phosphorus input to the lake are 3.83 and 1.73 g P m^{-2} yr^{-1} using catchment export values from Esthwaite Water and Dartmoor catchments respectively.

As shown by Vollenweider (1976), the critical phosphorus loading of comparable lakes is directly proportional not only to their mean depth but also to the residence time of the water. The shorter the residence or replacement time for the lake volume, the less susceptible the lake will be to increased phosphorus loading. Vollenweider (1976) examined this relationship for phosphorus-controlled lakes, and deduced that the critical loading value which determines the transition between oligotrophy and eutrophy can be described by the equation

$$Lc = [P]_c^{SP} \bullet q_s (1 + \sqrt{\overline{Z}/q_s}$$

where Lc = critical specific loading (mg m^{-2} yr^{-1})

$[P]_c^{SP}$ = critical lake concentration of total phosphorus at early spring (mg m^{-3} = µg l^{-1})

$\overline{Z}$ = mean depth (m)

q_s = hydraulic load (m yr^{-1}) = Q_Y / A_O

where Q_Y = total yearly lake discharge (m^3 yr^{-1})

A_O = lake surface area (m^2)

For Bassenthwaite, using values of Q_Y and A_O given in Section 2,

$Lc = 15 \times 79.5\ (1 + 0.258)$

$= 1500$ mg P m^{-2} yr^{-1}

-If a specific loading value for total phosphorus of 2 g P m^{-2} yr^{-1} is accepted as reasonable for Bassenthwaite, then applying the Vollenweider model- which takes account of both mean depth and retention time - the lake would beconsidered highly productive. However, this model is somewhat uncertain inapplication since Bassenthwaite falls outside the range of retention times that Vollenweider considered and the deductions are here made by extrapolation.

For nitrogen there is insufficient data to attempt even rough estimates of inputs to the lake. These have probably increased in recent decades as indicated by the increase in mean annual concentrations of nitrate-nitrogen (**Table 8**).

9.3 Implications

Both the winter concentrations of soluble reactive phosphorus (**Table 7**) and the calculations of total phosphorus loading **(Table 22)** point to Bassenthwaite being appreciably enriched with respect to this element. That the lake can withstand its present nutrient enrichment is due to its short retention time, together with the high proportion of the lake volume that remains mixed even during summer stratification (Section 2).

A major anxiety from increasing eutrophication is its possible effect on the population of vendace (Section 6). As well as the ways discussed in Section 6 whereby the vendace may be endangered by nutrient enrichment, a change in climate or weather patterns leading to drier, warmer summers would have serious consequences. It would lead to stronger stratification, higher surface water temperatures and increasing deep-water anoxia. Increased retention time would exacerbate these problems, and probably induce summer blooms of blue-green algae as now experienced in other enriched Cumbrian lakes.

10. RECOMMENDATIONS FOR FUTURE MONITORING

10.1 Changes in chemical status (J.F. Talling)

There is a need for information on the main inflow below inputs from Keswick, especially for total- and PO_4-P, $N0_3$-N, and Si; also for corresponding analyses from the lake itself. Monthly sampling in the March -September period would be appropriate. Further analysis of annual records of temperature and oxygen stratification during the period June - August, in relation to meteorological factors and river discharge, is desirable to clarify variability of importance to the fish (especially vendace) populations.

10.2 Changes in plankton (S.I. Heaney)

With increasing levels of enrichment there have been appreciable changes in quality and quantity of phytoplankton in other Cumbrian lakes such as Windermere and Esthwaite Water. The much shorter retention time and high volume of through-flow of Bassenthwaite should provide a buffer against severe or abrupt change.

A programme of samples collected from the 0-5 m layer during the four seasons at 5-yearly intervals should be sufficient to detect major changes of phytoplankton composition and abundance. Provision should be made for opportunistic sampling at times of severe draught or for unforeseen special circumstances. Vertical net hauls for zooplankton counts should be collected at the same time that phytoplankton samples are obtained.

10.3 Changes in benthic invertebrates (J.M. Elliott)

Although some information exists on the benthic invertebrates, very little is known about the profundal benthos and especially the sub-littoral benthos, both of which must provide large quantities of food for fish. The last detailed survey of the shore fauna was in 1966-67 and a more recent survey is urgently needed to discover if there have been any major changes in the last 22 years, especially in relation to eutrophication.

10.4 Changes in fish populations (C.A. Mills)

It would be desirable to obtain additional base-line information on the perch, pike and roach populations in the lake, but the priority - both for additional research and monitoring - must be the vendace, due to its great rarity and its sensitivity to eutrophication. New research should be directed to understanding the ecology of the egg, larval and juvenile stages, about which virtually nothing is known. Enough is now known about the adult vendace and its behaviour to estimate population size and biomass. This would require a more sophisticated echo-sounder than that used in the recent study, to analyse the size-distribution of the fish surveyed. We have now obtained suitable equipment and once it has been tested it would be possible to design a relatively inexpensive monitoring programme to detect any changes in the biomass and size-structure of the vendace population.

In addition we have conducted trials which demonstrate the feasibility of rearing juveniles from eggs for restocking (and some similar work is now being carried out by Dr P.S. Maitland). Thus, it should be possible to establish additional populations of vendace in other suitable lakes as a safeguard.

11. SUMMARY (J.F. Talling)

1 . Bassenthwaite Lake is a relatively large and distinctive Cumbrian lake of acknowledged conservation (SSSI) status, with freehold now owned by the Lake District Special Planning Board. Although not the subject of intensive scientific study, much scattered ecological information exists and is here summarized.

2. The lake has richer lowland soils and sediments in its immediate surroundings, but most of its large catchment is mountainous with nutrient- and base-poor soils. The high ratio of catchment area to lake volume results in a short mean water retention time, estimated indirectly as about 24 days. Inflows are subject to floods and lake level to considerable seasonal variation. The lake has a deep (19-20 m) central region that undergoes a variable and generally short summer stratification, but elsewhere there are large shallow areas which result in the more mixed 0-5 m layer accounting for 64% of the lake volume. Light penetration is the lowest in any major Cumbrian lake; transparency fluctuates over the year, probably with influence of flood-waters and of bottom sediments resuspended by wind-action.

3 . Chemical information on the near-surface lake water is tabulated from intermittent sampling between 1928 and 1988. There is evidence for much seasonal and some long-term change. Of the seven major ions, Cl- is somewhat enriched by local seepage; the $HC0_3^-$ concentration (alkalinity) increases in summer, and has also trended upwards since about 1949. Strong deviations of pH from its mean value (6.9) are uncommon. All the major plant nutrients measured - Si, $N0_3$-N, NH_4-N, PO_4-P, total P - show large seasonal changes. The first four generally reach winter maxima, after which there is a spring-summer depletion under the influence of algal (+ macrophyte?) growth and (for N0,-N) bacterial denitrification. A more irregular variation of total P

may reflect disturbance of sediments. Long-term trends of concentration increase appear to be shown by NO_3-N, total P, and probably PO_4-P, but not by Si. That of P has the greatest implications for eutrophication, and probably derives from sources near the lake. A seasonal internal loading from sediments is also likely, but the short retention time acts against longer-term storage in the water-mass. An oxygen depletion occurs in deep water under summer thermal stratification, typically ends early (in August), and is variable from year to year with accentuation by warm weather after June.

4. The floristic composition and seasonal development of the phytoplankton has been recorded from intermittent sampling since 1920. Diatoms have always been a major (often dominant) component and blue-green algae a minor one. Estimates of biomass development, based on cell counts and chlorophyll a analyses, indicate that the Lake was and is one of the most productive of the Cumbrian lakes. There is no firm evidence of major long-term trends in either the species-composition or total abundance, although cryptomonads and colonial green algae seem to have had variable incidence. The short retention time is likely to lead to 'episodic' wash-out effects, and to favour the predominance of rapidly growing species (e.g. diatoms) rather than slow growing ones (e.g. larger blue-green algae).

5 . The principal qualitative and quantitative studies of zooplankton have been in 1961-2 and 1986-8. These, and some earlier records, do not suggest major long-term trends. There is a pronounced seasonal incidence of various copepods, cladocerans and rotifers, known from quantitative samples in 1987.

6. The bottom-living invertebrates of shallow shore areas are mainly known from a survey in the winter of 1966-7. In general character the fauna appeared similar to that of the most productive Cumbrian lakes of Esthwaite Water and

Windermere South Basin, although probably influenced by a fine-grained substratum. It lacked some common species of wide distribution, and had distinctive species of a freshwater shrimp (Crangonyx pseudogracilis), water-louse (Asellus meridianus) and mayfly (Ephemera danica). An uncommon water-bug (Aphelocheirus montandoni) may have disappeared. Several studies on the communities of deep water (5 m +) show a dominance of oligochaete worms (7 species recorded), chironomid larvae and pea-mussels (Pisidium spp.). The relative representation of these groups varies with depth. There is very little information on the extensive areas between 1 and 10 m depth, where the sub-littoral benthos is important as a source of food for fish.

7. A number of widespread fishes are recorded from the Lake, where their ecology is not well known: perch, pike, roach, trout, eel, salmon and - in the margins - minnow. However principal interest centres on the vendace, that is now known elsehwere in Britain only from Derwentwater, and was studied intensively during 1987. It is liable to be extinguished by advancing eutrophication, as in two Dumfriesshire lochs and in Central Europe, but in 1987 was probably the most abundant fish in the Lake. Here - but not in Derwentwater - the 1981 year class was predominant. Distinct growth curves have been calculated for male and female fish, that rise to higher asymptotic values of length and weight than in Derwentwater. The condition factor (or 'fatness') is also higher in Bassenthwaite, and rises seasonally between April and June during which the main source of food changes from the bottom fauna (e.g. chironomids) to the zooplankton which had increased in density. There is little feeding before April or after August. Spawning mainly occurs in December, possibly associated with submerged macrophytes, and the youngest catchable fish are 2 years old; artificial fertilisation and rearing are practicable. Echo-sounding and catchability show that the vendace rise from near the bottom about sunset and at night can be located in mid- or deep-water,

although they appear to avoid near-anoxic deep water. Rough quantification of numbers from echograms suggested an order of 10^5 fish for the lake population and the considerable mean density of 15-32 kg (wet weight) ha . The vulnerability to eutrophication could arise from further development of summer anoxia, from competition of increased cyprinid populations, and from a restriction of reproductive sites as by loss of submerged macrophytes.

8.1 The aquatic macrophytes of the Lake, submerged and emergent, are reasonably well-known floristically from surveys about 1915-20 and in the late 1970's. More than 40 species are represented, in a rich flora of acknowledged conservation value that includes relatively rare species of *Callitriche*, Elatine, *Juncus*, *Potamogeton* and *Carex*. Extensive sedimentation has favoured an extensive development of reedswamp in shallow and sheltered areas. The submerged communities would be particularly susceptible to eutrophication or local pollution, and the emergent ones to sustained lowering of lake level.

8.2 The Lake is recognised for its diversity of both wintering and summer-breeding birds, with consequent measures for their protection. In recent years winter counts are available, which at maxima regularly exceed 1000 birds and are derived from mallard (c. 650 birds), wigeon, tufted duck, greylag goose, and coot (each c. 300 birds), and goldeneye (c. 100 birds). These favour especially the shallow and sheltered areas on the eastern and southern sides, where aquatic plants are most abundant. The flooding associated with high water-levels causes dispersal of duck onto the marshy area between Bassenthwaite and Derwentwater. Summer-breeding waterbirds and post-breeding plus moulting wildfowl are important, and at least 25 species nest in wetland areas round the Lake.

9. Direct measurements of nutrient inputs are lacking, but such inputs have probably increased during the past 40 years. Here rough estimates of P loading are derived by summing the urban contribution (from a population per capita basis) and the diffuse catchment contribution (from catchment area and values of export per unit area of two other catchments). For soluble reactive phosphorus (PO4-P) the last term is probably overestimated, and so also the derived loading per unit lake area of 1.65 g m^{-2} yr^{-1}. However the true value is unlikely to be less than 1 g PO_4-P m^{-2} yr^{-1} , a high value associated with lake enrichment elsewhere. The best estimate for total phosphorus is c. 2 g m^{-2} yr^{-1} . Its significance for eutrophication is interpreted with reference to other experience, summarized quantitively by Vollenweider, that allows for greater susceptibility in shallow-lakes and lesser susceptibility in lakes of short retention time (= high hydraulic loading). Although the estimate of total P loading is slightly greater than a calculated critical level for eutrophication, an extrapolation involved makes the difference of doubtful significance. Empirically, it seems likely that the Lake has not responded greatly to its heavy P loading because of its short retention and possibly its limited storage capacity. However further accentuation of deep oxygen depletion below the summer thermocline is not excluded, and could adversely affect the survival of vendace.

10. Recommendations are given for future monitoring, with especial reference to inflow chemistry, deep anoxia, phytoplankton quality and quantity, bottom fauna for changing species and depth-related communities, and missing information on the vendace. In all instances there is a relevance of possible further change under eutrophication and its undesirable consequences.

12. ACKNOWLEDGEMENTS

We wish to acknowledge our special indebtedness to Mr Raphael Mubamba for making available his extensive studies on the lake in 1986-8, embodied in his forthcoming Ph.D. thesis. We are also grateful to Dr J.W.G. Lund FRS for earlier data on Phytoplankton and dissolved nutrients; to Mr A. Fishwick (Lake District Special Planning Board) and Dr I. Bonner (Nature Conservancy Council) for other information on the lake; to Ms Christine Butterwick and Mrs Paula Tullett for help with text-figures and Tables; to Mrs Joyce Long for preparing the typscript.

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APPENDIX 1

File Ref: NY 22/2

COUNTY: CUMBRIA SITE NAME: BASSENTHWAITE LAKE

DISTRICT: ALLERDALE

Status: Site of Special Scientific Interest (SSSI) notified under Section 28 of the Wildlife and Countryside Act 1981.

Local Planning Authority: Lake District Special Planning Board.

National Grid Reference: NY 215295 Area: 575 ha. 1420 ac.

Ordnance Survey Sheet 1:50,000: 89,90 1:10,000: NY 15 SE; NY 22 NW; NY 23 SW

Date Notified (Under 1981 Act): Date of Last Revision:

Reasons for Notification:

Bassenthwaite Lake lies in a wide valley between the Thornthwaite and Skiddaw Fells and approximately 4 kilometres north of Keswick. It is a large and relatively undisturbed mesotrophic lake (moderately rich in nutrients). It has a varied and typical aquatic flora and fauna and in addition has diverse fringing habitats of reedswamp, fen, wet grassland, willow scrub and alder woodland.

Of the major lakes in Cumbria, Bassenthwaite, together with Derwentwater contrast with the oligotrophic (nutrient poor) lakes of Wastwater, Buttermere and Ennerdale and the more eutrophic (nutrient rich) Esthwaite water. Bassenthwaite lake ranks as the fourth largest in the Lake District (surface area 5.2 km^2) and it is the shallowest. It also has the largest catchment area (238 km^2) and consequently is subject to rapid through-flow of water and wide fluctuations in level.

The combination of shallowness, large volumes of through-flow and moderate nutrient status provide a good habitat for an abundance of water plants. A wide variety of pond-weed (Potamogeton) species are found. P. perfoliatus, P. berchtoldii, P. crispus and P. natans are widespread while P. alpinus. P. gramineus and P. pusillus are more locally distributed. Nuttall's waterweed (Elodea nuttallii) is abundant; amongst other submerged species are the uncommon autumnal water-starwort (Callitriche hermaphroditica) and six stamened waterwort (Elatine hexandra).

The vendace is of particular significance among the fish fauna of Bassenthwaite. This rare fish is now thought to be extinct in Scotland and apart from Bassenthwaite, Derwentwater is its only other location in Britain.

Bassenthwaite has one of the most extensive undisturbed shorelines compared with the other major Cumbrian lakes. Much of the shore is shingle or gravel but soft peat stretches are found in Bowness Bay and at the south end of the lake. Reed canarygrass (Phalaris arundinacea) is the main emergent plant while areas dominated by common reed (Phragmites communis) are limited. Bulrush (Schoenoplectus lacustris), bottle sedge (Carex rostrata) and common spike-rush (Eleocharis palustris) are locally abundant. The transitions from emergent vegetation inland to mixed fen, willow and alder woodland or wet grassland are particularly well developed around the northern and southern ends of the lake and the Broadness-Bowness Bay stretch. These habitats are the best examples of their type in North Cumbria. On stony shores the diverse vegetation includes species such as globe flower (Trollius europaeus), saw-wort (Serratula tinctoria), hemlock water-dropwort (Oenanthe crocrata) and lesser meadow-rue (Thalictrum minus). Slender rush (Juncus filiformis) is a notable nationally rare, species also found on the stony lake shores. Sedges (Carex species) are abundant on peaty shores, and include the local Northern sedge (Carex aquatilis). Fringing willow scrub is extensive particularly at the northern end while at Lakeside Wood and Moss Wood, alder woodland occurs, merging in places to drier ash, elm and oak, birch woodland. In grazed areas, mixed fen grades into wet grassland. Tufted hair-grass (Deschampsia caespitosa). purple moorgrass (Molinia caerulea) and rushes (Juncus spp.) are abundant and have a rich associated tall herb flora. Meadowsweet (Filipendula ulmaria), greater burnet (Sanguisorba officinalis), common valerian (Valeriana officinalis) and wild angelica

(Angelica sylvestris) are typical species, others present include devil's bit scabious (Succisa pratensis), ragged robin (Lychnis flos-cuculi), skull-cap (Scutellaria galericulata) and large bird's-foot trefoil (Lotus uliginosus).

Bassenthwaite has considerable ornithological interest. The food from an abundance of water plants, sheer size of the lake and diverse fringing habitats support a varied bird fauna. Over 70 breeding species have been recorded around the lake. Birds breeding in the vegetation cover of the water margins include little grebe, red-breasted merganser, mute swan and the locally uncommon great crested grebe. Several pairs of sandpipers breed on the open stony shores. The fringing woodlands harbour species such as sedge warbler, willow warbler and redpoll. Reed bunting and grasshopper warbler inhabit the tall herb vegetation and the wet grasslands hold redshank, snipe and lapwing. Significant numbers of birds come to the lake in winter to roost and feed. Over 2,000 birds may be present at one time, particularly in the sheltered water at the southern end and Bowness Bay. Species recorded include teal, widgeon, goldeneye, tufted duck and mallard.

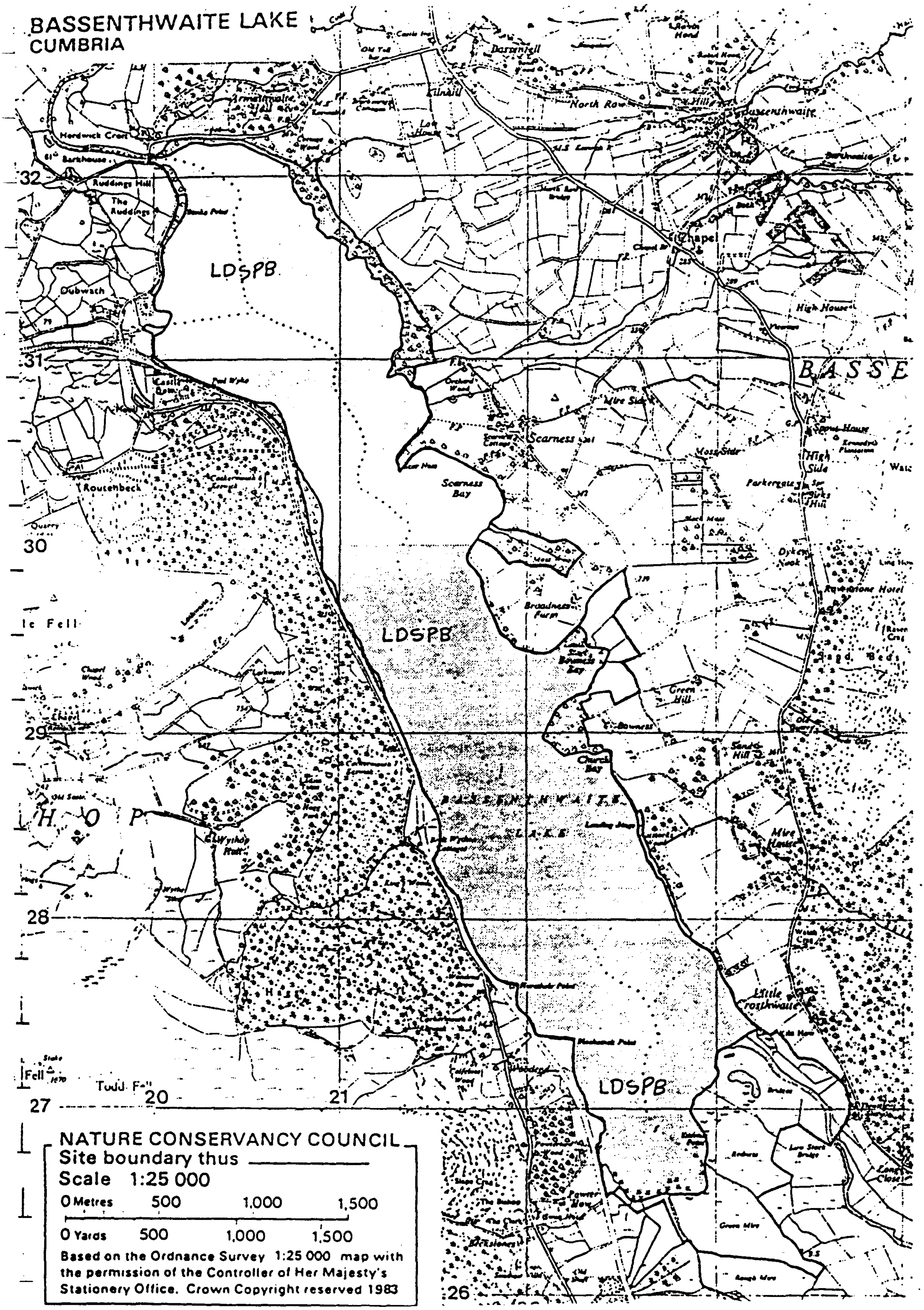
Other Information

1. The site lies within the Lake District National Park.

2. The site also forms part of the proposed Derwent and Cocker River system SSSI.

3. The site is considered to be equivalent in status to those sites listed in "A Nature Conservation Review" (ed. D A Ratcliffe 1977 C.U.P.).

BASSENTHWAITE LAKE
CUMBRIA



NATURE CONSERVANCY COUNCIL

Site boundary thus

Scale 1:25 000

0 Metres	500	1,000	1,500
0 Yards	500	1,000	1,500

Based on the Ordnance Survey 1:25 000 map with the permission of the Controller of Her Majesty's Stationery Office. Crown Copyright reserved 1983

TABLE 1

TABLE 1.. Morphometric features of major lakes and tarns (from Jones, 1972; Ramsbottom, 1976; unpublished data) studied in the present survey (1974-78) and in a previous survey (1955-56) of surface water chemistry. Also shown, in the last column, are the numbers of determinations for major cations done on surface water samples during the previous survey. **From Sutcliffe et al (1982).**

No.	Lake	Altitude (m)	Max. lake depth (m)	(1) Lake area (km^2)	(2) Area of drainage basin (km^2)	(3) Volume (m^3 x 10^6)	$\frac{(1) + (2)^*}{(3)}$	No. of determinations (1955-56)
	Group 1							
1	Levers Water	411	38	0.1	—	—	—	2†
2	Buttermere	101	28.5	0.9	16.9	15.2	1.2	8
3	Blea Tarn	187	7	<0.1	—	—	—	3†
4	Thirlmere	179	46	3.3	29.3	52.5	0.6	9
5	Wastwater	61	76	2.9	48.5	115.6	0.4	8
6	Ennerdale Water	112	42	3.0	44.1	53.2	0.9	7
7	Crummock Water	98	44	2.5	43.6	66.4	0.7	8
8	Goats Water	502	13	<0.1	—	—	—	13
	Croup 2							
9	Haweswater	240	57	3.9	26.6	91.6	0.3	8
10	Grasmere	62	21.5	0.6	27.9	5.0	5.7	6
11	Rydal Water	53	19	0.3	32.1	—	—	4
12	Derwentwater	75	22	5.4	82.7	29.0	3.0	9
13	Brotherswater	173	15	0.2	12	—	—	5
14	Ullswater	145	62.5	8.9	145.5	223.0	0.7	9
15	Windermere (N)	39	64	8.1	230.5‡	201.8	0.8§	3
16	Coniston Water	44	56	4.9	60.7	113.3	0.6	8
	Group.3							
17	Windermere (S)	39	42	6.7	—	112.7	—	3
18	Bassenthwaite Lake	69	19	5.3	237.9	27.9	8.7	8
19	Loweswater"	121	16	0.6	8.9	5.4	1.8	8
20	Blelham Tarn	42	14.5	0.1	4.3	0.7	6.3	2†φ
21	Esthwaite Water	65	15.5	1.0	17.1	6.4	2.8	2†φ

* Inversely related to retention times.

† Includes determinations done in 1953-54.

‡ Total area for north and south basins of Windermere.

§ For both basins combined.

φ One determination for Ca^{a+} and Mg^{2+}.

TABLE 2

Table 2. Depth-time variation of temperature (°C) in Bassenthwaite during 1987/8.

Depth (m)	15 Jan	19 Feb	12 Mar	9 Apr	18 May	15 Jun	9 Jul	17 Aug	24 Sept	15 Oct	9 Nov	14 Dec	4 Jan
0	1.0	3.2	2.5	5.5	10.9	13.0	18.5	17.2	12.9	8.4	7.5	4.0	6.8
1	0.8	3.0	3.0	5.5	10.9	13.0	18.6	17.1	12.9	8.3	7 4	4.0	6.8
2	0.8	3.0	3.2	5.5	10.9	13.0	18.5	16.9	12.9	8.3	7.3	4.0	6.8
3	0.8	3.0	3.2	5.5	10.8	12.8	18.5	16.7	13.0	8.1	7.3	4.0	6.8
4	0.8	3.0	3.2	5.5	10.6	12.7	17.7	16.4	13.0	8.1	7.3	4.0	6.8
5	0.8	3.0	3.0	5.5	10.6	12.5	17.7	16.2	13.0	8.1	7.3	4.0	6.8
6	0.8	3.0	3.0	5.5	10.6	12.3	16.6	15.9	13.0	8.1	7.2	4.0	6.8
7	0.8	3.0	3.0	5.5	10.5	12.2	16.0	15.8	13.0	8.1	7.2	4.0	6.8
8	0.8	3.0	3.0	5.5	10.5	12.0	15.4	15.7	13.0	8.1	7.2	4.0	6.8
9	0.8	3.1	3.0	5.5	10.5	12.0	14.7	15.6	13.0	8.1	7.2	4.0	6.8
10	0.8	3.1	3.0	5.5	10.5	12.0	14.1	15.6	13.0	8.1	7.2	4.0	6.8
11	0.8	3.1	3.0	5.3	10.5	11.9	13.5	15.5	13.0	8.1	7.2	4.0	6.8
12	0.8	3.1	3.0	5.3	10.5	11.9	13.1	15.5	13.0	8.0	7.2	4.0	6.8
13	0.8	3.2	3.0	5.3	10.5	11.8	12.4	15.5	13.0	8.0	7.2	4.0	6.8
14	0.8	3.2	2.9	5.3	10.2	11.8	12.2	15.4	13.0	8.0	7.2	4.0	6.8
15	1.0	3.3	2.9	5.3	10.2	11.5	12.0	15.3	12.5	8.0	7.2	4.0	6.8
16	1.0	3.2	2.9	5.3	10.2	11.3	11.0	15.2	12.4	8.0	7.2	4.0	6.8
17	1.2	3.2	2.9		10.2	11.2	11.8	14.9	12.4	8.0	7.2	4.0	6.8
18		3.2	3.0		10.2		11.8		12.4	8.0	7.2	4.0	
19					10.0					8.0	7.2	4.0	

TABLE 3
TABLE 4

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. From 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	−16‡	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. Mean concentrations ± 95% CL confidence limits (*n*), in μequiv. l^{-1}, of (1) nitrate, (2) sulphate (by difference), (3) SO_4^{2-} + NO_3^-, in the surface waters of twenty lakes and tarns during (a) 1955–56 (top row) and (b) 1974–78 (bottom row); values in brackets are for 1953–55. The differences in mean concentrations between periods (a) and (b) are given for NO_3^- and SO_4^{2-} + NO_3^- From Sutcliffe et al (1982).

Lake	(1) NO_3^-	(2) SO_4^{2-}	(3) SO_4^{2-} + NO_3^-	Difference for (1)	Difference for (3)
Group 1					
1. Levers Water	—	—	[128 (2)]		
	30 ± 8 (15)	101 ± 8 (14)	138 ± 5 (55)	—	+ 10
2. Buttermere	8 ± 4 (8)	89 ± 6 (8)	97 ± 7 (8)		
	9 ± 1 (9)	91 ± 13 (9)	102 ± 6 (25)	+1	+5
3. Blea Tarn	—	—	[86 (3)]		
	7 ± 2 (36)	123 ± 7 (34)	137 ± 6 (83)	—	+51
4. Thirlmere	10 ± 3 (9)	124 ± 7 (9)	134 ± 8 (9)		
	13 ± 2 (10)	112 ± 10 (10)	131 ± 7 (24)	+3	−3
5. Wastwater	10 ± 3 (8)	100 ± 3 (8)	110 ± 3 (8)		
	18 ± 1 (13)	101 ± 16 (13)	121 ± 10 (29)	+8	+11
6. Ennerdale Water	10 ± 5 (7)	98 ± 10 (7)	108 ± 11 (7)		
	15 ± 3 (10)	102 ± 19 (10)	118 ± 8 (26)	+5	+10
7. Crummock Water	6 ± 1 (7)	98 ± 5 (7)	105 ± 5 (8)		
	13 (2)	106 (2)	121 ± 8 (15)	+7	+16
8. Goats Water	21 ± 4 (12)	132 ± 8 (12)	151 ± 8 (13)		
	34 ± 5 (9)	128 ± 18 (9)	168 ± 13 (17)	+13	+17
Group 2					
10. Grasmere	15 ± 7 (6)	150 ± 11 (6)	164 ± 7 (6)		
	17 ± 2 (98)	138 ± 5 (64)	155 ± 5 (77)	+2	−9
11. Rydal Water	16 (3)	148 (3)	159 (4)		
	13 ± 3 (13)	135 ± 11 (13)	149 ± 6 (47)	−3	−10
12. Derwentwater	7 ± 2 (9)	106 ± 5 (9)	113 ± 7 (9)		
	8 ± 3 (10)	109 ± 25 (9)	115 ± 11 (25)	+1	+2
13. Brotherswater	23 ± 10 (5)	156 ± 24 (5)	179 ± 33 (5)		
	12 ± 5 (8)	157 ± 22 (8)	165 ± 11 (22)	−11	−14
14. Ullswater	12 ± 3 (9)	143 ± 7 (8)	154 ± 9 (8)		
	11 ± 2 (10)	136 ± 10 (10)	146 ± 5 (26)	−1	−8
15. Windermere (N)*	17 ± 1 (96)	144 (3)	165 (3)		
	24 ± 2 (102)	157 ± 4 (73)	182 ± 4 (79)	+7	+17
16. Coniston Water	18 ± 4(8)	161 ± 23 (8)	179 ± 25 (8)		
	22 ± 2 (9)	183 ± 15 (9)	203 ± 8 (27)	+4	+24
Group 3					
17. Windermere (S)*	18 ± 1 (95)	159(3)	178 (3)		
	25 ± 2 (101)	171 ± 4 (78)	199 ± 5 (84)	+7	+21
18. Bassenthwaite Lake	18 ± 9 (8)	156 ± 21 (8)	174 ± 18 (8)		
	16 ± 4 (9)	147 ± 21 (9)	183 ± 15 (23)	−2	+9
19. Loweswater	9 ± 3 (8)	162 ± 8 (8)	171 ± 13 (8)		
	30 ± 5 (12)	171 ± 14 (12)	197 ± 9 (25)	+21	+26
20. Blelham Tarn*	23 ± 2 (89)	206 (1)	[232 (2)]		
	34 ± 5 (77)	242 ± 8 (69)	279 ± 9 (74)	+11	+47
21. Esthwaite Water*	15 ± 1 (95)	197 (1)	[214 (2)]		
	31 ± 5 (81)	231 ± 6 (71)	265 ± 8 (76)	+16	+51

TABLE 5

Table 5. Concentrations of major ions, nitrate, and pH in near-surface water of Bassenthwaite, 1954-6 and 1974-6. 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)

Date	Na	Ca	Mg	K	Alk	S.A.	Cl	NO_3	SO_4	pH
15.1.54	(178)	(240)	(95)	(15)	137	368	215			
6.5.55	(217)	(243)	(102)	(15)	170	410	256	10	144	
10.6.55	(218)	(244)	(87)	(13)	162	404	252	38	114	
8.7.55	(213)	(234)	(112)	(15)	180	388	246	9	133	
17.10.55	(235)	(278)	(118)	(17)	196	436	252	19	165	
Nov. 55	(235)	(297)	(98)	(15)	178	450	262	18	170	
5.1.56	(208)	(275)	(68)	(14)	128	420	242	19	159	
7.2.56	(217)	(305)	(91)	(30)	162	486	286	5	195	
15.3.56	(243)	(289)	(107)	(18)	168	480	284	29	167	
Period: 6.5.55 - 15.3.56										
n	8	8	8	8	8	8	8	8	8	
mean	223	271	98	17	168	434	260	18	156	
C.L.	11	23	13	5	16	30	14	9	21	
C.V.	6	10	16	32	12	8	6	59	16	
22.4.74	213	270	84	17.5	190	440	275	21	144	
15.5.74	232	290	84	19	210	435	273	19	143	
7.6.74	244	300	92	20.5	210	450	297	14	139	
1.7.74	240	310	108	17.5	229	435	300	19	116	9.0
12.8.74	244	290	92	17	199	415	295	8	112	7.2
2.9.74	219	290	88	16	219	400	282			6.9
17.10.74	221	280	100	14	190	385	235	17	133	6.9
2.12.74	252	280	100	18	154	475	315			7.1
16.1.75	403	300	190	16	175	725	456			6.2
9.2.75	288	280	140	15	130	560	359	26	175	6.5
27.2.75	292	290	130	16.5	145	560	378			6.5
16.4.75	259	300	130	16.5	170	510	326			7.1
9.5.75	232	280	88	17	192	469	289	12	168	6.9
4.6.75	239	300	120	17	184	499	296	11	192	7.1
4.7.75	247	320	130	18.5	225	468	305			7.1
15.8.75	241	300	95	20.5	223		277			7.0
11.9.75	243	320	100	19	209		295			6.9
26.11.75	239	260	140	14	148	488	300			7.0
7.1.76	242	340	108	22	180	512	288			7.2
10.2.76	251	340	100	18.5	151	545	314			7.0
17.3.76	251	360	113	19	160	545	333			7.1
14.4.76	251	360	109	18	161	520	323			6.9
21.5.76	243	350	119	16.5	206	481	274			7.1
23.6.76	243	340	94	15.5	204	502	301			7.3
23.7.76	256	400	124	18.5	271	518	326			7.4
Period: 22.4.74 - 23.7.76										
n	25	25	25	25	25	23	25	9	9	22
mean	251	310	111	18	189	493	309	16	147	6.9
C.L.	15	14	10	1	14	31	17	4	21	-
C.V.	14	11	21	11	17	14	14	34	18	-

TABLE 6

Table 6. Depth-time variation of dissolved oxygen (mg l^{-1}) in Bassenthwaite during 1987/8.

Depth	15	19	12	9	18	15	9	19	24	15	9	14	4
(m)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan
0	12.5	11.6	12.6	11.2	10.6	10.5	11.4	10.1	10.0	10.6	10.8	13.4	11.1
1	12.4	11.6	12.6	11.2	10.6	10.4	11.4	10.1	10.0	10.3	10.8	13.4	11.1
2	12.4	11.6	12.6	11.2	10.7	10.4	10.8	9.9	10.0	10.3	10.8	13.4	11.1
3	12.4	11.6	12.6	11.2	10.6	10.2	10.4	9.6	10.0	10.3	10.7	13.4	11.1
4	12.4	11.6	12.6	11.2	10.8	9.9	9.8	9.2	10.0	10.3	10.7	13.4	11.1
5	12.4	11.5	12.6	11.2	10.8	9.9	9.3	8.9	9.9	10.2	10.7	13.4	11.1
6	12.4	11.5	11.6	11.2	10.8	9.8	8.0	8.4	9.9	10.2	10.7	13.4	11.1
7	12.4	11.5	12.6	11.2	10.8	9.7	8.0	8.2	9.9	10.2	10.7	13.4	11.1
8	12.4	11.5	12.6	11.2	10.8	9.7	7.2	8.0	9.9	10.2	10.7	13.4	11.1
9	12.4	11.5	12.7	11.2	10.6	9.6	6.0	7.8	9.8	10.2	10.7	13.4	11.1
10	12.4	11.5	12.7	11.2	10.6	9.6	5.2	7.5	9.8	10.2	10.6	13.4	11.1
11	12.3	11.4	12.8	11.2	10.6	9.6	4.8	7.4	9.8	10.2	10.6	13.4	11.1
12	12.3	11.4	12.8	11.2	10.6	9.5	4.3	7.3	9.8	10.2	10.6	13.4	11.1
13	12.2	11.4	12.8	11.2	10.6	9.5	3.6	7.2	9.8	10.2	10.6	13.4	11.1
14	11.5	11.4	12.8	11.2	10.6	9.4	3.0	6.7	9.8	10.2	10.6	13.4	11.1
15	11.5	11.3	12.9	11.2	10.2	8.3	2.6	6.6	9.4	10.2	10.6	13.4	11.1
16	11.5	11.3	13.0	11.2	10.2	7.4	2.3	5.6	9.3	10.2	10.5	13.4	11.1
17	11.5	11.3	13.2		10.2	7.2	2.1	3.1	9.2	10.2	10.5	13.4	11.1
18		11.2	13.2		9.6		1.9		9.0	10.2	10.5	13.4	11.1
19					6.8					10.2	10.4	13.4	11.1

Table 7. Seasonal variability of surface water characteristics in Bassenthwaite during (a) 1928 (from Pearsall 1932), (b) 1949 (Mackereth & Lund unpublished), and (c) 1987-8 (Mubamba 1989)

(a) 1928	31 Jan	24 Mar	5 May	1 June	10 July	16 Aug	20 Sept	3 Nov	22 Dec
Silicate (as SiO$_2$, mg l^{-1})	2.3	1.7	0.7	0.1	0.8	0.5	1.4	2.2	1.5
Nitrate-N (μg l^{-1})	150	85	85	100	30	30	63	120	160
Soluble reactive phosphorus (μg l^{-1})	3	5	2.5	1	1	0.9	0.7	2.7	2.5
Alkalinity (μeq l^{-1})	240	140	100	170	200	200	150	134	174
pH	6.4	6.8	7.1	7.1	7.6	7.3	7.3	6.8	6.8

(b) 1949	13 Jan	10 Feb	7 Mar	7 Apr	6 May	1 June	28 June	26 July	24 Aug	31 Sept	19 Oct	16 Nov	14 Dec
Silicate (as SiO$_2$, mg l^{-1})	3.3	3.3	3.2	2.5	2.5	1.8	0.4	0.55	0.55	0.5	0.75	2.3	2.6
Nitrate-N (μg l^{-1})	250	300	200	270	170	190	40	20	30	70	75	180	300
Soluble reactive phosphorus (μg l^{-1})	1	1.5	1	1	1	1.2	1	<1	<1	-	<1		–
Alkalinity (μeq l^{-1})	100	130	106	104	114	136	150	164	160	164	152	82	110

TABLE 7

(c) 1987-8	19 Feb	12 Mar	9 Apr	18 May	15 June	9 July	17 Aug	24 Sept	15 Oct	9 Nov	14 Dec	4 Jan
Silicate (as SiO_2, mg 1^{-1})	2.36	1.81	1.11	0.82	0.24	0.51	1.10	1.03	1.88	2.26	2.65	2.06
Nitrate-N (µg 1^{-1})	519	579	423	426	316	196	232	225	281	398	425	391
Ammonium-N (µg 1^{-1})	43	7	5	15	6	5	32	10	10	27	41	16
Soluble reactive phosphorus (µg 1^{-1})	8.40	1.82	1.30	1.59	0.91	<0.60	3.15	1.67	4.51	6.31	11.64	17.55
Total phosphorus (µg 1^{-1})	28.5	15.2	55.5	56.9	88.9	35.7	35.0	27.7	38.4	24.3	28.1	28.1
Conductivity (µS cm^{-1}, 25 °C)	69.0	78.2	65.0	69.5	69.8	70.5	73.0	66.9	65.9	81.0	75.5	63.0
Alkalinity (µeq/1^{-1})	147	151	131	160	162	193	245	234	231	206	212	128
pH	6.8	6.9	6.7	6.8	6.8	6.6	6.8	6.9	6.6	7.0	7.1	7.0
Secchi disc transparency (m)	2.5	2.25	2.0	3.0	3.0	2.5	2.5	1.75	2.25	3.0	3.25	1.25
Water level (m above 67.67 m.O.D) monthly means	0.99	1.26	1.18	0.75	0.96	1.07	0.99	1.28	1.55	1.21	1.15	-

Table 8. Long-term records of surface water characteristics in Bassenthwaite. Multiple observations are recorded as mean values with number of measurements in brackets. Pre-1974 values of alkalinity (except b) are corrected by a factor of -20 μeq l^{-1} (Sutcliffe et al. 1982).

	Year									
	1920^a	1928^b	1939-40	1946^d	1949^d	1955-6^e	1971^f	1974-6^g	1984^h	1987-8^i
Secchi transparency (m)	2.2	-	-	-	-	-	-	-	-	2.5(12)
conductivity (k_{20}, μS cm^{-1})	-	-	52.0(3)	-	-	-	69.3(7)	-	-	63(12)
alkalinity	-	148(9)	137(2)	-	129(13)	168(8)		189(25)		188(12)
pH	-	7.0(9)	6.6	-	-	-	-	6.9(22)		6.8(12)
NO_3-N (μg l^{-1})	-	91(9)	(3)	-	151(13)	(252(8)	-	224(9)	390(4)	370(12)
PO_4-P (μg l^{-1})	-	2.1(9)	-	-	1(10)	-	0.85(2)	-	1(4)	5.0(12)
total-P (μg l^{-1})	-	-	-	14	-	-	19(3)	-	23(2)	35(12)
Si as SiO_2 (mg l^{-1})	-	1.2(9)	-	-	1.9(13)	-	-	-	1.22(4)	1.54(12)
chlorophyll a (μg l^{-1})	-	-	-	-	-	-	10.6(2)	-	-	15.3(12)

Sources:				
	a	Pearsall 1921	f	Jones 1972
	b	Pearsall 1920	g	Sutcliffe et al. 1982
	c	Mortimer, unpublished notebooks (FBA)	h	FBA unpublished
	d	Mackereth & Lund, unpublished	i	Mubamba 1989
	e	Sutcliffe et al. 1982		

TABLE 8

Table 9. Seasonal abundance (cells ml^{-1}) of the 3 principal planktonic diatoms during 1949, 1950 and 1961. ND = not determined. (Lund, unpublished data)

Year	1949																	
Day	13	29	10	24	7	28	31	7	6	1	28	26	24	21	19	16	28	14
Month	1	1	2	2	3	3	3	4	5	6	6	7	8	9	10	11	11	12
Asterionella formosa	11	20	68	38	8	0.02	0.3	0.1	16	20	334	641	1191	704	10	48	41	22
Fragilaria crotonensis	0	0	0	ND	0	ND	ND	0	0	28	0	0	190	932	5440	0	ND	0
Tabellaria flocculosa	4	0	0	0	0	ND	ND	0	0	0	0	0	0	0	0	0	ND	0

Year	1950										
Day	11	9	8	19	3	25	31	7	27	11	17
Month	1	2	3	4	5	5	5	6	6	7	8
Asterionella formosa	0.3	4	38	3860	3510	348	2132	1538	0	1	61
Fragilaria crotonensis	0	0	0	ND	0	ND	0	ND	3	0	806
Tabellaria flocculosa	0	0	0	ND	0	ND	0	ND	0	0	0

Year	1961							
Day	4	17	1	28	24	10	7	20
Month	1	1	3	3	4	5	6	9
Asterionella formosa	0	15	24	324	0	0	24	39
Fragilaria crotonensis	0	0	0	0	0	0	0	0
Tabellaria flocculosa	0	48	98	1228	831	268	0	0

TABLE 9

TABLE 10

Table 10. Average standing crops of algae in the English Lakes. Data are means of differing numbers of samples per lake, 21–25 in 1949–1951, 9–17 in 1955–1956, and 6–9 in 1961–1963. Grasmere data for "large algae" in 1949–1951 exclude a sample containing a swarm of Uroglena *which would raise the average to 3,786. The approximate total dry weight, for a lake in which one algal category was not counted, is estimated by assuming the rounded group mean for that category in which the data for other algal groups indicate it ought to belong.* From Gorham et al (1974).

	A µ-algae cells ml^{-1}			B "Large algae" cells ml^{-1}			C Cyanophyta indiv ml^{-1}			Approx dry wt*			
	1955 1956	1961 1963	Mean	1949 1951	1961 1963	Mean	1949 1951	1961 1963	Mean	A	B µg l^{-1}	C	Total
Group 1													
Wastwater	713	586	650	4	2	3	0	0	0	14	9	0	23
Thirlmere	919	454	687	19	6	13	+	0	0	15	40	0	55
Buttermere	569	442	506	20	17	19	0	0	0	11	59	0	70
Brothers Water	--	--	--	35	11	23	0	0	0	--	71	0	85
Ennerdale Water	782	401	592	35	17	26	0	0	0	13	80	0	93
Crummock Water	793	842	818	24	28	26	1	+	1	18	80	9	110
Mean										14	57	2	73
Group 2													
Hawes Water	1,056	831	944	162	56	109	+	1	1	21	340	9	370
Elterwater	--	284	--	233	55	144	10	+	5	6	440	47	490
Coniston Water	3,341	1,958	2,650	45	431	238	0	0	0	58	730	0	790
Grasmere	--	--	--	(325)	234	280	1	+	1	--	860	9	910
Rydal Water	--	--	--	75	595	335	1	0	1	--	1,000	9	1,000
Windermere N Basin	2,424	2,633	2,529	360	500	430	1	3	2	56	1,300	19	1,400
Derwentwater	1,947	1,608	1,778	103	1,079	591	+	1	1	39	1,800	9	1,800
Mean (rounded)										36	920	15	970
Group 3													
Loweswater	2,102	2,271	2,187	376	820	598	17	37	27	48	1,800	260	2,100
Windermere S Basin	6,054	3,438	4,746	369	1,228	799	28	20	24	100	2,500	230	2,800
Blelham Tarn	5,270	4,261	4,766	749	1,470	1,110	3	12	8	110	3,400	76	3,600
Loughrigg Tarn	--	--	--	1,161	--	--	7	--	--	--	3,600	66	3,700
Ullswater	1,292	1,800	1,546	1,387	1,016	1,202	+	14	7	34	3,700	66	3,800
Bassenthwaite Lake	5,966	3,238	4,602	1,010	1,658	1,334	+	4	2	100	4,100	19	4,200
Esthwaite Water	3,317	914	2,116	1,438	2,260	1,849	191	37	114	47	5,700	1100	6,800
Mean (rounded)										73	3,500	260	3,800

*Rounded to two figures.

TABLE 11

Table 11. Seasonal abundance of phytoplankton in Bassenthwaite, 1987-8: counts of cells, colonies or filaments per 0.1 ml of sample.

Alga (genus)	J	F	M	A	M	J	J	A	S	O	N	D	J
Diatoms:													
Melosira	38	30	131	21		1	1	1		13	8	100	7
Synedra	13	8	-	22	-	-	-	-	-	-	-	-	-
Tabellaria	7		36	2	1	296	-	1	-	10	4	17	-
Asterionella	1	14	1	5	6	9	-	10	7	53	108	81	2
Fragilaria	-	-	1	-	-	-	2	90	80	48	2	2	-
Centric diatoms	2	7	50	7	-	80	6	-	1	19	60	34	5
Cryptomonads:													
Rhodomonas	1	8	2	1	34	112	29	90	54	16	49	300	7
Cryptomonas	-	1	-	2	18	9	60	76	54	27	17	45	6
Green algae:													
Gemellicystis	-	-	1	-	15	3	101	300	213	314	209	16	-
Sphaerocystis	-	-	-	-	-	2	35	108	100	18	2	5	-
Spondylosium	-	-	3	1	-	3	-	13	90	24	2	-	-
Staurastrum	-	-	-	-	-	1	-	-	-	-	2	-	-
Scenedesmus	-	-	-	-	1	-	-	-	-	-	-	-	-
Ankistrodesmus	-	-	-	1	-	-	-	-	-	-	-	-	-
Chrysomonad:													
Dinobryon	-	-	-	1	1	-	-	1	3	5	9	12	-
Dinoflagellates:													
Peridinium	7	1	-	-	-	-	2	-	1	-	-	-	-
Ceratium	-	-	-	-	-	-	-	3	2	1	-	-	-
Blue-greens:													
Oscillatoria	-	-	-	-	-	-	-	1	-	-	-	-	-
Anabaena	-	-	-	-	-	-	-	-	-	1	-	-	-

TABLE 12

Table 12. Seasonal changes of chlorophyll *a* concentration, 0-5 m layer (mg m^{-3}).

1987	
19 Jan	1.08
16 Feb	2.66
16 Mar	12.4
13 Apr	19.0
18 May	14.8
15 June	17.5
14 July	28.6
17 Aug	21.4
14 Sept	24.2
12 Oct	31.2
9 Nov	8.06
21 Dec	3.17
1988	
4 Jan	1.84

Table 13. Seasonal distribution of zooplankters (animals m^{-3}), 1986-88.

	D	J	F	M	A	M	J	J	A	S	O	N	D	J	Aug
Crustacea:															
Eudiaptomus	68	68	42	219	24	1741	2838	1981	1711	737	289	681	841	78	3858
Cyclopoids	5			4	56	228	292	334	616	391	167	65	24	10	240
Daphnia	63	12	4	6	4	1604	1223	1558	25971	3007	1532	266	430	166	282
Diaphanosoma							9				4	42			77
Polyphemus											15	4			9
Leptodora						152	137	36	137	4					78
Bosmina	26	3	8	26	12	23				4	133	126	1207	112	
Crustacean nauplii						76	91	145	684	68	110	53	74	10	222
Crustacean eggs	21		15	22			9	153	1848	141	137	46	152	10	385
Ephippia of Daphnia					4		9		34	40					
Rotifers:															
Asplanchna						4669				40	335	164	74		
Keratella					4	8	73								
Kellicottia							228	8							
Filinia							5								
Hexarthra							5								
Trichocerca							18								

Table 14. Invertebrate taxa taken on the shore (water depth < 60 cm) at 50 sites (see Fig. 1) between November 1966 and January 1967; % frequency of occurrence is given (number of sites expressed as percentage of total number of sites) together with total numbers taken in all samples.

Taxa		% frequency	Total numbers
Flatworms	*Polycelis nigra*	44	356
	Dugesia lugubris	24	58
	Dendrocoelum lacteum	2	1
Snails	*Valvata piscinalis*	2	1
	Lymnaea palustris	2	1
	L. peregra	70	262
	Physa fontinalis	52	339
	Planorbis albus	22	20
	P. contortus	18	48
	Ancylus fluviatilis	50	170
Leeches	*Glossiphonia complanata*	12	9
	Helobdella stagnalis	8	20
	Erpobdella octoculata	24	19
Water louse	*Asellus meridianus*	72	222
Shrimps	*Gammarus pulex*	96	618
	Crangonyx pseudogracilis	62	150
Mayflies	*Centroptilum luteolum*	10	9
	Ephemera danica	4	3
	Caenis moesta	18	20
Stoneflies	*Nemoura avicularis*	20	18
	Leuctra inermis	2	1
	L. hippopus	18	12
	Diura bicaudata	50	54
	Chloroperla torrentium	6	4
Water bugs	*Micronecta poweri*	20	75
	Corixa punctata	6	3
Beetles	*Deronectes assimilis*	2	3
	Oulimnius tuberculatus	4	6
Caddis flies	*Agapetus fuscipes*	2	1
	Polycentropus flavomaculatus	62	139
	P. irroratus	8	5
	Cyrnus trimaculatus	30	60
	C. flavidus	2	1
	Tinodes waeneri	58	183

Table 15. Monthly estimates of the density (numbers m^{-2}) of the profundal benthos (from depths between 12 m and 18 m).

Months	D	J	F	M	A	M	J	J	A	S	O	N	D
<u>Taxa</u>													
Chironomidae													
Eggs					178								
Larvae	3969	6075	1347	1200	3600	622	711	0	1320	3391	2667	4876	3409
Pupae					133	89							
Tubificidae	711	11899	4978	5822	1524	6458	1320	591	4787	9778	636	3320	1911
<u>Pisidium</u>	3511	2769	178	44	1644	2031	2769	1809	933	5320	1956	1498	267
Bryozoan statoblast				591			591	636			591		
Ephemeroptera nymphs	44												
Ostracoda										591			
<u>Asellus</u>					89								
<u>Gammarus</u>	44				44								
<u>Daphnia</u> ephippia	7104	4737	10065	20721	7739	3552	85248	18395	6012	24273	36199	19536	28416

TABLE 15

Table 16. Estimates of the density (numbers m^{-2}) of the benthos at two depths (4 m, 18 m) in February 1987.

Depth	4 m	18 m
Taxa		
Chironomid larvae	12876	1347
Pisidium	2858	178
Tubificidae	1187	4978
Chironomid eggs	533	0
Ephippia of *Daphnia*	2369	10065
Coleoptera larvae	44	0
Ephemeroptera nymphs	178	0
Ostracoda	1187	0
Nematoda	1187	0

Table 17. The fork lengths (mm) of Bassenthwaite vendace caught in multi-meshed gill nets during autumn and winter.

Age (completed growing seasons)	Female Fish			Male Fish		
	n	mean length	standard deviation	n	mean length	standard deviation
3	6	149.7	6.2	4	165.2	15.2
4	11	190.8	22.3	8	196.2	5.4
5	23	214.7	7.7	17	206.5	8.2
6	36	219.0	6.1	31	207.0	7.2
7	20	227.2	6.8	14	214.6	9.3
8	8	233.3	8.9	6	211.2	10.2
9	5	225.2	4.3			
10	7	231.6	2.0			

TABLE 18

Table 18. The state of stomach fullness in vendace from Bassenthwaite and Derwentwater, 1986/87

		D	J	F	M	A	M	J	J	A	S	O	N
Bassenthwaite:													
No. of fish	examined	44	123	19	36	34	37	46	17	27	36	53	14
	Empty	44	123	18	36	0	0	2	3	5	35	53	10
	$^{1}/4$ Full	0	0	1	0	0	0	1	5	1	0	0	3
	$^{1}/2$ Full	0	0	0	2	0	0	3	0	3	0	0	1
	$^{3}/4$ Full	0	0	0	0	2	0	3	0	2	0	0	0
	Full	0	0	0	0	30	37	37	9	16	1	0	0

Table 19. Percentages of prey organisms in the stomachs of vendace and environment (integrated water column samples) in Bassenthwaite. The χ^2 values indicate whether the stomachs contained a significantly different proportion of each category from the environmental samples.

PREY	Daphnia		Eudiaptomus		Cyclopoids		Other Cladocera		Chironomids		Bosmina		Others	
MONTH	FISH	ENV	FISH	ENV	FISH	ENV	FISH	ENV	FISH	ENV	FISH	ENV	FISH	ENV
APR	0.0	2.5	0.0	15.0	2.1	53.7	0.0	0.0	32.3	8.7	0.0	15.0	65.6	5.0
χ^2-value	1.00		1.00		34.72		-		12.96		2.25		70.53	
Significance	NS		NS		***				***		NS		***	
MAY	23.4	18.7	40.0	20.3	7.4	2.7	4.0	2.1	25.2	0.2	0.0	0.3	0.0	55.8
χ^2-value	1.88		3.36		2.53		0.62		5.88		10.38		123.60	
Significance	NS		NS		NS		NS		*		**		***	
JUN	94.5	25.1	0.0	57.2	0.5	6.0	3.3	2.8	0.2	0.0	Absent		0.5	8.9
χ^2-value	499.65		116.34		64.41		0.05		1.0				5.75	
Significance	***		***		***		NS		NS				*	
JUL	54.8	38.4	0.0	48.6	25.9	8.3	16.7	0.9	1.6	0.0	Absent		0.9	3.8
χ^2-value	3.22		1548.70		3.40		19.31		3.86				50.50	
Significance	NS		***		NS		***		*				***	
AUG	92.4	89.1	0.1	5.9	3.57	2.1	1.5	0.5	2.0	0.0	Absent		0.4	2.3
χ^2-value	0.53		112.11		1.50		1.44		1.09				5.10	
Significance	NS		***		NS		NS		NS				*	

NS Not significant
* $p < 0.05$
** $p < 0.01$
*** $p < 0.001$

TABLE 19

Table 20. Observed mean lengths ($\bar{x}$, in mm) of perch in relation to age, with standard deviation (S D) and sample size (n).

AGE (Yrs)	$\bar{x}$	SD	n
1	50.5	5.7	4
2	101.9	6.2	17
3	142.4	25.1	13
4	213.3	10.7	11
5	227.8	16.8	9
6	235.7	13.4	3
7	273.0	21.2	2

TABLE 21

Table 21. Records of frequency, abundance, and depth-range of macrophytes in Bassenthwaite 1976-1979 (from Stokoe 1980).

A. Offshore Species found	Distribution				Depth Range (m.)	
	Frequency	Abundance			Upper	Lower
		A	P	S		
Callitriche hamulata	7	-	6	1	0.7	3.0
" hermaphroditica	7	2	-	5	1.0	1.5 (3.0)
Elatine hexandra	2	1	-	1	0.5	1.0
Elodea canadensis	6	-	2	4	0.5	2.0
" nuttallii	7	4	3	-	0.5	2.5
Equisetum fluviatile	4	-	3	1	0.5	
Isoetes lacustris	11	-	10	1	0.5	2.0
Juncus bulbosus	4	-	4	-	1.0	
Littorella uniflora	13	3	9	1	0.0	1.2
Myriophyllum alterniflorum	11	1	9	1	0.5	2.0
Nuphar lutea	2	-	1	1	1.0	
Potamogeton alpinus	1	-	1	-	0.7	1.5
" berchtoldii (2 forms)	2	-	-	2	0.5	1.5
" crispus	3	-	2	1	1.0	1.5
" gramineus	3	1	1	1	0.5	2.0
" natans	1	1	-	-	0.5	0.7
" perfoliatus	6	-	2	4	1.0	2.5
" pusillus	1	-	-	1	?	
Ranunculus peltatus	10	-	7	3	0.5	2.5
Schoenoplectus lacustris	4	2	2	-	0.5	1.0
Sparganium angustifolium	1	-	-	1	0.5	
Fontinalis antipyretica	4	-	4	-	0.5	2.2
Nitella opaca/flexilis agg.	12	7	4	1	0.5	4.0

Notes

1. Frequency

The number of sections (out of 13) in which each species has been found is indicated.

2. Abundance

The quantitative individual observations have been summarised for each section and the number of sections in each of the following categories for each species are shown, thus:

A - Abundant, P - Plentiful, S - Sparse

B. Offshore species not found on survey

Apium inundatum (Old record)
Lobelia dortmanna (drift, only)
Nymphaea alba (old record)
Sparganium minimum (old record)

C. Littoral Species

Littoral Species	Frequency
Agrostis stolonifera	6
Alisma plantago - aquatica	2
Callitriche (platycarpa)	1
" stagnalis	1
Caltha palustris	4
Carex nigra	3
" vesicaria	3
Eleocharis palustris	5
Galium palustre	4
Glyceria fluitans	1
Hydrocotyle vulgaris	1
Iris pseudacorus	7
Juncus acutiflorus	1
" articulatus	5
" effusus	8
" filiformis	4
" tenuis	1
Lemna minor	1
Lysimachia vulgaris	3
Lythrum salicaria	5
Mentha aquatica	4
Montia fontana	1
Myosotis caespitosa	2
" scorpoides	3
Oenanthe crocata	3
Phalaris arundinacea	11
Phragmites australis	2
Polygonum amphibium	1
" hydropiper	1
Potentilla palustris	1
Ranunculus flammula	3
" repens	3
Rorippa nasturtium - aquatica	2
Scutellaria galericulata	3

Note The number of sections (out of 13) in which each species has been found is indicated.

D. Sectional frequency of species

	Number of Species		
	Aquatic	Littoral	Total
1. South end - Redness Point	15	26	41
2. East side - Little Crosthwaite	10	2 *	12
3. " " - Church Bay	5	4 *	9
4. " " - Bowness Bay	18	3 *	21
5. " " - Broadness	5	1 *	6
6. " " - Scarness	11	5 *	16
7. " " - Lakeside Wood	12	24	36
8. North end - Ouse Bridge	7	6	13
9. West side - Dubwath	9	14	23
10. " " - Peel Wyke	11	20	31
11. " " - Wythop Wood	3	2 *	5
12. " " - Beck Wythop	4	1 *	5
13. " " - Hursthole Point	12	14	26
Total	23	34	57

* probably under-recorded

TABLE 22

Table 22. Estimates of annual input of phosphorus into Bassenthwaite.

1. Sewage-derived phosphorus (largely soluble reactive, PO_4-P)
   (a) Keswick
      residents (1981 census)
      4777 x 1.8 g day^{-1} x 365 days = 3138 kg
      resident visitors
      April-October inclusive; assumes an overall 60% occupancy
      6000 x 0.9 g day^{-1} x 215 days = 1161 kg
      Keswick Convention
      10 000 x 0.9 g day^{-1} x 14 days = 126 kg
      non-resident visitors (as person-days)
      1 000 000 x 0.9 g day^{-1} = 900 kg

      5325 kg

   (b) Braithwaite
      exact population not available from census as included in large parish of Portinscale; estimated as 600
      600 x 1.8 g day^{-1} x 365 days = 394 kg

      Total Keswick + Braithwaite = 5719 kg
      Assume 88% passes through sewage works, then annual input to
      Bassenthwaite = 4575 kg

2. Catchment-derived phosphorus (excluding sewage works contributions)
   (a) Soluble reactive phosphorus
      North West Water obtained a value of 17.5 kg P km^{-2} yr^{-1} for the catchment of Esthwaite Water. Assuming the same level of loading from the Bassenthwaite catchment this would mean an annual input of
      17.5 kg km^{-2} x 237.9 km^{2} = 4163 kg

   (b) Total phosphorus
      (i) Using the value of 66 kg P km^{-2} yr^{-1} obtained by North West Water for the catchment of Esthwaite Water, Bassenthwaite catchment would annually receive 66 kg km^{-2} x 237.9 km^{2} = 15701 kg P.

      (ii) Using the value of 19.9 kg P m^{-2} yr^{-1} obtained for a grazed granitic catchment (Dartmoor) (Rigler 1979), Bassenthwaite catchment would annually receive 19.9 kg km^{-2} x 237.9 km^{2} = 4734 kg P

Input of soluble reactive phosphorus to Bassenthwaite = 4575 + 4163 = 8738 kg yr^{-1} or 1.65 g m^{-2} yr^{-1}

Input of total phosphorus to Bassenthwaite

(i) Using figures of P export from Esthwaite Water catchment
= 4575 + 15701 = 20276 kg yr^{-1} or 3.83 g m^{-2} yr^{-1}

(ii) Using figures of P export from a Dartmoor catchment
= 4575 + 4734 = 9309 kg yr^{-1} or 1.73 g m^{-2} yr^{-1}

FIG. 1

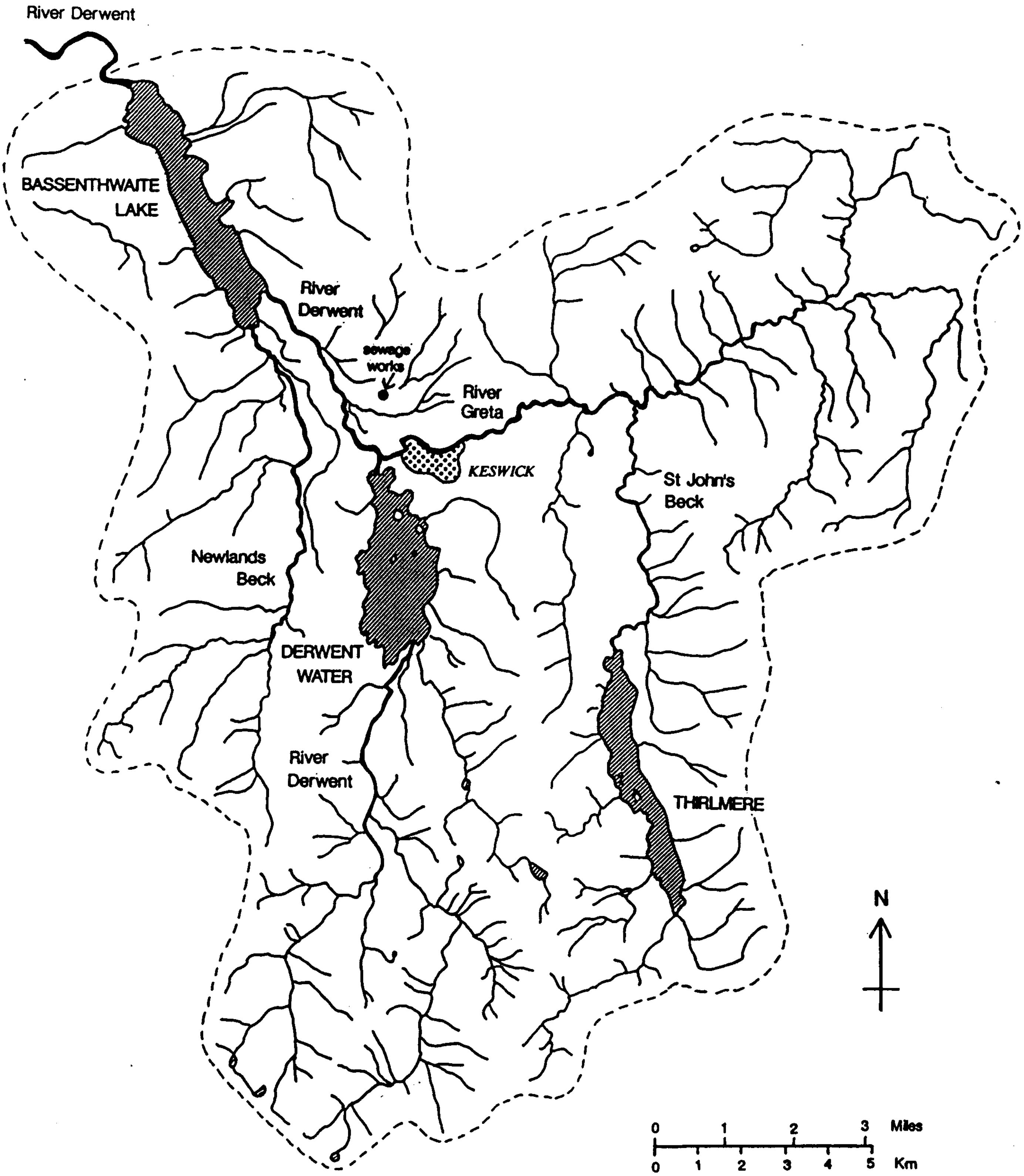
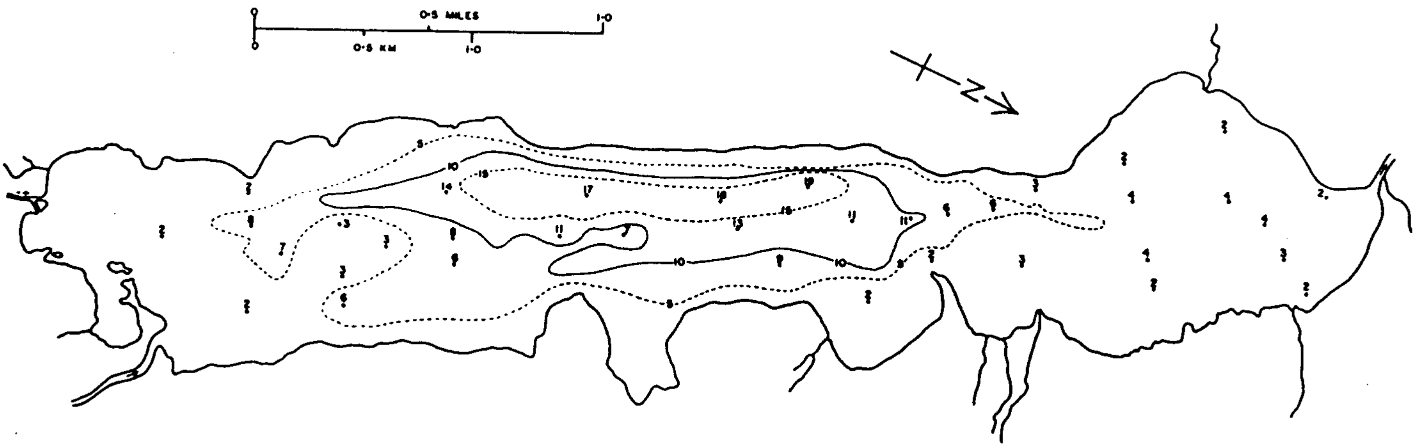
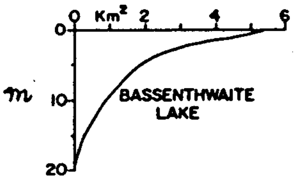


Fig. 1. Map of Bassenthwaite Lake and drainage within its catchment.

FIG. 2



Depth of contour m	Area enclosed by contour km²	 %	Layer m	Volume of layer m³×10⁶	 %
0	5·284	100	0-5	17·770	64
5	1·824	35	5-10	6·690	24
10	0·852	16	10-15	2·858	10
15	0·291	6	15-19	0·582	2
19 (bottom)					



	Level above O.D. at time of survey ft	 m	Length km	Max. depth m	Mean depth m	Area km²	Volume m³×10⁶	Area of drainage basin km²
Bassenthwaite Lake	225·6	68·8	6·2	19	5·28	5·284	27·900	237·9

Fig. 2. Bathymetric features of Bassenthwaite (depths in m).
(from Ramsbottom 1976)

FIG. 3

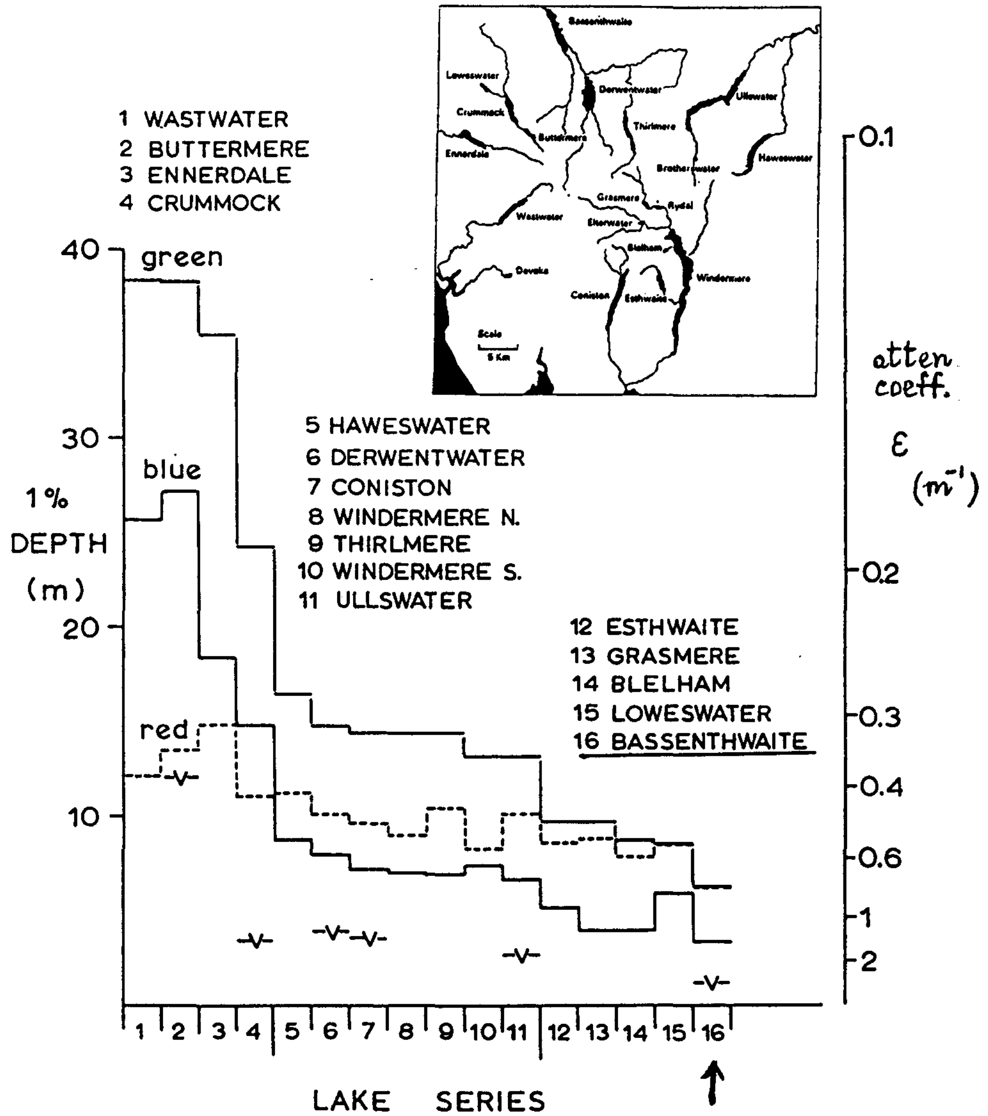


Fig. 3. The penetration of green, blue, red, and near ultra-violet (V) light into a series of English lakes, arranged in order of increasing ε_{min}, from measurements during June — September 1952. An inset shows the location of the lakes.

(from Talling 1971)

FIG. 4

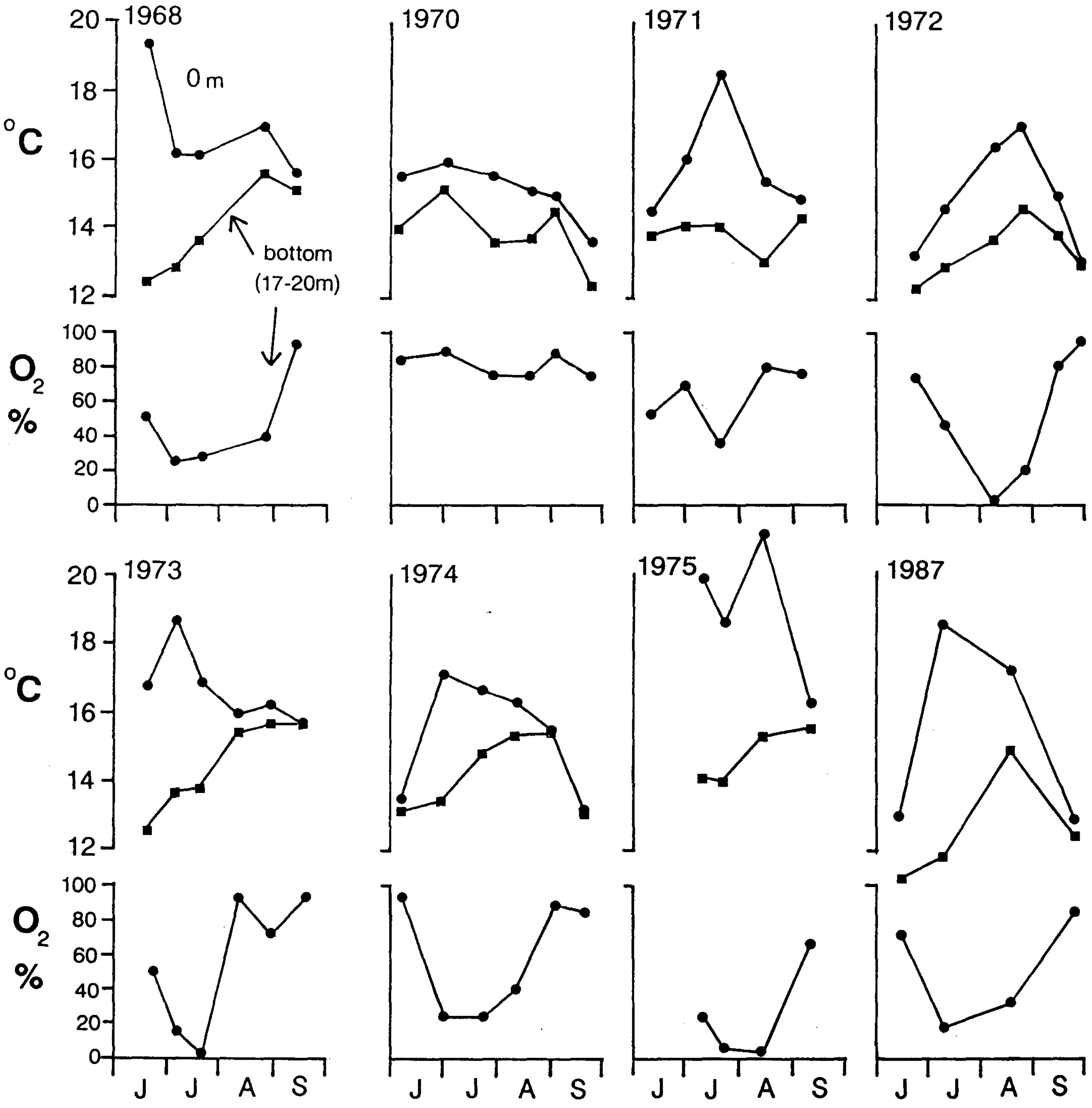


Fig. 4. Changes in the divergence of temperature between surface and bottom (17-20 m) water during the summers of 8 years, and the accompanying depletion of dissolved oxygen (as % saturation) in bottom water.

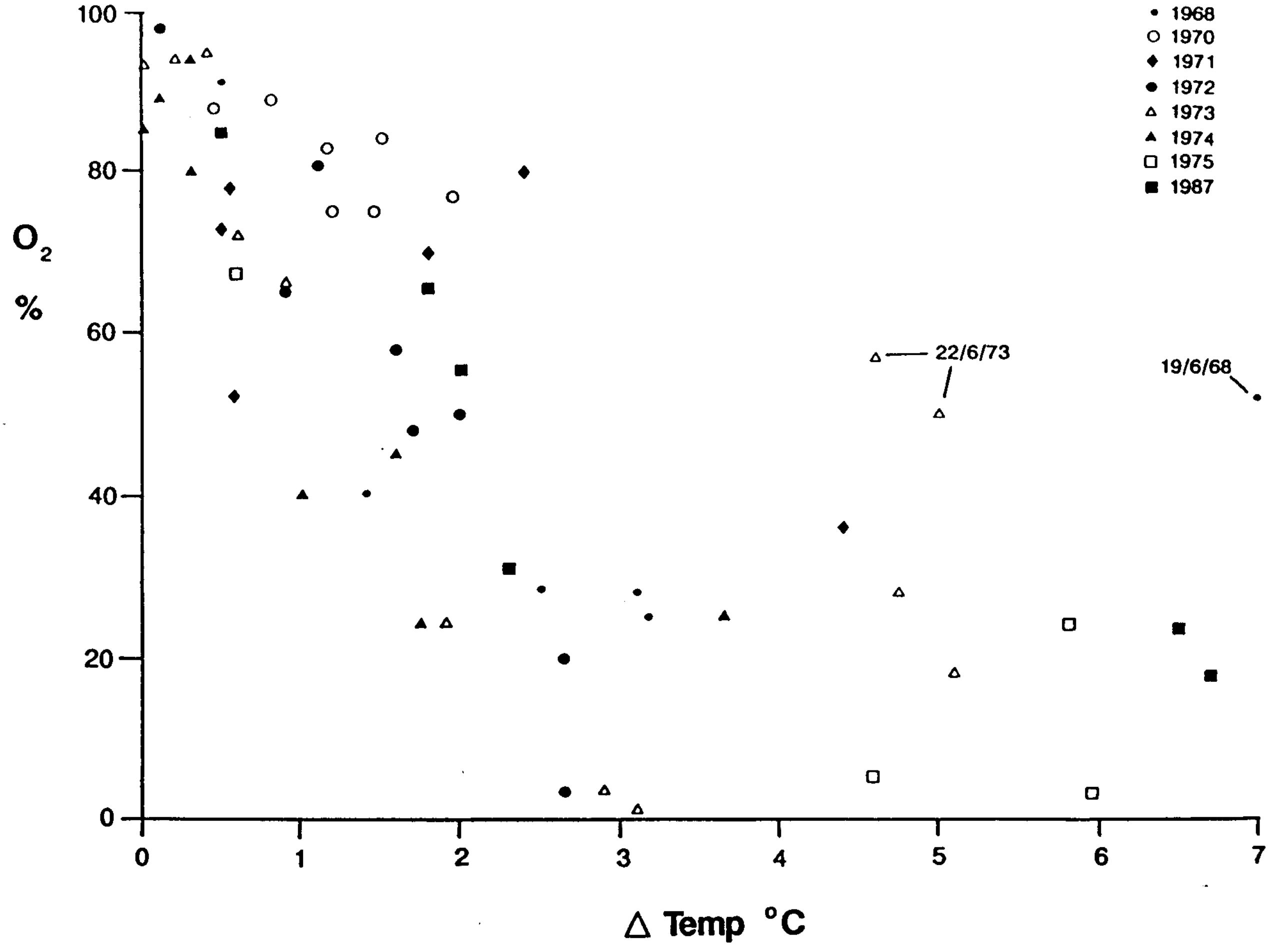


Fig. 5. Measurements of the oxygen concentration in bottom (17-20 m) water in relation to the accompanying divergence in temperature from that in surface water. Values from the summer periods (June - September) of 8 years, as in Fig. 4; those from two occasions of exceptionally early summer stratification are indicated.

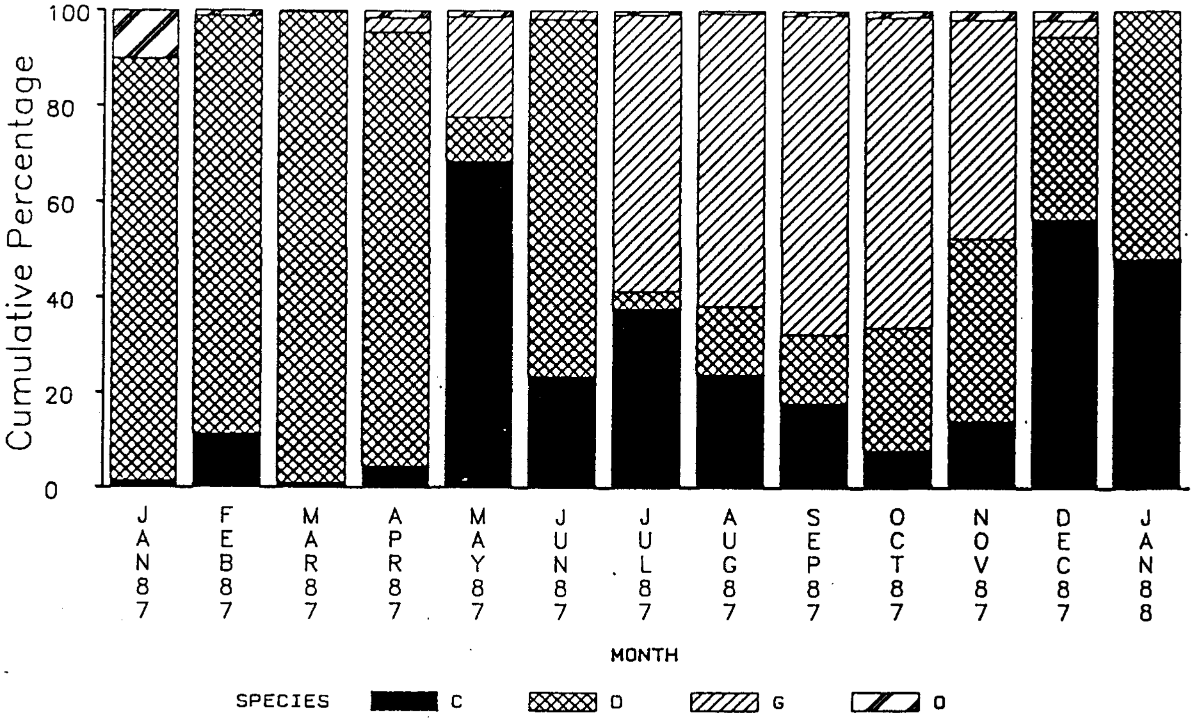


Fig. 6. Seasonal occurrence of phytoplankton groups in Bassenthwaite during 1987 and January 1988. The percentages are of the whole estimated phytoplankton as total numbers of individuals, colonies or filaments counted; C = cryptomonads, D = diatoms, G = green algae, O = others.

FIG. 7

Zooplankton

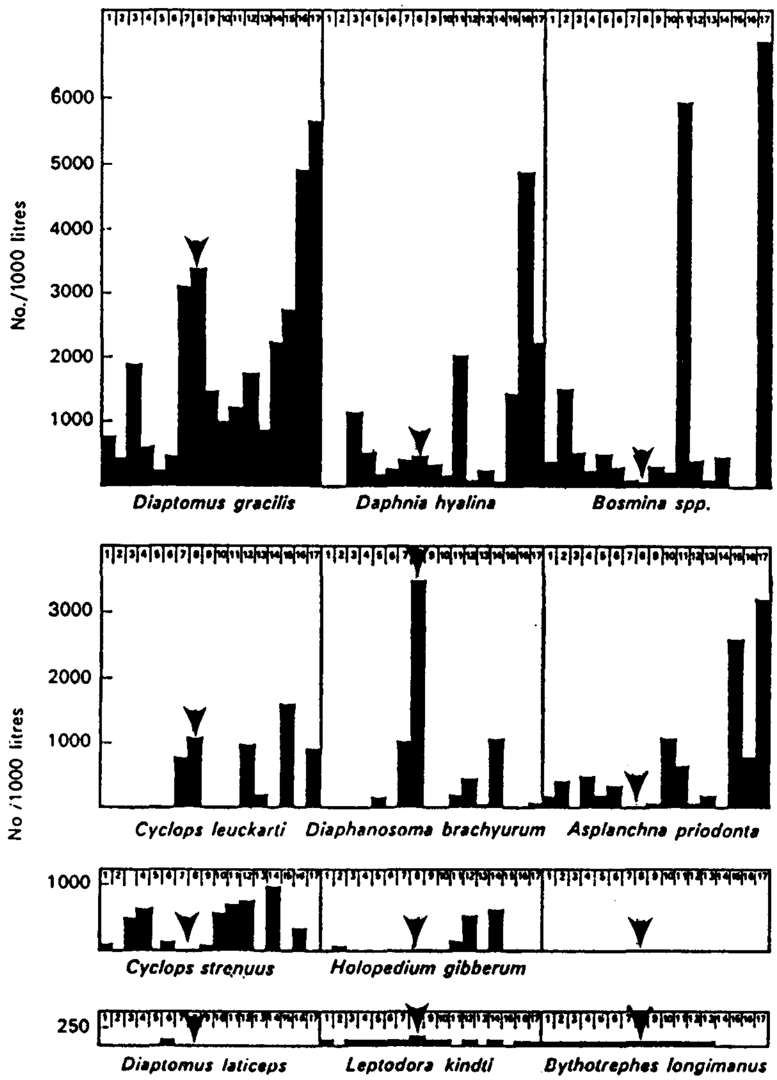


Fig. 7 Mean numbers per 1000 litres of eleven common planktonic Crustacea caught in the lakes of the Lake District in vertical net hauls in 1961 and 1962.

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. 8

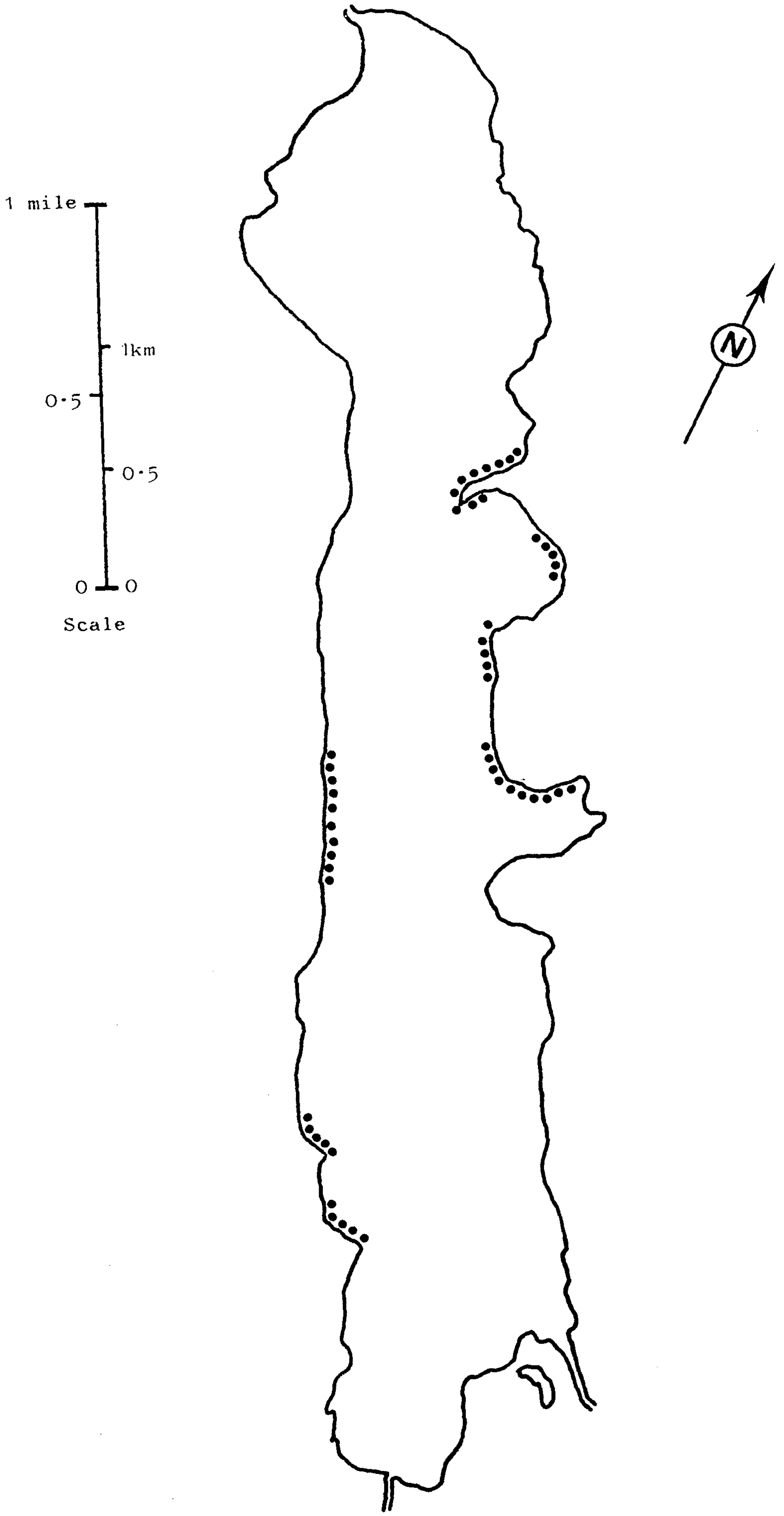


Fig. 8. Sites for shore collections of bottom fauna in Bassenthwaite.

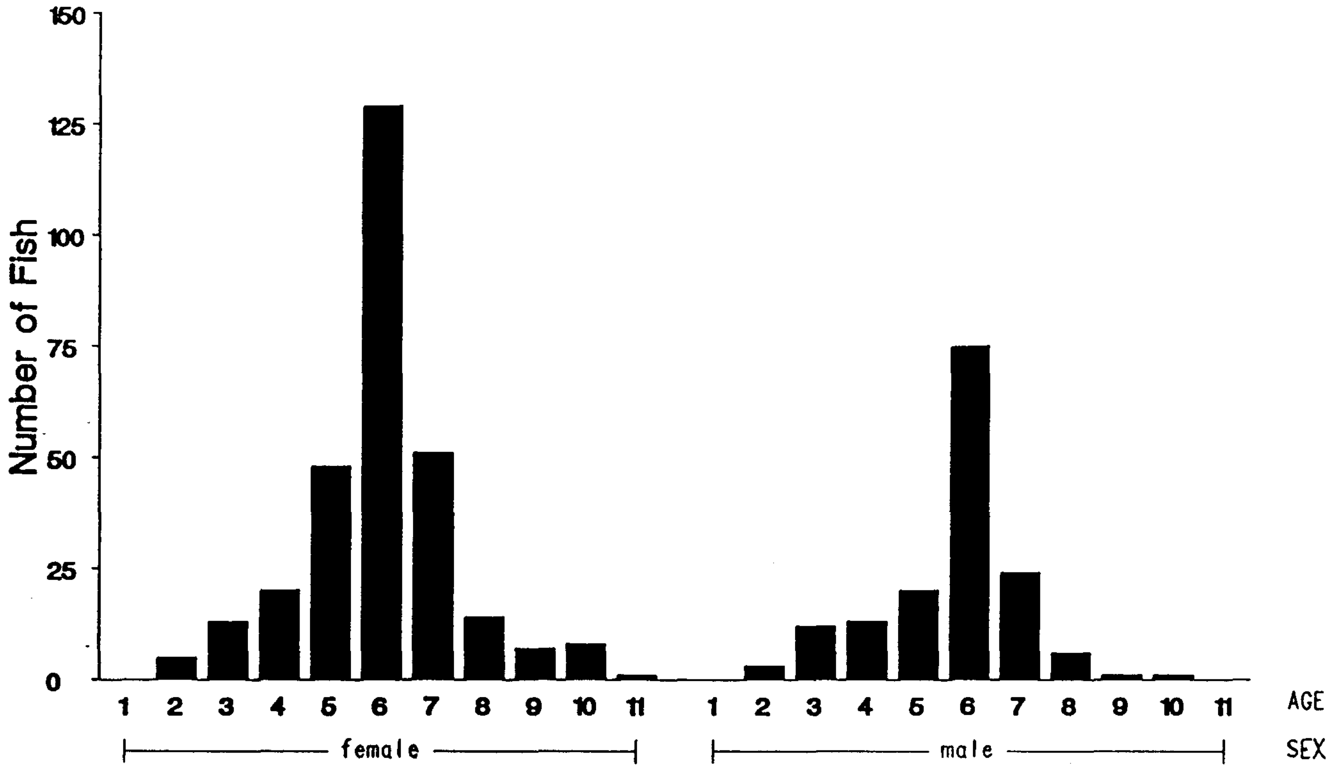


Fig. 9 Age Composition of Vendace Catches from Bassenthwaite

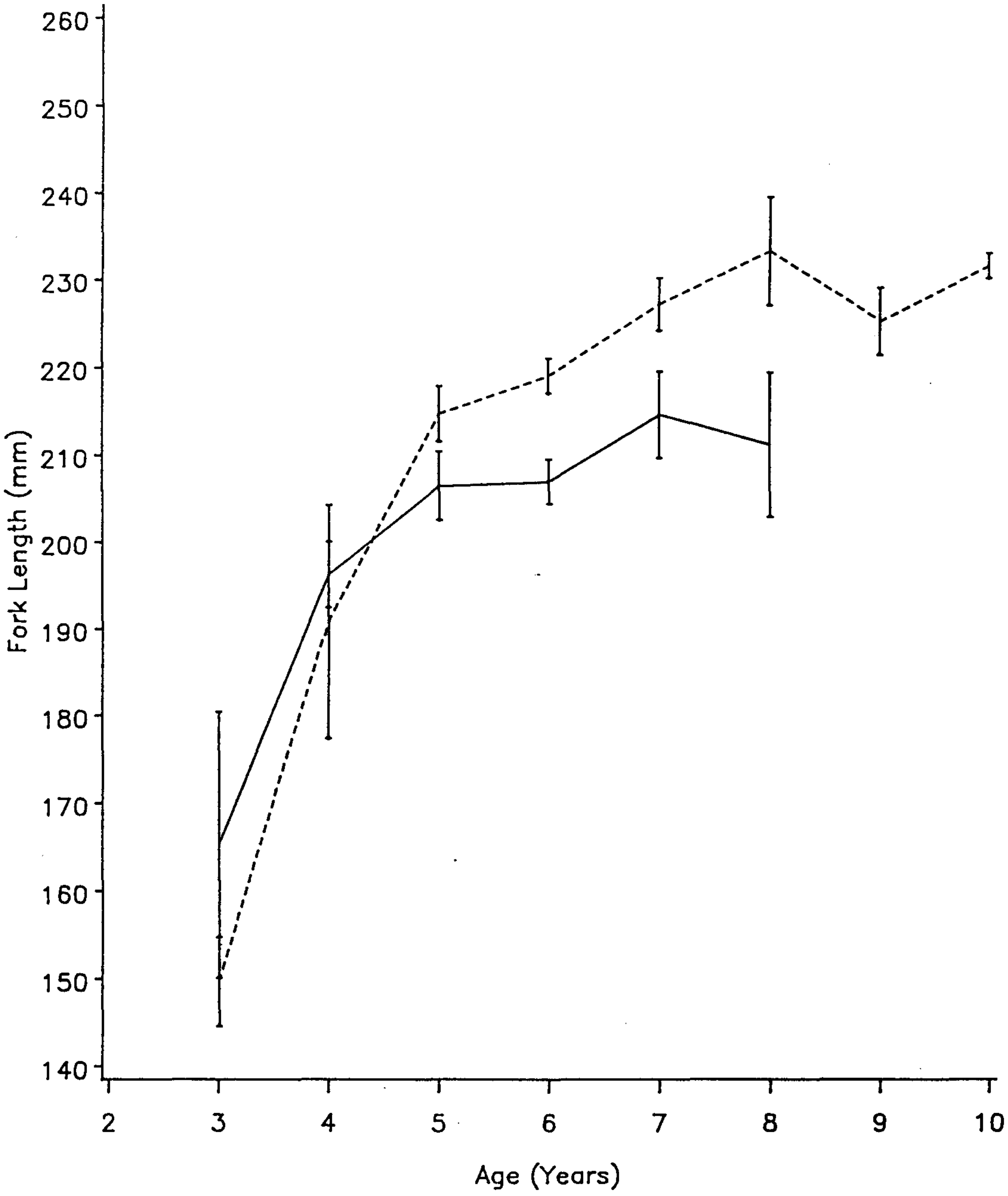


Fig. 10. Growth of male and female vendace in Bassenthwaite, 1986/87
solid line = males, dashed line = females, vertical bars show 95% C.L.

FIG. 11

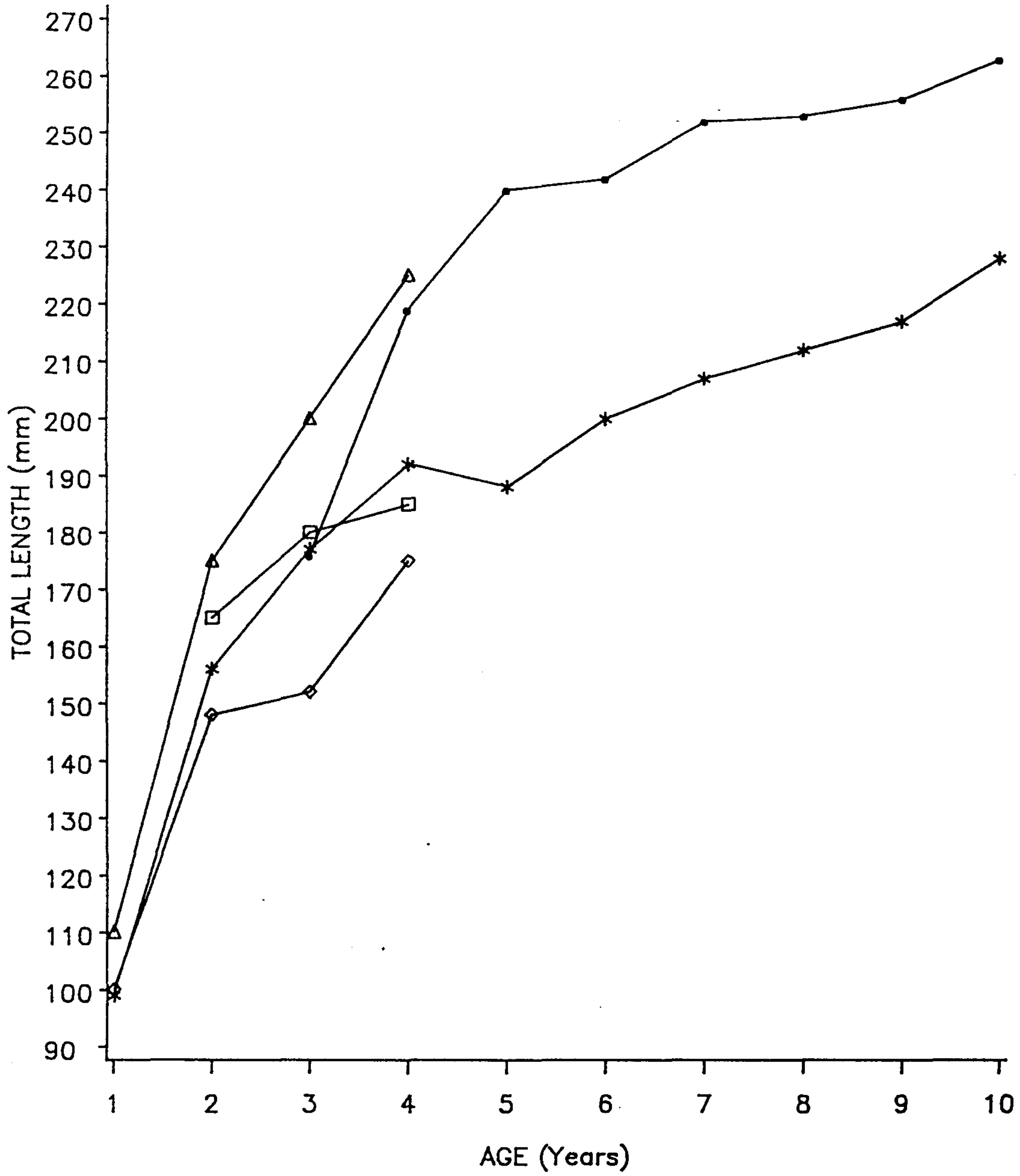


Fig. 11 Growth of vendace from Bassenthwaite(B) and Derwentwater(D) (England), Finland(F) , Sweden(S) , and Germany and Poland(GP) (combined)

See Hamrin (1986) for other data sets

dot = B, star = D, diamond = F, square = S, triangle = GP

FIG. 12

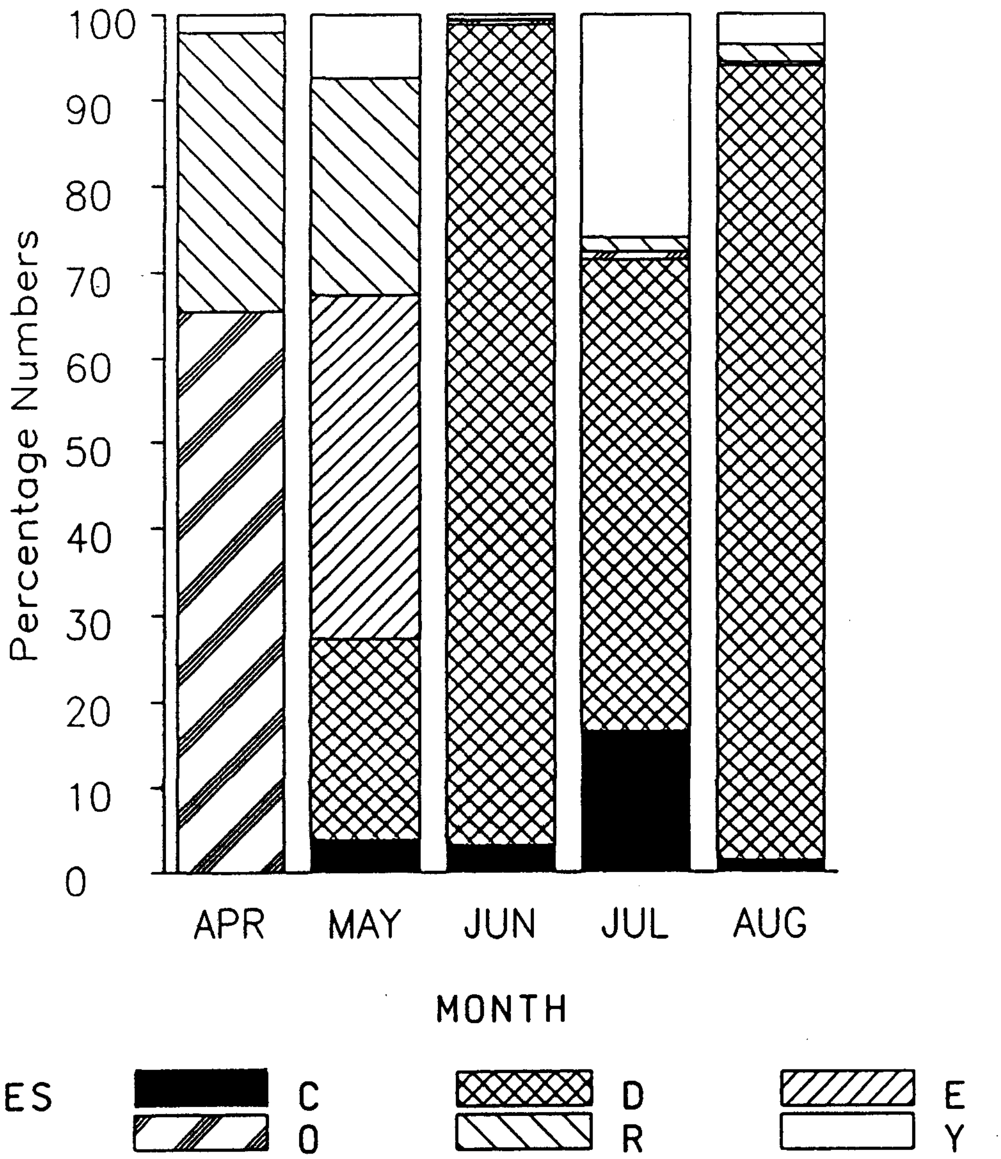


Fig. 12 **Seasonal variation in food organisms in vendace of Bassenthwaite ,1987**

C= Cladocera (other) D=Daphnia E= Eudiaptomus
O= other organisms R= chironomids Y= cyclopoids

FIG. 13

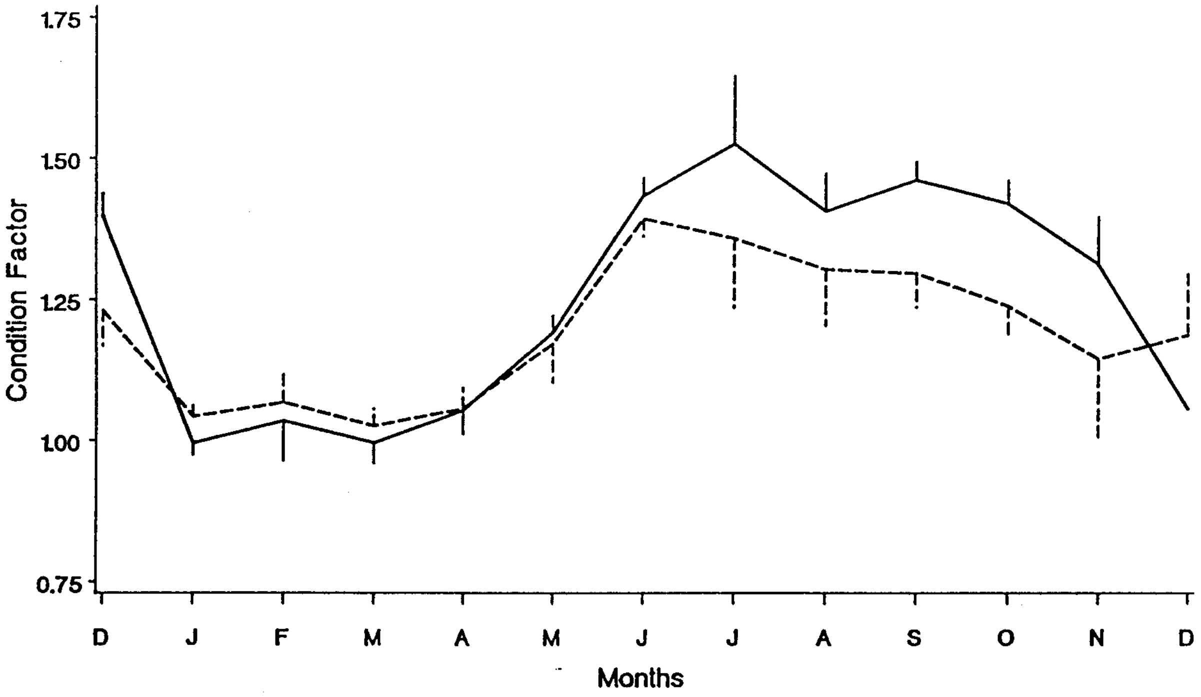


Fig. 13 . Total Condition of Bassenthwaite Vendace
Solid Line-Females, Dashes-Males
Vertical lines-95% CI

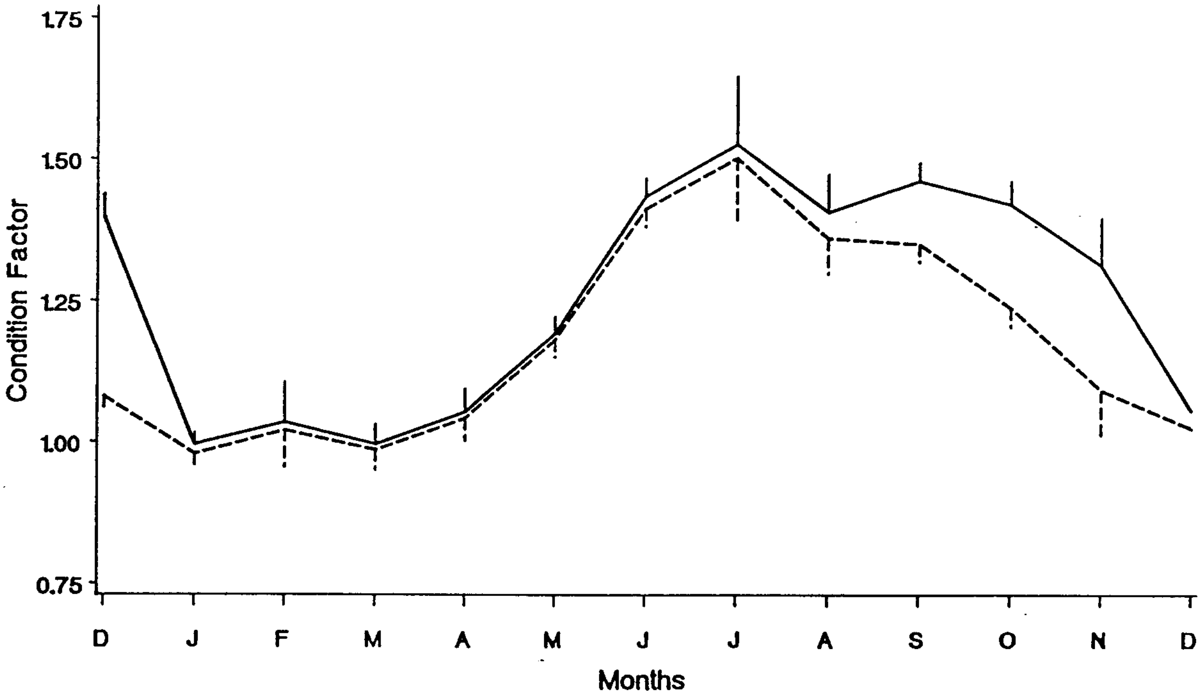


Fig. 14 **Female Bassenthwaite Vendace**
Solid Line-Total Condition, Dashes-Somatic Condition
Vertical lines-95% CI

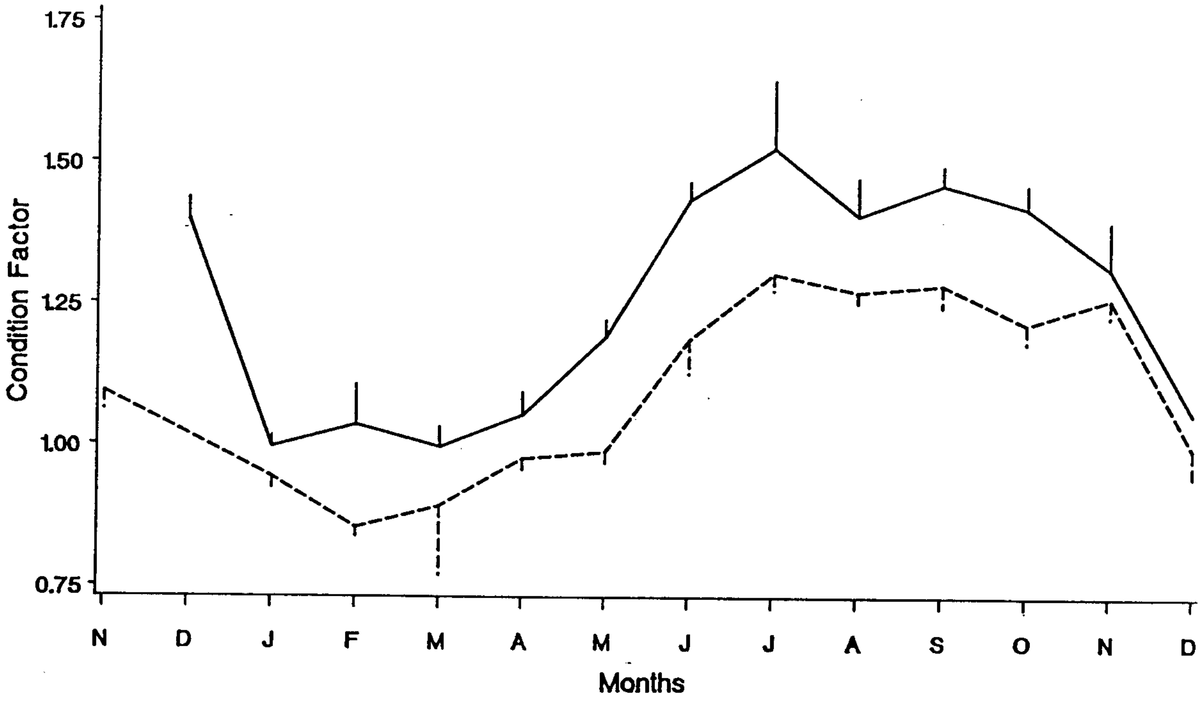


Fig. 15 Total Condition of Female Vendace
Solid Line-Bassenthwaite, Dashes-Derwentwater
Vertical lines-95% CI

FIG. 16

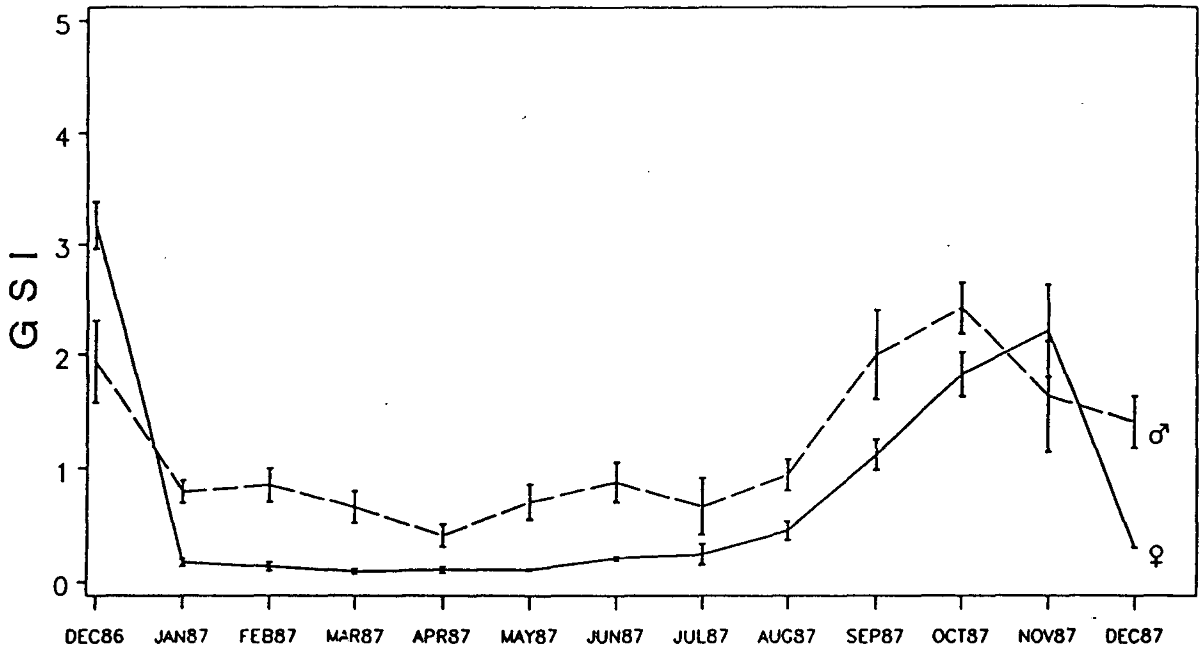


Fig. 16 . Variation of gonadosomatic index in male and female vendace in Bassenthwaite,1986/87
Vertical lines are 95% confidence intervals

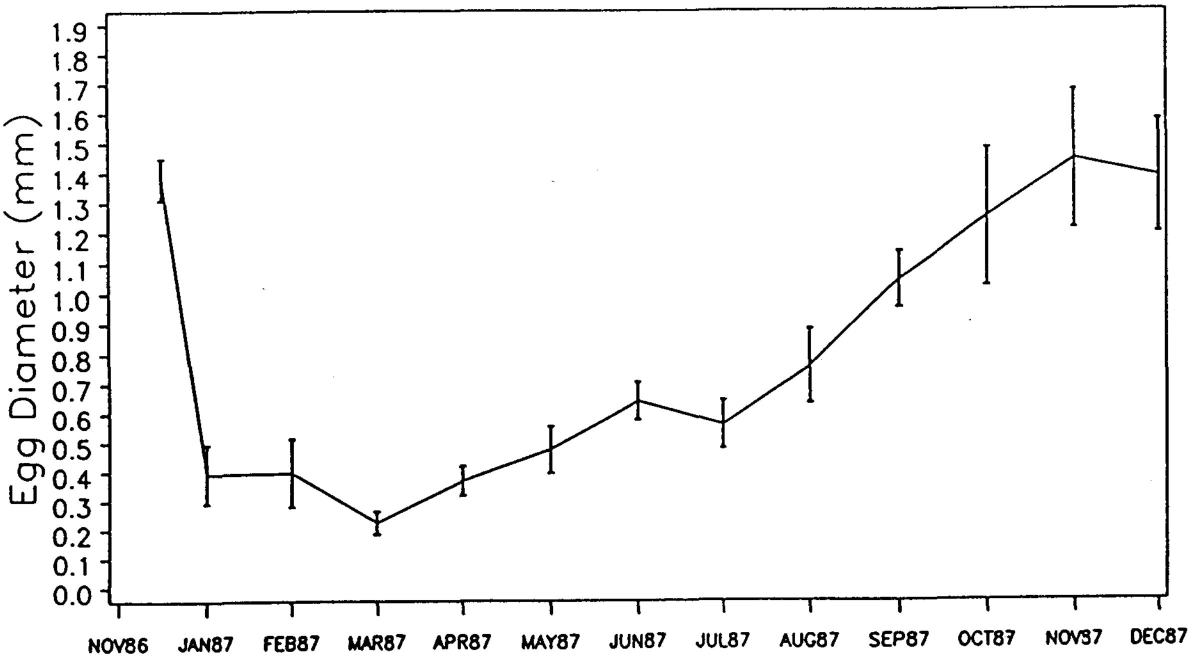


Fig. 17 **Egg development in a standard vendace of Bassenthwaite, 1986/87**
A standard female is about 202 mm
Vertical lines are 95% confidence limits

FIG. 18

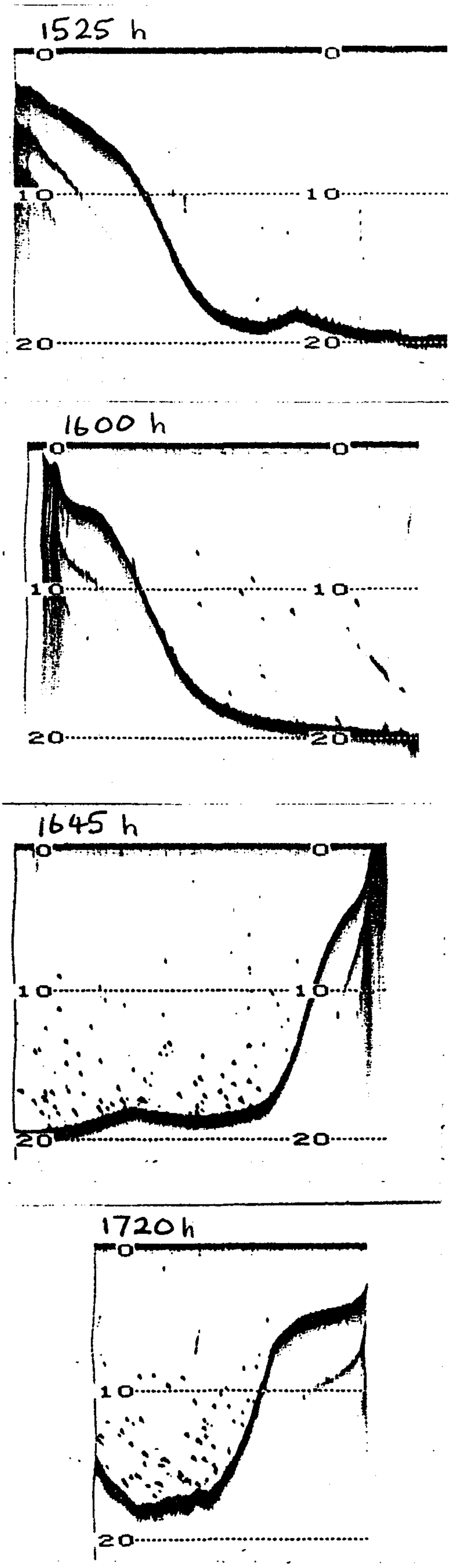


Fig.18 Depth-time distribution of vendace in Bassenthwaite on 9 Nov 87. Sunset was at 16.15 hours.

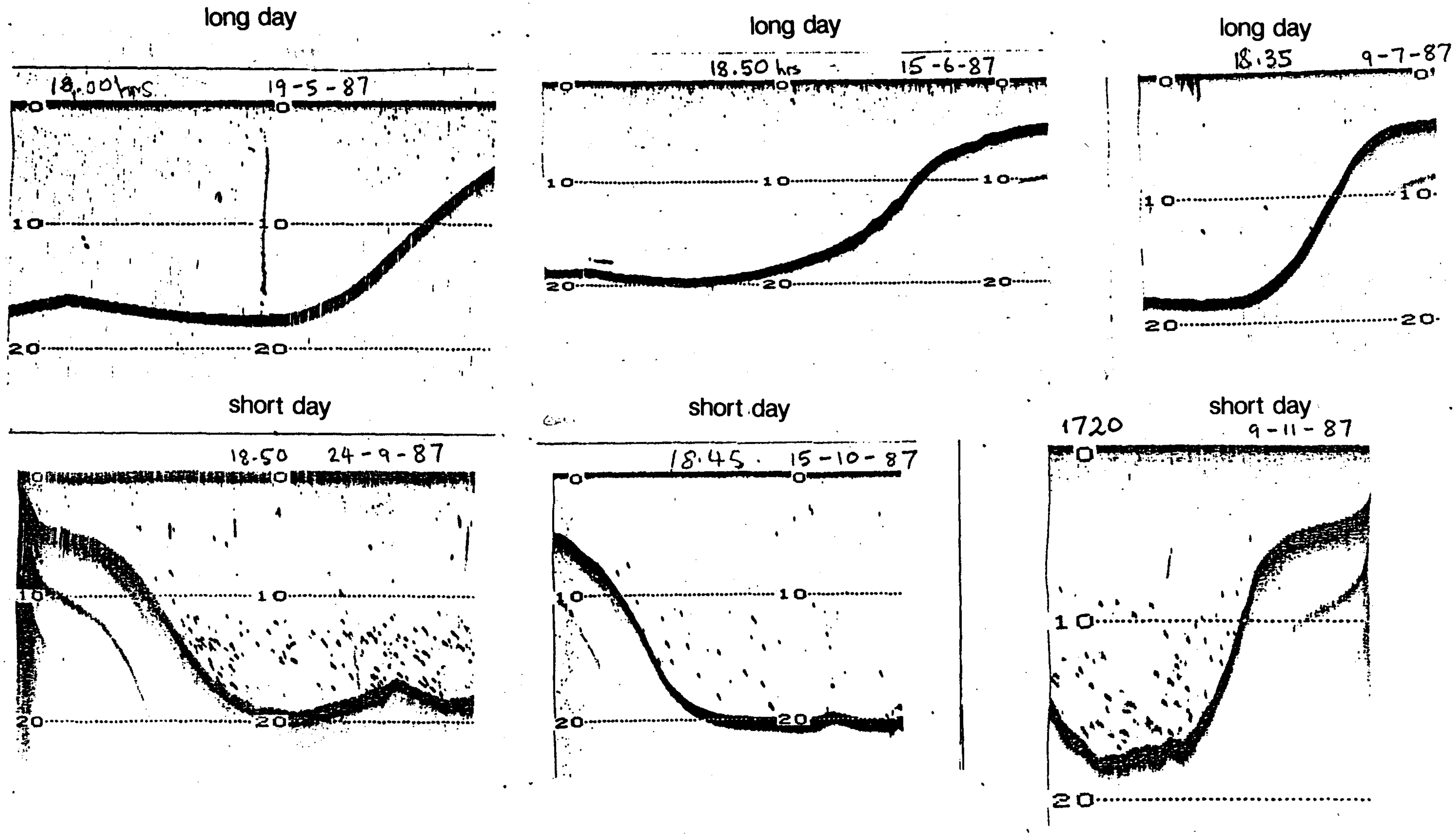

long day
18.00 hrs 19-5-87
long day
18.50 hrs 15-6-87
long day
18.35 9-7-87
short day
18.50 24-9-87
short day
18.45 15-10-87
short day
1720 9-11-87

Fig.19 The effect of day length or early sunset on nocturnal activity of vendace in Bassenthwaite (all soudings taken 17.00-19.00 hours)

FIG. 19

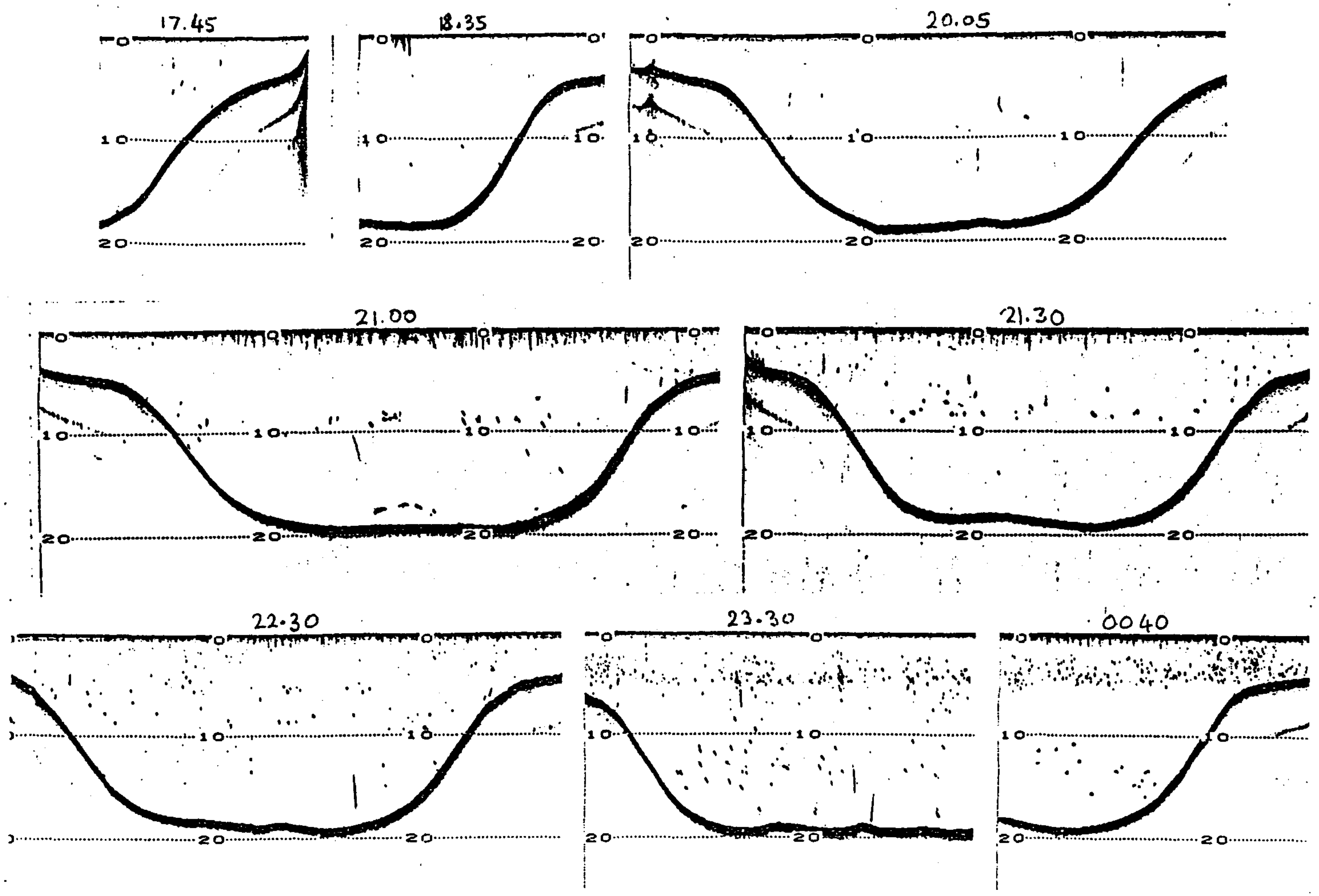


Fig.20 The effects of low oxygen concentration and high temperature on the distribution of vendace in Bassenthwaite on 9 Jul 87 (see Tables for details of dissolved oxygen and temperature)

FIG. 20

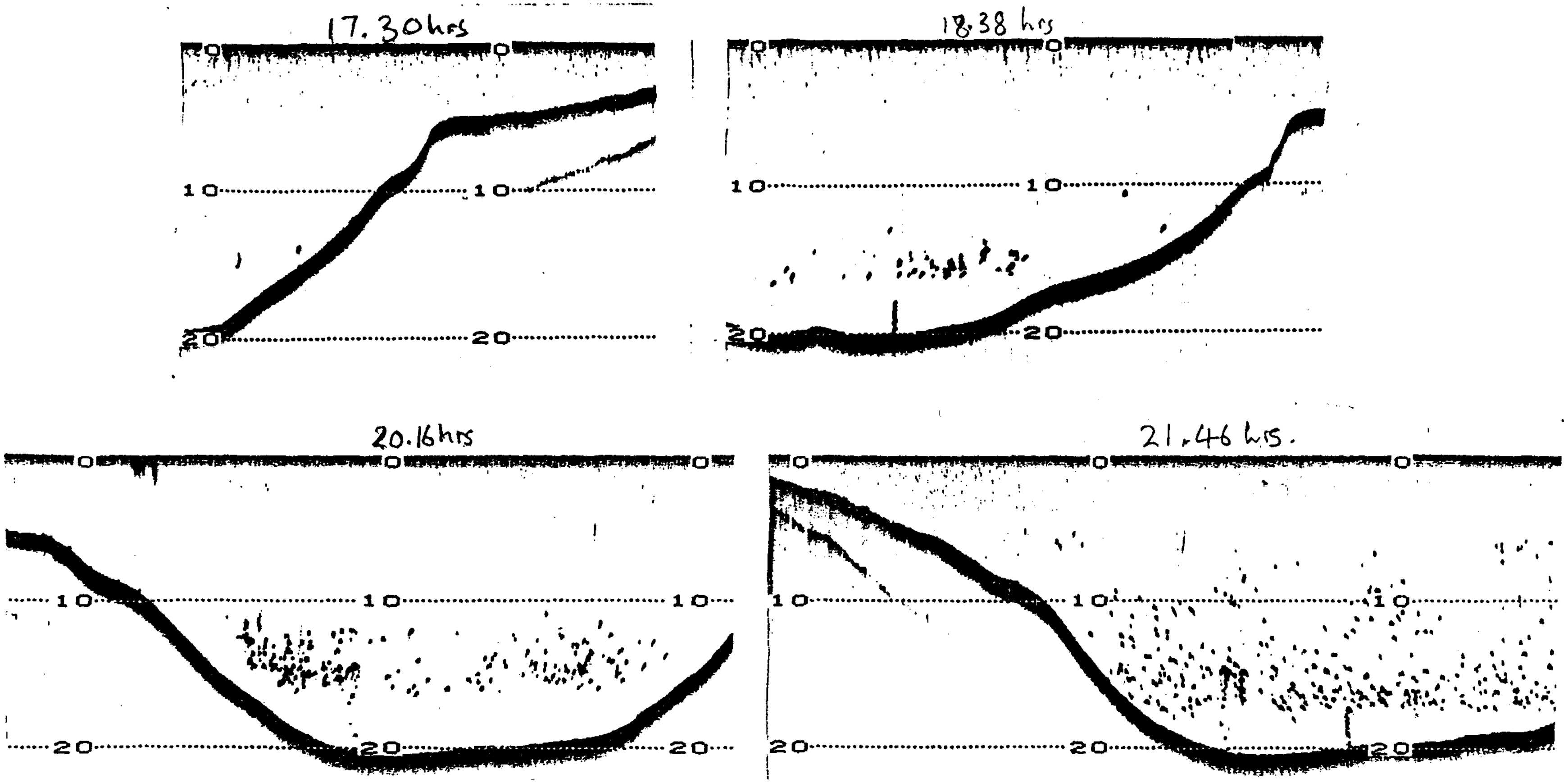


Fig.21 The effect of a near-anoxic hypolimnion 0-1.6mg/l oxygen, between 17 and 20m, on depth distribution of vendace in Derwentwater on 6 Aug 87

FIG. 21

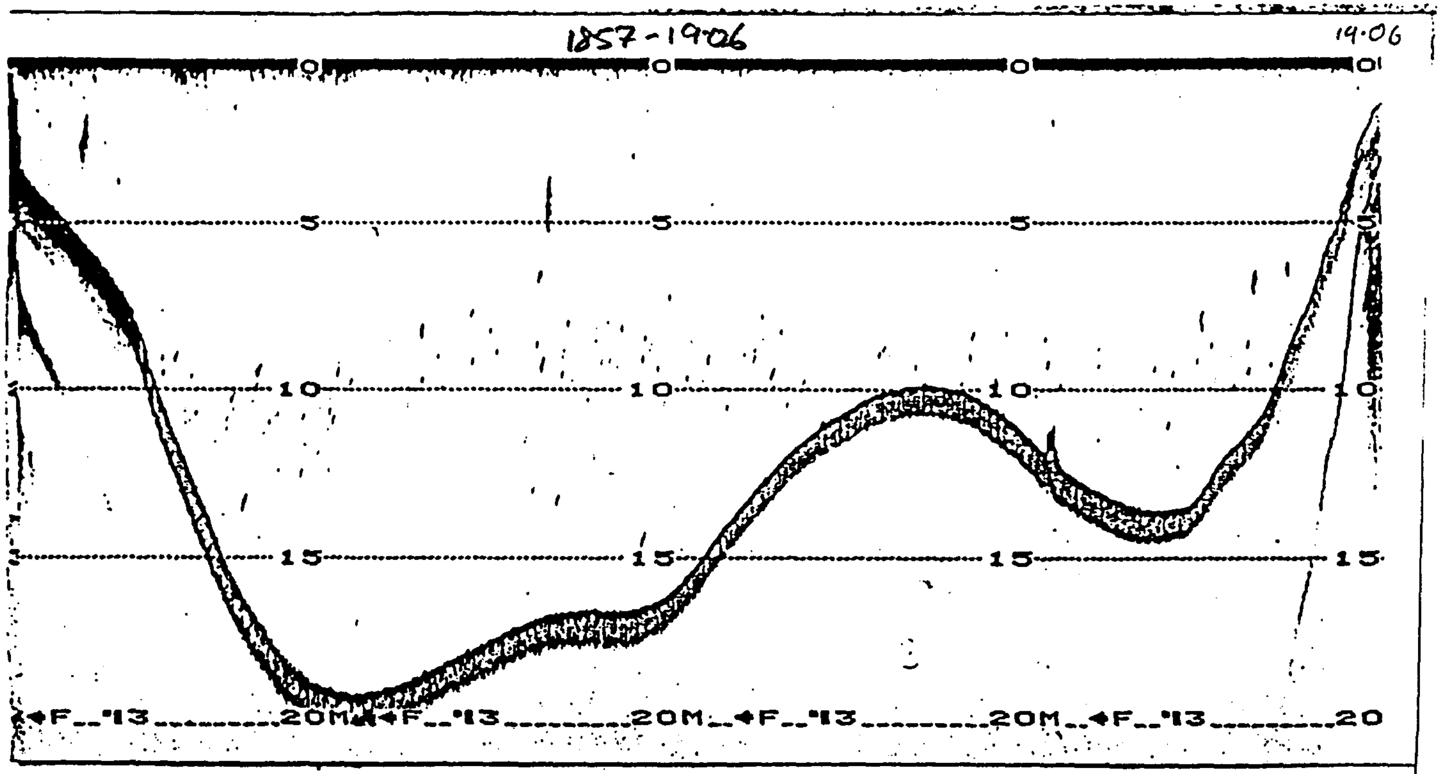


Fig.22 Horizontal distribution of vendace in Bassenthwaite on 4 Aug 88
Direction: From launch point to Bowness Point

FIG. 22

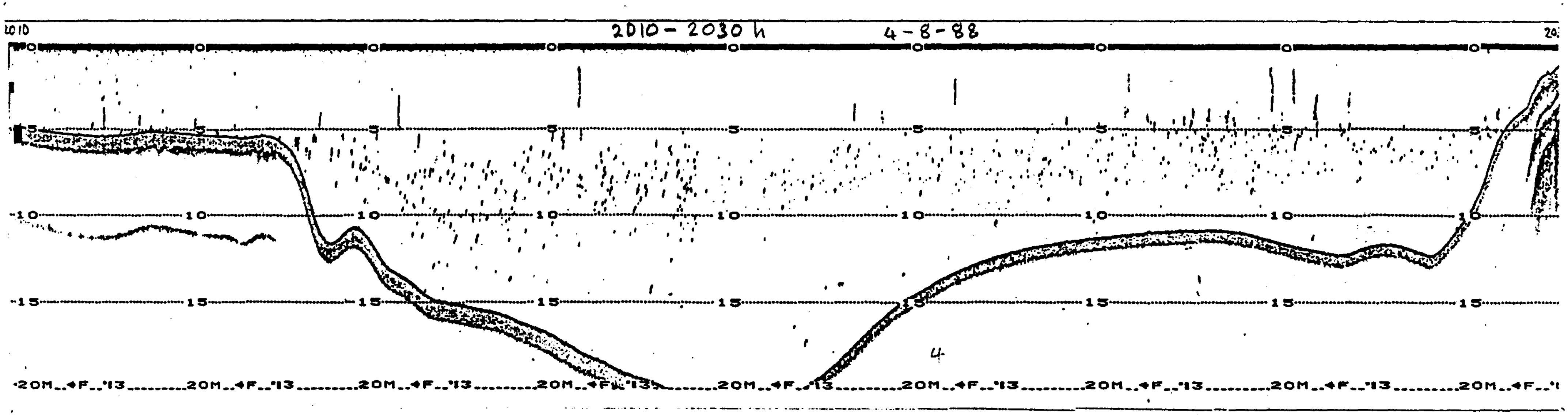


Fig.23 Horizontal distribution of vendace in Bassenthwaite on 4 Aug 88.
Direction: From launch point towards north end of the lake.

FIG. 23