Studies on the Phytoplankton of Loch Lomond and of neighbouring lochs North and South of the Highland Boundary Fault

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by

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CHAPTER 1

INTRODUCTION

"... . this lake doth contain sixty islands and receiveth sixty rivers, albeit that but a single stream doth flow from thence into the sea. Upon these islands are sixty rocks plain to be seen, whereof each one doth bear an eyre of eagles that there congregating year by year do notify any prodigy that is to come to pass in the kingdom by uttering a shrill scream altogether in concert ...."

Geoffrey of Monmouth 1140

Book IX, Chapter 6

describing Loch Lomond

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Twenty miles north-east of the city of Glasgow lies Loch Lomond, one of the finest of the Scottish fresh water lochs. It has frequently been praised for its beauty and has earned the title, given to it by many writers, as the pride and Queen of Scottish lochs (Gregory, 1928). Lamond (1931) describes the change from the polluted Leven to Loch Lomond as "like a step from a sordid slum to a fairyland."

Loch Lomond has existed for 11,000 years (Hunter, 1971). Much of the lake lies in a narrow valley which was once occupied by glaciers whose moving mass drained towards the south-east. The ice action gouged out a river valley to form a deep, steep-sided trough. This may be regarded as a typical valley rock basin (Murray, 1910; Gregory, 1928; Slack, 1954, 1957). In the remaining southern portion of the Loch the deep glacial excavation has ceased and part of the bed rock is overlain by alluvium which is to some extent marine in origin (Slack, 1954).

Scotland is traversed from the north-east to the south-west by a major dislocation in the earth's crust, the Highland Boundary Fault. This separates the ancient metamorphic rocks of the Highlands from the younger and more easily eroded sediments of the midland valley of Scotland. This fault passes from Stonehaven to Kintyre, to the north of this fault the land rises for thousands of feet (Highlands). South of it the land subsides for thousands of feet (Lowlands) (Lamond, 1931). Loch Achray and Loch Ard lie to the north of the fault, Loch Rusky and Lake of Menteith lie to the south, ~~as~~ and the fault actually crosses Loch Lomond from Balmaha in the north-east to Arden in the south-west. One of the remarkable feature of the Highland Boundary Fault is the presence, throughout its length, of a band of varying width of serpentine and associated intrusive igneous rocks (Loch Lomond Management Plan Report, 1964).

The general direction of Loch Lomond is north to south, traversing three series of rocks, the northern end is gneiss, mica-schist and schistose quartzite. South of the line from Luss to Ross peninsula lies a band of non-schistose rock, slates, grits and conglomerate which are cut off abruptly to the south by the Highland Boundary Fault. To the south and east of it, the lake lies almost entirely on the sandstone and conglomerates of old red sandstone age.

Although Loch Lomond is often said to be the largest of Scottish lochs, this claim is true only for ~~a~~ superficial area. Loch Lomond is not as long as Loch Awe nor as deep as Loch Morar, nor is it as long or as deep as Loch Ness whose basin has the greatest capacity of all Scottish Lochs. In fact, Loch Lomond has a length of 22.64 miles (36.427 km^2), a mean depth of 121.3 feet (36.97 metres), a capacity of 92,805 million cubic feet with a superficial area of 27.4 sq. miles.

The upper part is a typical highland loch, being a narrow, deep, steep-sided trough extending southwards for nearly 13 miles (20.9 km) and having a mean width of 1 km. In contrast the lower part of the loch is wide and shallow with numerous islands. In this part Loch Lomond reaches its maximum width of about 5 miles (8.04 km), 3 miles above the exit of the Leven which drains the loch to the Clyde.

From the head of the loch southwards for nearly 2 miles (3.2 km) is termed the Ardlui basin (Slack, 1954, 1957; Murray, 1910). This region has a maximum depth of 63 metres (207 feet) and terminates at a relatively shallow bar where the loch reaches its narrowest point. South of this bar where the water does not exceed 30 metres in depth, extends the deepest region of the loch, the Tarbet basin. This is a narrow fjord-like basin with a mean depth of 100 metres and a maximum depth of 198 metres. This is the maximum depth of the entire loch and is located in a depression nearly 1 mile north-east of Tarbet Island, near Cailness. These two basins comprise the high land or upper loch (Murray, 1910; Slack, 1954) which has a total length of 18 km (11 miles) and a mean width of 1 km. The metamorphic rocks in which the entire upper loch lies is Dalradian mica-schist.

The termination of the upper loch is marked by an outcrop of Ben Ledi grit, which crosses the loch from Rowardennan on the east side to Inverbeg on the west. This rock is more resistant to erosion than is mica-schist and gives rise to a shallow plateau where the maximum water depth is not more than 15 metres (Murray, 1910).

South of this bar the loch continues in mica-schists and schistose grit for another 3 km; here the loch widens slightly but only reaches 67 metres (220 feet) at its maximum depth. The loch widens still further beyond Ross Point, a promontory, formed by another outcrop of resistant grit. This outcrop does not cross the loch completely and south and west of it the lake bed lies in softer rocks, mainly the outcrop of Luss slate. This area is called the Luss Basin. This basin contains the first group of islands which lie in the form of a "U" open to the east, 1.5 km south of Ross Peninsula, in an outcrop of massive pebbly grit. Slack (1954) called this area the Strath-cashell Basin. The whole basin from Inverbeg bar to the first group of islands, including the Strathcashell basin is termed the Middle or Luss basin.

The expanse of the remaining part of the loch is the shallowest region with a maximum depth of 23 metres (75 feet). This region is referred to by Slack (1954) as the "Fault Basin" and by Murray (1910) as the "Balloch Basin". This extensive part of the loch has a maximum width of approximately five miles and includes the second island group. These islands lie along the line of resistant rock which comprises the Highland Boundary Fault, crossing the loch diagonally from Balmaha to Arden at the south-west. The part of the loch to the north of the fault lies in strata of upper old red sandstone and to the south the rock is mainly lower old red conglomerate. The areas north and south of the Highland Boundary Fault are joined by the channels, running between the islands. These channels are as deep as the rest of the profundal floor and because of this Slack (1954) includes both areas in a single basin - "Fault Basin".

The entire area south of the Inverbeg bar, including the Luss, Strathcashell and Fault basins, constitutes the lower loch.

Climatically Loch Lomond has more affinities with the wet west coast oceanic regime rather than the east coast type. The wettest months are December and January while the driest months are May and June. Figures from the Clyde River Purification Board show that the rainfall in December, January and February is twice that of the months May, June and July. There is a relation between height location and total rainfall, the higher the ground and more north-westerly the area the greater the quantity of rainfall. Tittensor and Steele (1971) show the annual rainfall on the islands is 1,524 mm whilst the precipitation falling on Ben Lomond amounts to 2540 mm.

The loch has a small catchment area 296.87 sq. miles (768.91 km^2) in comparson with other Scottish lochs and the ratio of watershed to surface area is 10.79. The average annual volume of water passing to the Leven is 1,254 million cubic metres. The surface area of the loch to the north of Ross Point is approximately one-third of the total surface area but this area receives almost two-thirds of the input.

The water level in the loch fluctuates between 22.86 and 32.1 feet (6.91-9.78 metres) with an annual mean of 25.5 feet (7.77 metres). Scott (1901) stated that a depression of 30 feet in the water level would admit sea water to Loch Lomond. In general the variation in the level of water follows the rainfall changes with a lag of about one month (Slack, 1957).

The prevailing winds are from the west and south-west frequently reaching gale force in the winter; there are however no long-term records of wind strength or direction available. Buchannan (1885) noted that the prevailing winds tend to blow across the loch and were directed into squalls but on the whole the geographical position of the loch tends to neutralize the effect of wind. In general the climate is fairly typical of much of the west coast of Scotland, being rather cool and wet with temperatures ranging from zero to 25°C.

Tittensor and Steele (1971) studied the soils in the area which were of two main types. Podsols and incipient podsols were found in the southern mainland while brown-earths and degraded brown earths were almost entirely restricted to northern mainland area.

The Falloch water and all other burns and rivers inflowing from the north of the Highland Boundary Fault flow over hard metamorphic rocks and poor agricultural land; this consists mainly of hill land with a natural vegetation of mountain pasture, acid peat bogs and woodland. The higher ground is grazed by hill sheep, red deer and goats (Maitland, 1972) on the other hand the Endrick flows over softer rocks and rich well-fertilized farmland. The in-flowing water to the loch is thus generally poor with the exception of the Endrick which is rich in mineral salts (Tippett, 1974).

The river Falloch traverses the Glen leading from Crianlarich to Ardlui, entering the head of the loch about 8 miles from its source. It contributes more water to Loch Lomond (22.18 %) than any of the other rivers (Clyde River Purification Board). The Endrick, which has a larger catchment area, lies in an area of lower annual rainfall and thus contributes less.

On the west side of the loch the Inveruglas water issuing from Loch Sloy enters the loch 3 miles beyond Tarbet. Douglas water enters the loch at Inverbeg forming a delta over the shallow bar of Inverbeg by the deposition of sediments. Two small tributaries combine to form Luss water whose total course is almost six miles enters the loch at Luss. The Finlas and Fruin follow roughly parallel courses, the latter river rising in the hills above

Garelochhead and passes through the fertile valley of Glen Fruin to enter the loch almost 3 miles north of Balloch.

On the eastern side of the loch, the Inversnaid Water (Arklet Water) draining from Loch Arklet enters the loch at Inversnaid almost opposite Inveruglas Water. Between this and the Endrick there are few burns of any importance. Lamond (1931) states that by the rugged weathering of the hard gneisses, clefts and gulleys rather than valleys, have been formed on both sides of the loch above Rowardennan and Luss where a multitude of precipitous torrents rather than any streams of considerable size carry the rainfall from the mountain tops to the lake.

The watershed of the Endrick lies almost entirely within the Midland valley of Scotland, rising at a height of just under 500 metres above sea level and flowing in a mainly westerly direction for a distance of 49 km to enter Loch Lomond in its south-eastern corner (Maitland, 1966). The drainage area of 297.4 km^2 represents 35.6% of the total catchment area of Loch Lomond and yields a mean flow equivalent to 22.9% of the mean discharge of the loch to the Leven (C.R.P.B.Tech. Rep. No. 12).

At present 6,500 people live in the Endrick valley and their sewage passes almost untreated into the river which also receives the effluent from a whisky distillery. The water draining the surrounding arable farmland also contributes to the general enrichment process (Maitland, 1966, 1972).

Although little detailed chemical analyses of river water are available, apart from that of the Endrick, Slack (1957) published calcium levels in the major rivers inflowing to Loch Lonond. These range from 15.8 and 10.3 mg/l in the Endrick and Fruin to 2.2 mg/l in the Falloch with the Douglas, Luss and Finlas being intermediate in level. In general the more calcium and alkaline salts there are in highland streams and lochs the more fertile they are.

Maitland (1961) presents results of chemical analyses of the Endrick taken from the source of the river to the mouth, the calcium content and pH increases from the source towards the mouth (pH from 6.8 to 7.3), calcium from

11.2 to 18.2 mg/l, while magnesium levels were about 5.5 mg/l. A detailed study of vertebrates and benthic invertebrate life in the Endrick has been made by Maitland in 1966.

Loch Lomond occupies an historic place in our knowledge of the vertical distribution of water temperature being among the three lochs studied by James Gardyne in 1812-1814, the first ever series of vertical temperature measurements (Hutchinson, 1957). These were not published at the time but were printed much later by Buchan (1871). Buchan's own study in 1871 of vertical temperature distribution clearly showed the presence of a thermocline and hypolimnion. From his results he made the important conclusion that in deep water the temperature always remains at or very near 42°F (5.6°C).

Buchannan (1885) showed that the depth and the structure of deep water of uniform temperature (hypolimnion) varied with the time of year in Loch Lomond being one hundred feet nearer the surface in April than in November. He was the first to compare the depth of thermocline layer in different regions in Loch Lomond. He also observed that the mean temperature in the Ardlui basin was less than that in the Luss basin; this he attributed to the influence of the Falloch Water.

Murray and Pullar (1910) included Loch Lomond in their survey of 562 fresh water lochs of Scotland. Temperature of the water was not considered in detail but they observed that the temperature of the large lochs has a small annual range rarely reaching 20°F (11.1°C). West and West (1912) made a few records of surface water temperature in Loch Lomond, showing that the annual range was from 5.0 to 13.3°C.

Slack (1954-1957) in the first detailed survey of the thermal structure of the water in Loch Lomond, investigated the temperature gradients in the three main basins, Tarbet, Luss and Fault basin. He showed that each basin has its own distinctive thermal structure, both in range of temperature and vertical distribution.

The Tarbet and Luss Basins are thermally stratified for more than half the year, from May to January in Tarbet and from May to November in the Luss basin. Slack showed that a definite thermocline is initiated at a depth of about 6 metres, descending to about 30 metres in Tarbet basin and reaching its maximum development in September. As late as the beginning of January the thermocline may be discerned at a depth of 70 metres immediately before the overturn occurs. Formation and vertical translocation of the thermocline is closely similar in the Luss basin, but the deep hypolimnion is warmer. Both basins can be regarded as having a continuous epilimnion.

Stratification in the Fault basin shows no great stability although a transient temperature gradient may be established during the period June to August. Slack showed no clear separation of an epilimnion from hypolimnion in the Fault basin and stated that the water body in this basin cannot be considered as an extension of the epilimnion of the Luss basin. The relatively greater exposure of the lower part of the loch allows the wind to reach its maximum fetch. Thus he stated any strong wind can easily overturn the whole water mass in this shallow region of the loch.

The lower water (hypolimnion) of the Fault basin has a large annual temperature range (7.6°C) while in the deep Tarbet basin the range is not more than (1°C); the Luss basin is intermediate between these two with a range in temperature of (5°C).

Chapmann (1966) clearly showed the pattern of thermal stratification in Strath Cashell basin, but no-one, till Hunter (1971) has attempted to describe the water circulation type of Loch Lomond. He states that the loch is a typical warm monomictic lake. However, in severe winters as occurred in 1878-1879 and 1963 the Fault basin may become frozen over, producing a reverse temperature gradient. Buchan (1886) recorded the temperature of the water in contact with the ice as 32°F (0°C) with the bottom temperature being 34.5°F (1.7°C). Thus in severe weather when the loch is frozen it is dimictic.

The annual amount of heat received and dissipated by each basin has been estimated by Slack (1957) during the year 1953 and 1954. The annual quantity transmitted and stored through each square metre of water surface in the Tarbet basin was 500 Ton/calories, at Luss basin about 300 Ton/calories and 240 Ton/calories at Fault basin. The high hills bordering the upper loch reduce the daily direct solar radiation from the sun, but the annual heat budget is twice that of the lower loch where frequent mixing occurs.

The only measurement of light penetration available are those made by Slack (1957) and Chapmann (1966). The latter author gave readings varying from 3 to 7.5 metres while the normal Secchi transparency is 5 to 6 metres (Maitland, 1972). Tippett (1974) estimates that light penetration in Loch Lomond restricts plant growth to the top 20 to 30 feet, while Slack (1957) states that the light penetration below 4 metres in Loch Lomond is only sufficient for the growth of diatoms which are adapted to light of longer wave lengths.

Slack (1957) and Hunter (1971) suggest that the amount of solar radiation received in the south of Loch Lomond is much greater than that of the north. This reduced light regime in the mountainous north was confirmed by Tippett (private communication); using curtis ~~contour~~-meters to record the incident solar radiation, he suggests that both the steep-sided mountains and the generally greater cloud cover at the region are instrumental in reducing the radiation input.

Loch Lomond lies at a latitude of 56'N and the daylength varies from a minimum of 7 hours during the winter to a summer maximum of just under 18 hours.

During periods of complete circulation the dissolved oxygen levels are normally at or near saturation point. Slack (1954) states that oxygen saturation is rarely likely to fall to low levels since the volume of the hypolimnion is great compared with the surface area. The lowest level so far recorded being 62% which occurred on 26th July in the Tarbet basin about 1 metre above the floor of the loch.

Even in the profundal zone of the loch the upper layer of the sediment will be in an oxidised condition. Slack (1954) in his exhaustive study of the deposits of Loch Lomond suggested from visual evidence that the boundary between the oxidised and reduced state always occurred below the surface of bottom sediment. Littoral cores show deep oxidation with the production of ferric hydroxide, but as the depth of water increases the penetration of oxygen into the sediment decreases.

The occurrence of iron in profundal deposits is greater in the upper than in the lower loch. A firm, black iron pan forms over the sand in many localities. This effectively seals the sand against the penetration of oxygen and prevents any exchange of the minerals between water and the sediment. Areas of around 100 metres square have been found in a number of locations in the loch particularly in the south region.

Slack (1954) states that at all stations in Loch Lomond and at all times of the year, a surface covering of organic material will be found in the profundal zone. In the Tarbet and Ardlui basin this layer is 0.3 to 0.5 cm thick while in the lower loch, the layer of organic material is finer in texture and up to 1 cm deep. These two sediments can be easily distinguished by the absence of mica flakes in the latter. In general the deposits of the Luss and Strath Cashell basin resemble those at the Fault basin but differ from those of the upper loch (Tarbet and Ardlui).

The percentage of organic matter in the deposit of the lower loch increases from 5 to 10% as the water deepens, in the upper loch it exceeded 16% at all depths greater than 35 metres. In samples taken from the lower loch the organic matter decreases below the surface layer while in the north the reverse is true. The carbon and nitrogen ratio in the deposits is generally between 11-30 in Loch Lomond; the ratio in the upper loch (Tarbet and Ardlui basin) is mainly around 18.

The organic debris in the upper basin is mainly of allochthonous origin being composed chiefly of higher plant remains containing large amounts of woody material. This accounts for the large quantities of lignin and low protein found in this detritus, and makes it less susceptible to bacterial decay. Decomposition in this region is also hindered by the low ambient temperature ($4^{o}C$), the low pH from the peaty water, higher concentration of iron and the consequent small number of bacteria. The high C:N ratio for the upper loch is thus a function of the C:N ratio of terrestrial plants generally lying between 25 to 40.

The preponderance of allochthonous material in the narrow northern basin of Loch Lomond is contrasted in the wide expanse of the southern region by the higher proportion of autochthonous material. The lower loch includes eight-tenths of the littoral area of the loch with a greater exposure to wind and wave action. The larger number of easily decomposed plants (benthic diatoms and filamentous algae) with a lower C:N ratio (between 5 to 10) coupled with higher average annual temperature at the bottom $11^{\circ}C$, increased water movement and higher pH results in a short decay period and a lower percentage of organic matter in the deposit.

Frustules of the diatom Melosira were found over the entire loch to a depth of 152 metres but they appeared to be particularly common in samples taken from the deep Luss and Strath Cashell basins (Slack 1954).

The water chemistry of Loch Lomond has not been adequately investigated. The small amount of data which are available come from isolated and irregular sampling. The total mineral content of the water in Loch Lomond is about 25 mg/l, ranging from 22 mg/l in the upper loch to 28 mg/l in the lower loch (Slack, 1957). The monovalent to divalent ion ratio ($K^{+} + Na^{+} : Ca^{++} + Mg^{++}$) ranges from 0.33 in the north to 0.27 in the south (Slack, 1965). The mean amounts of calcium were 7 mg/l in the upper loch, 9 mg/l in the Luss basin and 10.4 mg/l in the lower loch. The carbon dioxide content of the water is low having a value of around 0.5 mg/l (estimated as H_2CO_3). The water is on the acid side of neutrality with a mean value of pH 6.8 and varies from 6.6 in the north to 7.1 in the south (Slack, 1957), and Brook (1964) showed that the alkalinity in Loch Lomond ranges from 4.4 to 9.0 p.p.m. $CaCO_3$.

Slack (1957) stated that Loch Lomond is very low in dissolved phosphate. He considered in detail the role of oxygen in maintaining low levels of the nutrient and emphasized the necessity for the collection of quantitative data.

The amount of dissolved oxygen in the loch never falls to sufficiently low a level to allow the reduction of ferric ion, which exists in a colloidal form at the sediment surface. Phosphorus is thus precipitated as ferric phosphate and there is very little release of dissolved nutrients into the water from the bottom deposits. This fact allied with the nature of the rocks in the catchment area explains the natural paucity of the loch.

In the wide southern basin wind generated currents can reach velocities sufficient to lift bottom sediment and carry it into circulation with some release of contained nutrient. Lesser winds bring about the subsequent distribution of phosphorus throughout the water body. Slack further speculates that the phytoplankton production in the ensuing year depends to a certain extent on the strength and frequency of winter winds.

Silicate levels in the Middle basin of Loch Lomond for 1955 were shown by Chapmann (1965) to vary between 0.37 mg/l to 1.15 mg/l, phosphorus (quoted as total phosphorus) were shown to range from 0.003 mg/l to 0.012 mg/l and the variation in alkalinity was from 6.0 to 8.8 mg/l. These results, however, were based on only 7 samples, one per month in May, September, October, November and January, with two samples in July 1955.

The flora and fauna of Scottish freshwater lochs were comprehensively studied at the beginning of this century, by Murray and Pullar 1910, Scott 1901 and West and West (1903, 1905, 1909, 1912) they emphasised that the differences found between plankton in different areas may in part arise from the fact that they were examined at different seasons of the year.

Murray and Pullar obtained biological collections from nearly all of the 562 lochs investigated in Bathymethical survey of the Scottish fresh water lochs, from the examination of 400 collections they listed 150 spp. of phytoplankton, 120 of which were desmids. They stated that out of these, nine species of desmids and five diatoms appear to be generally distributed throughout the fresh water lochs in Scotland.

Although they could not represent the biological seasonal variation with any precision, they noted that pelagic fauna and flora are of much greater abundance in the warm summer months than during the rest of the year. They also observed the large increase in diatoms and other phytoplankton in the

Spring with a concomitant reduction in water transparency. The phenomenon of flowering was associated with species not commonly predominating in the phytoplankton. Chlorophyceae were associated with such flowerings in shallow, lowland lochs, while in northern lochs Myxophycean algae predominated; however West (1912) considered that blue-green algae were rare in Scottish lochs. In contrast to the Summer or Autumn flowering, Loch Earn flowered in mid-winter; however in the largest lakes this phenomenon was not apparent at any season (in Loch Lomond in August 1905 Dr Buchman describes a "Wasserblüthe" in which algae were seen floating scattered throughout the water).

Fundamental distinction between the Scottish and European lakes were made by West (1903), West and West (1909), Wessenberg-Lund (1905) and later by Murray & Pullar (1910). West and West showed the effect of climatic differences between Scotland and Central Europe on the thermal structure of the lochs. Central and northern Europe have a continental climate with cold winters whereas Scotland has a warm temperate climate with relatively high winter temperatures. Many of the lochs never freeze and most of the others only rarely become covered with ice and then for comparatively short periods. Most of the European lochs however freeze for long periods during the winter.

According to Murray and Pullar and Wessenberg-Lund (1910) the presence of certain Arctic crustacea many of which are present throughout the year is a peculiar feature of Scottish waters. On the other hand a number of species dominant in lakes of the European plain are rare or absent in Scotland. The abyssal fauna does not contain any peculiar forms to distinguish it from that of European lakes, Murray states that there is no reason for proposing any marine origin through the intermediary of great inland sea, as has been postulated for the central European lakes.

West (1903), West and West (1909 & 1912), Murray and Pullar 1910, drew attention to two features distinguishing the plankton of Scotland from that of central Europe. First the extraordinary richness of the phytoplankton in species of desmids, a peculiarity shared only with the plankton of Irish lakes and second the absence or comparative rarity of the species which predominate in the European flora.

They considered that Myxophycea are poorly represented in the deep lochs and are by no means numerous in the small shallow lakes. Consequently they play quite a secondary role compared with the general domination they achieve in the lakes of Europe. Diatoms too, though abundant, rarely occur in such large numbers as in Europe.

The unique abundance of desmids is coupled with a very localised distinction, sometimes as many as 50 species being found together in one loch. There is nothing to equal this elsewhere in the central European lakes which are generally poor in desmids. Wessenberg-Lund attributed the rich desmid flora to the peaty character of the water; this is in agreement with West and West who attributed it to the absence of lime and the presence of humic acid. They further state that the desmids distribution corresponds very accurately with the areas of old geological formation, these are mostly mountainous districts with hard igneous rocks. Murray and Pullar consider that climatic factors may restrict desmids to certain regions and they correlate it with the area of greatest rainfall.

In their 1909 paper West and West made the important observation that "it is very probably that the chemical composition of the water plays an important part in the distribution of phytoplankton". They elaborated on this theme in their publication in 1912 in which they stated that the principle factors controlling the abundance of desmids is the nature and the amount of dissolved salt in the water. Those lakes which contain the purest water are the only ones able to support a rich desmid population. These are found mainly in areas of old hard rock, the drainage water from which contains much less in the way of dissolved mineral salts, than that in areas of newer formation. The lime which, is decidedly unfavourable to the growth of most desmids, is absent from older rocks.

West and West classified areas such as Loch Lomond with a mixed population of diatoms and desmids, as intermediate in character with regard to dissolved salt level. They also observed the greater quantitative bulk of phytoplanktor produced in contaminated lakes and the consequent change in the dominant phytoplankton group from desmids to diatoms. In conclusion they stated that "with our present knowledge of the occurrence and distribution of British desmids the whole matter could be definitely settled by a careful and exact chemical investigation of the water of the lake areas".

There have been no thorough and systematic collections made of the fauna and flora of the Loch Lomond area and our knowledge is confined to specific areas particularly the low land part of the loch. Slack (1957) says that in general, the regional variety of fauna and flora in Loch Lomond is quantitative rather than qualitative. Weerekoon (1953) carried out a detailed survey of the benthic invertebrate fauna of Loch Lomond and demonstrated that these communities occupy five zones which are characteristic of much of the lowland loch and parts of the northern highland region. The first three zones are in the littoral region, an area of mud, sand and gravel which may be hundreds of metres wide in the shallow southern portion, while in the highland section this region is virtually absent.

The upper and lower loch can be further distinguished by their profundal fauna, there being a much greater density of animals per square metre in the south (400-500) than in the north (25). Mollusca have received detailed attention by Hunter (1957, 1959) and the fish present in the loch have been listed by Lamond (1931) and Maitland (1972). The latter indicates the presence of 15 species of fish, the largest variety of any of the Scottish lochs including the powan (fresh water herring) peculiar to Loch Lomond and Loch Eck.

The seasonal variation of the limnetic plankton was studied by Chapmann (1965) in the Strathcashell basin, showing maximal numbers of zooplankton in early summer and Autumn. Daphnia hyalina was present throughout the year with highest population densities in early Summer and Autumn whereas Bosmina was most abundant between Autumn and Spring. Details were also given of the seasonal cycle of Diaphomus, Mesocyclops, Cyclops, Leptodora and Bythrotrephes. The vertical distribution of Daphnia shows a peak at the surface during

Winter and Spring with a maximum at Twenty metres during the Summer. Maitland (1972) states that zooplankton communities are dominated by *Rotifera*, *Cladocera* and *Copepoda*, characteristic of the oligomesotrophic conditions of Scottish lochs.

From September 1908 to August 1909, West and West carried out the first qualitative survey of the seasonal variation of phytoplankton in Loch Lomond. Samples were taken at monthly intervals to the north-west of Luss using a tow net. Their results indicated the presence of two coincident maxima for *Asterionella* and *Tabellaria* both becoming very common in November and June. *Melosira granulata* (*M. italica subarctica* after Brook 1957) has a single peak in May, whereas the desmids are most abundant in September. *Coelosphaerium* and Staurastrum remain present throughout the year.

In general Loch Lomond is characterised by a mixed plankton of *Chlorophyceae* and diatoms. The total number of species recorded was 50 of which 50% were *Chlorophyceae*, 28% diatoms and 16% blue-green algae. The minimum quantity of phytoplankton is found during January and the maximum during late Summer.

In general West and West concluded from their extensive studies of British phytoplankton that the most abundant species of *Tabellaria* is *T. fenestrata* except in the English lakes where *T. flocculosa* is most frequent. They also made observations of the timing of maximal number of *Melosira* in different localities. In Windermere the maximum is reached in April (1.7°C), in Loch Lomond between May and June (5° to 13.3°C) whilst in Lake Victoria in Africa the maximum was reached at 21°C. From these observations the conclusion was drawn that temperature was of little importance ~~of~~ for diatoms and does no effect their seasonal distribution.

The occurrence of a single, annual peak of *Melosira italica subarctica* in Loch Lomond was explained forty years later by Lund (1954). He showed its similarity to South Windermere and that isothermal condition is an important factor for the resuspension and blooming of *Melosira*. This condition cannot be found in Loch Lomond till late January. When the light is insufficient for appreciable growth. In general there is a direct relationship between later maxima and increased depth, this illustrates how size alone may limit phytoplankton productivity, a condition he describes as morphometric oligotrophy.

Chapmann (1965) made a qualitative study of net phytoplankton, taking samples at a single station roughly once a month. She also carried out the first estimation of chlorophyll a in Loch Lomond (Strathcashell basin) for a period of one year. She remarked that the flora has a mainly diatom-cyanophycean aspect and that desmids and green algae are neither varied nor a abundant. The most abundant algae in the Spring was Melosira which after April was displaced by Asterionella, Staurastrum, Tabellaria and Dinobryon. From late Summer onwards Oscillatoria and Asterionella were predominant with Coelosphaerium being readily visible in the Autumn. The Spring burst of Melosira is reflected in the high chlorophyll level found in April (2.21 mg/m^3) while the higher values found in Autumn (3.6 mg/m^2) were attributed to the amount of blue-green algae.

Tippett (1974) indicates there may be as many as 65,000 plants per litre in Loch Lomond, Coelosphaerium is shown to occur throughout the year whereas Botryococcus appears only in the Summer months.

The only other work on phytoplankton is that of Brook (1964, 1957) who studied net samples taken from 200 Scottish lochs one of which was Loch Lomond. Apart from four lochs, the study was purely qualitative and no seasonal investigation was attempted. For Loch Lomond the area from which the samples were taken is not shown, and it is unlikely that they would be representative of the whole loch since Slack (1965, 1957) states that for any limnological study of the loch a single sample station is not sufficient.

Brook (1964) indicated the trophic status of each loch according to Nygaard's phytoplankton quotient:

$$\text{The compound quotient} = \frac{\text{Cyanophycea + Chlorophycea + Centrales + Euglenineae}}{\text{Desmidiaceae}}$$

which depends on the number of species present rather than on the density of phytoplankton. The validity of this approach was questioned by Rawson

(1956) who stated that the number of species observed will depend on the intensity of the research and the period of collection. He further stated that it is rather odd to determine the trophic state of a lake from, say, the desmids and chlorophyceae when diatoms constitute 95% of the population (Great Slave Lakes 1956).

A total of 37 phytoplankton are listed by Brook as occurring in Loch Lomond; of these 12 were desmids. From the calculation of Nygaards quotient, Brook indicates that Loch Lomond (0.9) is mesotropic. This is in disagreement with Slack (1954, 1957, 1965) who classifies Loch Lomond as generally oligotrophic with the southern region being more productive than the north part. He attributes the oligotrophic state of the loch to the nature of the catchment area and morphometry of loch basin.

The whole of the upper loch lies in a drainage area of hard metamorphic rocks, of Dalradian age, largely covered in peat, yielding nutrient poor water, the calcium content of which is generally low and the peat gives the water its acidic nature. The deep narrow nature of the upper basin with its small littoral zone and the large ratio between hypolimnion volume and surface area has already been remarked on. It is difficult for this volume of water to become deoxygenated and in general the dissolved oxygen concentration remains high, the lowest ever recorded being 62%. The allochthonous material which accumulates in the bottom deposit is highly resistant to decay, having low protein and a high carbon to nitrogen ratio (characteristic of higher plant material). The low decay rate of this type of organic material is reduced still further by the low temperature, low pH, large quantities of iron and small bacterial flora. The high level of oxygen does not permit the reduction to the ferrous state of the colloidal ferric ion which exists at the surface of bottom sediment, phosphorus is thus precipitated as ferric phosphate and there is little or no release of nutrient from the bottom sediment. The topography of the northern region with its high, steep sided mountains tends to reduce the daily incident solar radiation. The oligotrophic nature of this part is further demonstrated by the sparse profundal fauna.

Much of the lower loch is surrounded by rich Devonian and carboniferous strata yielding a greater quantity of soluble mineral salts with higher level of calcium than in the northern part. The catchment area contains rich, arable land, mostly devoted to cattle and sheep farming and market gardening. The largest inflowing stream to the south region is the Endrick Water which traverses rich farming areas. Considerable amounts of fertilizer are added to the grassland in its catchment area each year and the leaching of such material from the soil has almost certainly increased the amount of nutrient entering Loch Lomond from the Endrick and Fruin (Maitland, 1972).

The shallow southern region of the loch contains wide littoral and sub-littoral areas with large populations of benthic diatoms and filamentous algae. The accumulation of these easily-decomposed, autochthonous plant remains results in more rapid decay and recycling of organic material. The transitory nature of stratification, the effect of wind-induced currents, the higher pH and the greater annual range of temperature at the bottom allow rapid release and circulation of nutrients. This wide, open region receives more solar radiation than the north. These factors taken together lead Slack to the conclusion that the southern region is more productive than the northern part. The higher productivity is reflected in the greater number of profundal animals in this region.

Shafi and Maitland (1971) state that the designation of the northern loch as oligotrophic is undoubtedly true whereas the southern region is better described as mesotrophic . Maitland (1972) further states that there would have been a significant effect on the eutrophication of the southern region by nutrients from sewage, agriculture and industry were it not for the direction of main water flow of the loch. There is a continual tendency for the nutrient-poor water (from the north) to dilute the water, enriched by the Endrick in the south, which is continuously drained by the Leven. The northern catchment area because of its high rainfall receives relatively more water than the south and its diluting effect on the south is greater than the relative drainage area would suggest.

Loch Achray, Loch Ard, Lake of Menteith and Loch Rusky all lie to the east of Loch Lomond in the Forth Basin. Loch Achray and Loch Ard lie in the area of hard crystalline schist to the north of the Highland Boundary Fault while Lake of Menteith and Loch Rusky lie to the South in strata of lower old red sandstone. Loch Achray and Loch Ard are thus Highland lochs and are surrounded by areas of blanket peat bogs, poor hill grazing and forests. Of the two lowland lochs, Lake of Menteith is bordered by fertile arable land while Loch Rusky lies in a poor peaty district. Both lochs are rich in fish unlike the other two which have low populations of fish. Loch Achray ($56^{\circ}14'N$ $4^{\circ}23'W$) is situated north of the Highland Boundary Fault at the entrance of the Trossachs and lies in a mountainous area flanked to the south by Ben Venue (2,393 feet) and to the north by Ben Ledi (2,873 feet) and MeallGainmheich (1,851 feet). Completely enclosing the loch are forestry plantations which extend to a height of 1500 feet, the remainder of the land being peat bog and hill grazing.

Geologically (Peach and Horn, 1910) the surrounding area is hard metamorphic rocks, mainly schistose grit covered with various superficial deposits of glacial drift. The loch itself is a true rock basin excavated in an outcrop of less durable slates during the eastward movement of the ice. Thus the present basin extends roughly east to west and is crossed at its head by a powerful fault trending north-east to south-west.

Loch Achray was one of the lochs included in the Bathymetrical Survey of Scottish fresh water lochs by Murray and Pullar (1910). The surface water of the loch is 276 feet above sea level and its total length is 1.25 miles (2.01 km) the mean width being 0.26 miles (0.418 km). It has a total surface area of 0.32 sq. miles (0.828 km^2) with a mean depth of 36 feet and the estimated bulk of water contained is 321,000,000 cubic feet. About 70% of the area of the loch is less than 50 feet in depth, the region whose depth exceeds 90 feet lies approximately in the centre of the loch where the maximum depth is 97 feet. The total drainage area of 44.48 sq. miles (115.2 km^2) is 139 times the loch area and includes Loch Katrine which feeds it via the

Achray Water.

Loch Achray lies only 6 feet above the level of Loch Venachar into which it drains. Successive terraces show that the two lakes originally formed one sheet of water which stood at a somewhat higher level; however, they are now separated by a strip of alluvium.

Murray and Pullar (1910) made observations on the temperature of Loch Achray in June and November 1897 and April 1898 and showed that the surface temperatures were 59.5°F (15.3°C), 46°F (7.8°C) and 41°F (5.0°C) respectively, an intermediate observation at the depth of 30 feet on 12 June, 1897 gave 53.5°F (12°C). The highest reading of the surface was 64.1°F (17.8°C). So the annual temperature range is probably in excess of 32°F (17.8°C).

The mud from the deposit of Loch Achray was shown by Murray and Pullar (1910) to be grey-brown in colour, containing large quantities of vegetable and clayey matter. The mineral particles exceeding 0.05 mm in diameter made up between 30 to 40% of the total, some fine diatoms were noted and the loss on ignition after drying at 90°C was 12.84%.

Murray and Pullar (1910) studied the biology of Loch Achray and took tow-net samples in September, June, November and March, 1898. 12 species of Entomostraca were recorded but only Daphnia and Bosmina were shown to be common throughout the year. Four species of Mollusca and 50 species of Entomostraca were obtained by dragging the tow-net for a short distance over the bottom of the loch. Among them 15 species of crustacea were common in Loch Katrine and Loch Venacher. No specific reference is given to the phytoplankton of Loch Achray during their survey.

West and West (1903) found 22 species of phytoplankton in Loch Achray, 14 of which were desmids while in Loch Katrine 32 phytoplankton of which 17 were desmids. The genus Staurastrum was most commonly represented among the desmids. They placed Loch Achray among those lochs with a rich flora, according to the number of desmids found, even though the total number of phytoplankton species was only 22.

Brook (1959) includes Loch Achray among oligotrophic Scottish lochs and recorded the presence of <u>Closterium selaceium</u> and <u>C. kutzingii</u> in the loch.

No study appears to have been made of water chemistry of the loch or the inflowing water and a quantitative study of the biology of the loch does not exist.

Loch Ard (56°11'N 4°27'W) lies north of the Highland Boundary Fault directly to the east of Ben Lomond (3,192 feet) and is bordered on its southern side by the large expanse of Loch Ard Forest. Like Loch Achray it is a true rock basin (Peach and Horn, 1910) lying in an east to west direction along an outcrop of slates but bordered by two bands of schistose grit. The deepest part of the loch coincides with the outcrop of slates. The band of massive (Ben Ledi) grit which forms the southern msrgin of the loch acted as a barrier during glacial erosion. The geological structure of the basin as well as the easterly trend of the ice have had a strong influence on the development of the present topography.

Murray and Pullar (1910) show that the surface water of Loch Ard is 105 feet above sea level and it is over 3 miles in extreme length if the eastern prolongation is included. However the body of what may be called the loch proper is about 2.5 miles (4.02 km) in length with a mean breadth 0.67 miles (1.078 km). The area of the loch surface is 0.94 sq. miles (2.43 km^2) with a maximum depth of 107 feet. The mean depth of the loch is about 44 feet and the total capacity is 1150 million cubic feet of water. The main inflows to the loch are the Water of Chon and Ledard Burn while the outflow joins the Duchray Water, a tributary of the Forth.

The 100 feet depression occupies a central position, is 0.75 miles long and occupies 11% of the area of the loch. About 65% of the loch is less than 50 feet in depth. The total drainage area which includes those of Loch Chon and Loch Dubh, is 15.97 sq. miles (41.37 km^2) which is 16.99 times the loch area, a considerably smaller ratio than for Loch Achray.

The temperature of Loch Ard was recorded by Murray and Pullar in August 1899 and May 1900. The highest surface temperature, 64.6°F (18.3°C) was observed in August when the whole body of water was warmer. They also found a temperature gradient of $10^{\circ}F$ ($5.6^{\circ}C$) between the depth of 30 and 50 feet and showed an extreme range of temperature of $17^{\circ}F$ ($9.4^{\circ}C$) from surface to bottom. No steep gradient was observed in May.

Recent data (1971) on temperature and dissolved oxygen in Loch Ard from Mr Brian Morrison (private communication) show the highest surface temperature in August ($17^{\circ}C$). His data indicate a thermocline in August from 5 to 20 metres with a temperature gradient of $7.0^{\circ}C$. A similar, smaller gradient of $5.0^{\circ}C$ was present in June. The annual range of surface temperature was from $4.5^{\circ}C$ in February to $17.0^{\circ}C$ in August, the loch being isothermal from October to April. Dissolved oxygen values show little variation with depth at any time of the year, the concentration at 5 metres depth ranging from 9.9 mg/l in September to 12.8 mg/l in May.

Sediment samples taken from the deepest part of Loch Ard (Murray and Pullar, 1910) were dark grey in colour and consisted chiefly of vegetable and clayey matter. The mineral particles of mean diameter 0.1 mm did not exceed 10%. The organic remains, impregnated with ferric oxide, consisted of diatoms, sponge spicules and skeletal remains.

Chemical and biological data are lacking, except for a short reference to Loch Ard by Brook (1964). He gave the pH as 6.5 to 6.8 and the alkalinity as 10 to 15 p.p.m. $CaCO_3$. From net samples Brook recorded 23 species of phytoplankton, 6 of which were desmids, 3 species of diatoms and 4 species of Cyanophyta. He indicated from a calculation of Nygaard's quotient (1.2) that the loch is mesotrophic.

Lake of Menteith ($56^{\circ}10'N$ $4^{\circ}17'W$) claims the distinction of being the only lake in Scotland. It lies south of the Highland Boundary Fault, in an area of old red sandstone (Peach and Horne, 1910) although the lake itself lies in various superficial deposits partly composed of boulder clay.

The water surface of the Lake of Menteith as shown by Murray and Pullar (1910) is only 55 feet above sea level, its extreme length is 1.6 miles (2.57 km) and mean width 0.64 miles (1.02 km). The water covers an area of 1.02 sq. miles (2.64 km^2) and the maximum depth is 77 feet with mean depth of about 20 feet. The volume of water contained within the lake is estimated as 562 million cubic feet. The lake contains one large island, Inchmahome, and two smaller islands. The floor of the lake is generally irregular having three depressions greater than 25 feet in depth. The total catchment are of the Lake of Menteith is 6.35 sq. miles (16.45 km^2) this being 6.23 times its surface area.

Temperature readings were taken by Murray and Pullar in May and August, 1900. The surface temperature recorded was 63.2°F (17.2°C) in August and 52.2°F (11.1°C) in May. The temperature decreased gradually from surface to bottom in May, the range being 2°F (1.1°C).

There is no published biological or chemical data on Lake of Menteith apart from Brook (1964) who indicated from Nygaard's quotient (1.1) that the lake is mesotrophic and Maitland (1963) who stated that Lake of Menteith is "a relatively unproductive lake.".

Mr Brian Morrison (private communication) has kindly supplied me with the results of water analyses from a number of samples taken during 1968, 1969 and 1970. These show that the pH ranges from 6.94 to 7.86 and alkalinity from 12.8 to 21.2 p.p.m. $CaCO_3$. The divalent cations, calcium and magnesium have mean values of 10.8 and 1.2 p.p.m. respectively while of the monovalent cations Sodium averages 4.8 p.p.m. and Potassium 0.55 p.p.m. He indicates the presence of thermocline in 1969 from June to August while in 1970 the thermocline was absent. Dissolved oxygen showed little variation with depth (14.4 to 11.3 p.p.m.) except during the thermocline formation when it fell to low level at the bottom (1.66 p.p.m.) in August, 1969.

Net samples were examined for blue-green algae during the latter half of 1970 (B. Morrison, private communication); the presence of Coelosphaerium, Microcystis, Anabaena spiroides and Anabaena spp. was noted. Secchi disc transparency was generally low ranging from 1.75 to 4.25 metres.

Loch Rusky (56°13'N 4°14'W) as shown from geological and Ordnance Survey maps, lies South of the Highland Boundary Fault at 445 feet above sea level. It is in an area of lower old red sandstone though the loch itself lies in various superficial drift deposits. Its catchment contains poor infertile land with large areas of peat, strongly contrasted with the richer farmland surrounding Lake of Menteith which lies only 3 miles to the south-west. The loch has a maximum length of roughly 0.5 miles (0.8 km) and a mean width of about 0.3 miles (0.48 km); its surface area is roughly 0.12 sq. miles.

Loch Rusky was not included in the Bathymetrical Survey of Scottish freshwater lochs by Murray and Pullar, so no depth soundings are available. There also appears to be a complete absence of any physical, chemical or biological data on the loch.

The seasonal cycle of phytoplankton and nutrient in the freshwater lochs in Scotland is poorly documented and truly quantitative studies are few. The area of concern in the present study broadly defined as "Loch Lomond and the Trossachs" contains many areas of water of great economic importance, either for water supply or recreational purposes. Nevertheless they seem to have attracted little interest from scientific investigators who have confined themselves to isolated studies on particular areas.

The seasonal variation of phytoplankton and cycling of dissolved nutrients in Loch Lomond, Loch Achray, Loch Ard, Lake of Menteith and Loch Rusky have been quantitatively studied on regular bases for the first time. Previous investigators have limited themselves to surface water samples taking net phytoplankton only, in this survey surface and depth samples have been taken.

The sheer size of Loch Lomond and its varied topography indicate that for any limnological studies, a single station does not represent the whole loch. In this survey three main stations were taken (North, Middle and South) and three additional stations covering the entire 23 miles length of the loch.

This quantitative survey allows direct comparisons to be made of different regions of a single body of water or separate bodies of water lying in areas of different geological and topographical nature.

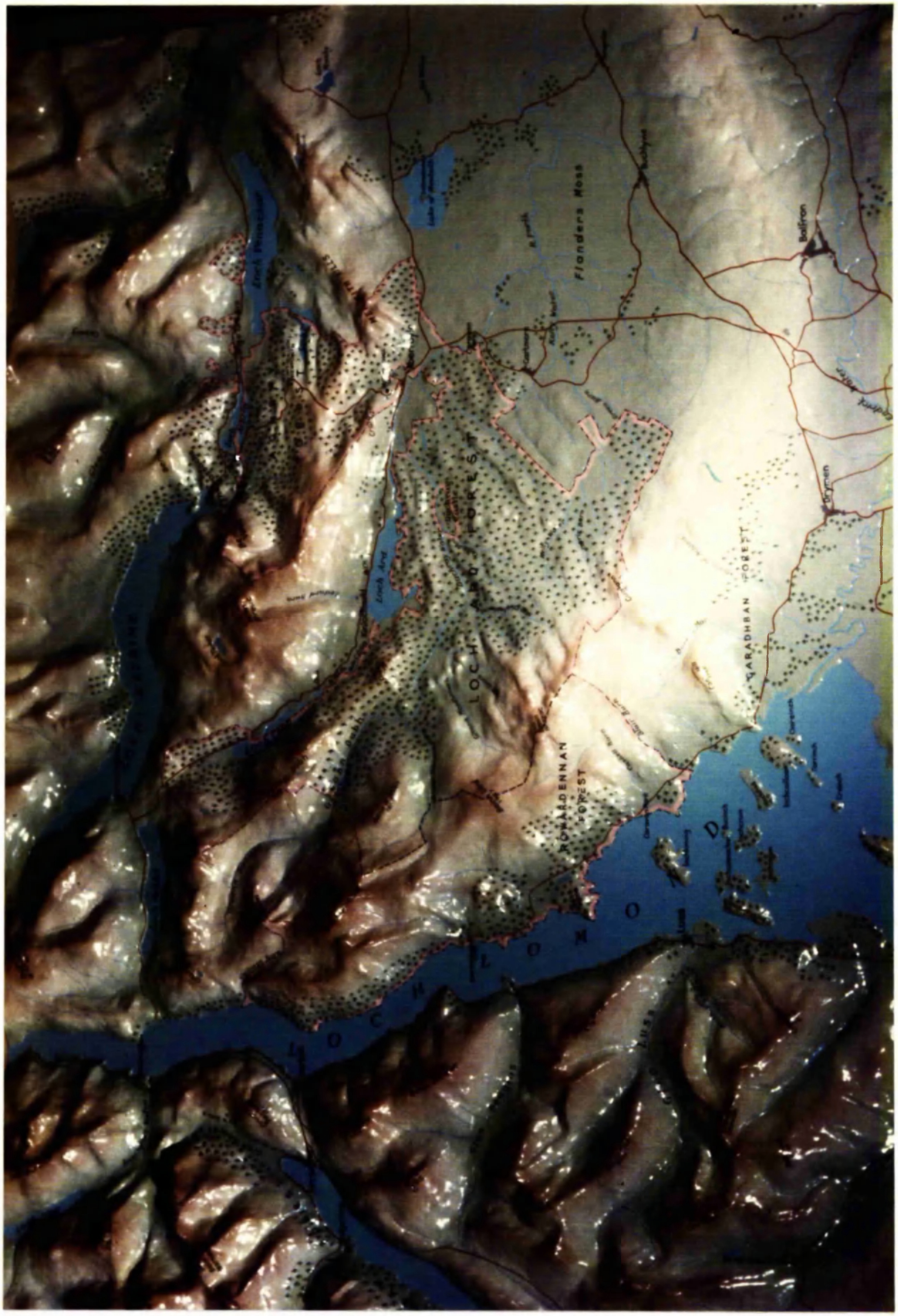
The paucity or complete absence of chemical data on most rivers and burns (streams) in the Loch Lomond watershed has in the past given rise to much speculation concerning the nature of this water. Regular chemical analyses of

17 of the main inflows covering almost the entire catchment area have been undertaken to remedy this situation. A similar lack of information on the water from drainage area of Loch Achray, Loch Ard, Lake of Menteith and Loch Rusky has been filled by regular water analyses of 5 main inflows.

Diurnal variation of phytoplankton and nutrient for a continuous 48-hour period have been studied in Loch Lomond. This being the first of such study in any freshwater loch in Scotland.

CHAPTER 2

Map I



LOCH LOMOND
LOCH ARD FOREST
ROWARDENNAN FOREST
GARADHBAN FOREST
Flanders Moss
Loch Ard
Balfron
Drymen

STATIONS, SAMPLING AND METHODS

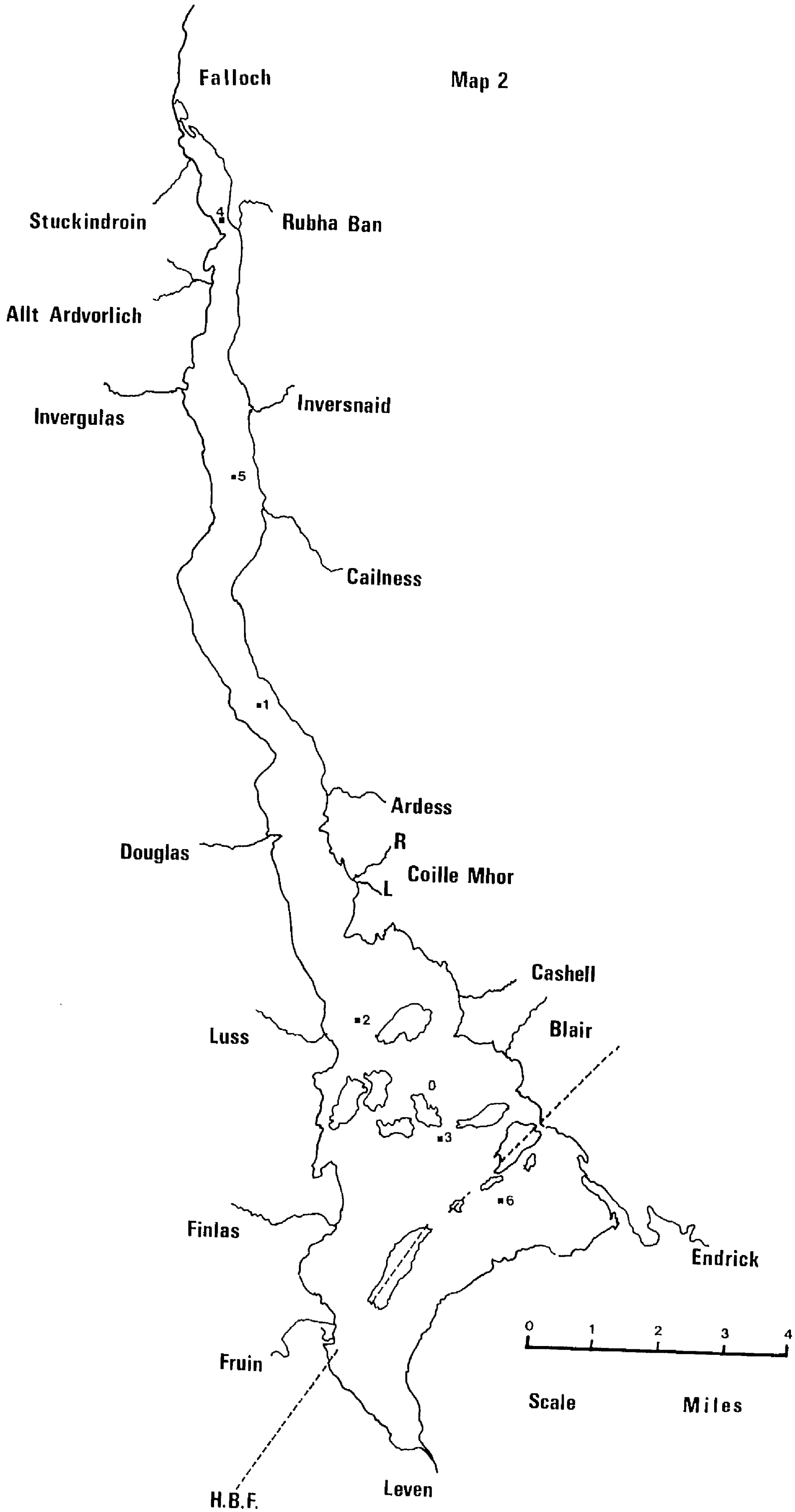
The field work for the present research was initiated in October 1971 and completed in September 1973. Although Loch Lomond was sampled from the commencement of the work, the quantitative ecological study of the loch started in March, 1972, with weekly sampling from three stations (1, 2, and 3 on Map 2). From August 1972, 17 major rivers and burns draining to Loch Lomond (Map 2) were sampled on a fortnightly or monthly basis. An extension of the research in October 1972 entailed the sampling of 3 additional stations in Loch Lomond (4, 5, and 6 on Map 2). At the same time sampling commenced in Loch Achray, Loch Ard, Loch Rusky and Lake of Menteith which are neighbouring Lochs (Map 1). The four lochs and Loch Lomond were thenceforward sampled on alternate weeks.

Table 1. Sampling Stations in Loch Lomond

Sampling Station	No. on Map 2	Max. Depth (m)	Location	Ordnance Survey Grid Ref.	Sampling Commenced
North Basin	1	150	Tarbet Basin, Upper Loch	NN 021 341	March, 1972
Middle Basin	2	47	Luss Basin, Lower Loch	NS 937 367	March, 1972
South Basin	3	23	Fault Basin, Lower Loch	NS 905 387	March, 1972
North Falloch	4	63	Ardlui Basin, Upper Loch	NN 139 327	Oct., 1972
North Inversnaid	5	198	Tarbet Basin, Upper Loch	NN 069 335	Oct., 1972
South Balmaha	6	17	Fault Basin, Lower Loch	NS 890 405	Oct., 1972

The three main stations "North", "Middle", and "South" basins were sampled at surface, 3 m, 5 m, 10 m, while North Inversnaid, North Falloch and South Balmaha were sampled at surface and 3 m only.

The "North Falloch" station is situated at the northern end of the Loch in the Ardlui Basin, just above the narrowest point, this area being largely affected by the inflow from the River Falloch. On both sides of the basin the hills rise abruptly to over 2,500 feet. The "North Inversnaid" station lies



Map 2
Falloch
Stuckindroin
4
Rubha Ban
Allt Ardvorlich
Invergulas
Inversnaid
5
Cailness
1
Ardess
R
Douglas
Coille Mhor
L
Cashell
2
Blair
Luss
0
3
6
Finlas
Endrick
0
1
2
3
4
Fruin
Scale
Miles
H.B.F.
Leven

in the Upper Tarbet Basin, 2 km south of Inversnaid over the deepest region of the entire loch. The hills still rise steeply but the loch is slightly wider here. The last station in the Upper Loch is the "North" Basin which is situated at the southern part of the Tarbet Basin where the loch is again narrow. The steep-sided hills rise to Beinn Bhreac (2,073 feet) in the west and to the dominating mass of Ben Lomond (3,192 feet) in the east.

The first station in the Lower Loch is the "Middle Basin" lying 1 km north-east of Luss in the Luss Basin. The hills in this region rise more gently and the Loch is much broader. The other two stations of the Lower Loch lie in the wide Fault Basin. The "South Basin" lies to the south of the island of Inchcruin and to the north of the Highland Boundary Fault, while "South Balmaha" station lies south of the chain of islands of Inchcailloch, Torrinch, Creinch and Inchmurrin which mark the Highland Boundary Fault. Thus "South Balmaha" is the only true lowland station in the loch.

From August, 1972 the following rivers and burns were sampled in the Loch Lomond catchment area on a fortnightly or monthly basis. The Ordnance Survey Grid Reference locates the points from which the samples were taken.

(1) River Falloch (NN 165 315) is the largest single inflow to Loch Lomond and joins the loch at its northernmost point. Its catchment includes Glen Falloch which runs north-eastward from the head of the loch.

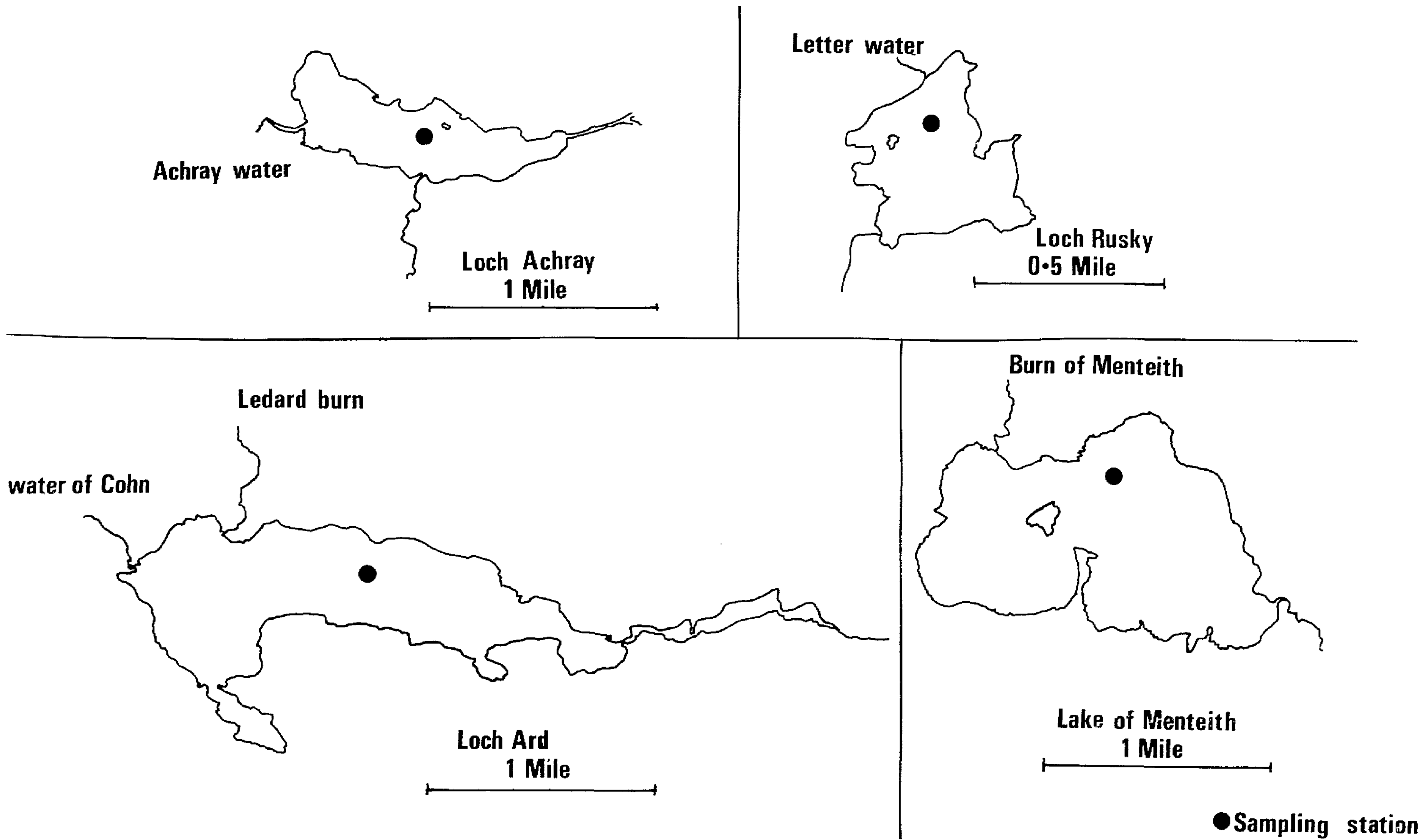
(2) Stuckindroin Burn (NN 151 320). The catchment of this burn extends to Ben Vorlich (3,082 feet) on the west side of the loch; like the River Falloch this burn runs into the Ardlui Basin.

(3) Rubha Ban Burn (NN 120 333). This is a small burn entering the east side of the loch at the northern end of the Tarbet Basin.

(4) Alt Ardvorlich (NN 120 324) enters the loch on the west side of Tarbet Basin at Ardvorlich. Its catchment, like Stuckindroin Burn, lies entirely on the slopes of Ben Vorlich.

(5) Inveruglas Water (NN 092 316) drains from Loch Sloy which lies 1000 feet above Loch Lomond. The water enters the Tarbet Basin at Inveruglas on the west side of the loch.

MAP 3



Achray water
Loch Achray
1 Mile
Letter water
Loch Rusky
0•5 Mile
Ledard burn
water of Cohn
Loch Ard
1 Mile
Burn of Menteith
Lake of Menteith
1 Mile
●Sampling station

(6) Inversnaid (NN 088 338). The water from Loch Arklet (500 feet above Loch Lomond level) enters the Tarbet Basin at Inversnaid. The point of entry is almost directly opposite Inveruglas.

(7) Cailness Burn (NN 062 342) drains from the north-west facing slopes of Ben Lomond to enter the east side of the loch 2.5 km south of Inversnaid.

(8) Ardess Water (NS 993 360) drains from the south-facing slopes of Ben Lomond entering the loch at the southern end of the Tarbet Basin at Rowardennan.

(9) Douglas Water (NS 979 343) has a fairly large catchment area and runs through Glen Douglas to join the loch on the west side of Inverbeg. The point of entry marks the boundary between the Tarbet and Luss basins.

(10) Coille Mhor River (NS 969 367) and (11) Coille Mhor Loch (NS 968 368) both enter the Luss Basin on the east side of the loch within a short distance of each other. Coille Mhor River drains from the lower hills to the south of Ben Lomond and Coille Mhor Loch represents the outflow from the Dubh Loch.

(12) Cashell Burn (NS 946 397) drains from Beinn Bhreac and Beinn Uird on the east side of the loch entering the Luss Basin at the southern end of Rowardennan Forest.

(13) Blair Burn (NS 930 407) also drains from Beinn Bhreac and runs parallel to Cashell Burn to join the Luss Basin at Milarrochy.

(14) Luss Water (NS 927 357). The three burns, Glen Mollochan, Gleann MaCaoruinn and Auchengavin, join to form the Luss Water which has a total course of 6 miles, and collects water from the hills to the west of Luss. This inflow joins the loch at Luss Basin.

(15) River Endrick (NS 873 472) has the largest drainage area of all the inflows to Loch Lomond and enters the loch at its south-east corner. This river is the largest single inflow to the Fault Basin.

(16) Finlas Water (NS 882 354) drains from the hills to the south of Luss entering the west side of the Fault Basin at Ross Park.

(17) Fruin Water (NS 857 357) rises in the hills above Garelochhead and runs roughly parallel with the Finlas to join the Fault Basin 3.5 km north of Balloch in the south-west corner of the loch.

Loch Achray, Loch Ard, Loch Rusky and Lake of Menteith

All lochs were sampled fortnightly from October, 1972. A single station from each loch was chosen. Surface and 5 m depth samples were taken from Loch Achray, Loch Ard and Loch Rusky, while surface and 3 m depth samples were taken from Lake of Menteith.

Loch Achray lies to the north of the Highland Boundary Fault about 17 km east of Loch Lomond. It is a fairly small loch (see Map 1, 3 and Table 2) elongated toward the east and surrounded by mountains rising to over 2,000 feet. The main inflow, "Achray Water", drains from Loch Katrine and joins the loch at its western end. The outflow from Loch Achray ("Black Water") leaves the loch at its most easterly tip and meanders for a distance of about 1 km before entering Loch Venacher. These lochs lie in the drainage basin of the River Forth.

The only sampling station was located centrally at Grid Reference NN 066 510 (see Map 3) over the deepest region of the loch. The main inflow was sampled at a point one third of a kilometre before it enters the loch (Grid Reference NN 065 504 - see Map 3). All samples were taken between 1100 and 1400 hours.

Loch Ard. South-west of Loch Achray but still in the Highlands lies Loch Ard. It is longer than the previous loch (see Map 1, 3 and Table 2) and elongated along an east-west axis. Loch Ard is situated in a mountainous area east of Ben Lomond and about 12 km east of Loch Lomond. The main inflow, the Water of Chon, drains from Loch Chon and enters the eastern end of the loch. A secondary tributary, the Ledard Burn, has a catchment area extending to Beinn Bhreac and enters the loch from the north.

The sampling station at Grid Reference NN 019 465 (see Map 3) was located over the deepest region in the loch. The main inflow and Ledard Burn were sampled at the point of entry at Grid References NN 023 448 and NN 024 459 respectively. All samples were taken between 1200 and 1600 hours.

Lake of Menteith. Lake of Menteith, the longest of these four lochs, lies to the south of the Highland Boundary Fault (Map 1 and 3, Table 2) almost due east from Loch Ard and about 22 km east of Loch Lomond. The surrounding land to the south is fairly flat whereas to the north the Menteith Hills rise to almost 1,400 feet. The main burn contributing to Lake of Menteith drains from the Menteith Hills and enters the lake near its north-west corner. The outflow is the Goodie Water which leaves south-east corner of the lake eventually enters the River Forth.

The sampling station is located at Grid Reference NN 005 584 (Map 3) over the deepest accessible part of the lake, off Port of Menteith. The burn was sampled at Grid Reference NN 012 571. Sampling was carried out between 0900 and 1100 hours.

Loch Rusky. This is the smallest of the four lochs and the second lowland loch. It lies in the hills to the north-east of Lake of Menteith and 28 km east of Loch Lomond. The main burn flowing into the loch - "Letter Burn" - drains from Ben Gullipen (1,357 feet) to the north; the outflow leaves the loch at its south-east corner, joining the Goodie Water which ultimately drains to the Forth.

Samples were taken at Grid Reference NN 036 616 (Map 3) the deepest accessible part of the loch. The main inflow was sampled at Grid Reference NN 038 614. All samples were taken between 1000 to 1300 hours.

Table 2.

Lochs	Elevation (feet)	Length (miles)	Breadth (miles)		Depth (feet)		Volume (cu. ft.)	Area (sq.miles)	Total drainage area (sq. miles)	Total drainage area : surface area
			Max.	Mean	Max.	Mean				
Achray	276	1.25	0.33	0.26	97	36.[illegible]	[illegible]	0.32	44.48	~~1.39~~ 139
Ard	105	2.3	1.1	0.41	107	43.863	1150	0.94	15.97	16.99
Menteith	55	1.6	1.0	0.64	77	19.77	562	1.02	6.35	6.23
Rusky	445	0.5	0.4	0.3	44	-	-	0.12	-	-
Lomond	23.9	22.64	4.83	1.21	623	121.29	92.805	27.45	270.43	9.9

Sampling Methods

Sampling at the various stations in Loch Lomond was carried out entirely from the Cattamaran 'Fiona', belonging to the University of Glasgow Field Station at Rowardennan. The vessel has a hydrographic winch situated amidships over an opening between two fibreglass floats. This is covered whilst the boat is in motion, but can be rapidly uncovered when a sampling station is reached. The twin 20 h.p. outboard motors give the cattamaran a top speed of 8.5 knots, enabling the sampling of the entire length of the loch to be carried out in about 8 hours.

A small, collapsible rowing boat was used on the four other lochs from which samples were taken (Lochs Achray, Ard, Rusky and Lake of Menteith). On arrival at a station the boat was anchored, the oxygen-temperature probe was connected to the meter and immersed in the lake water to equilibrate. During this period surface and depth water samples were obtained and net phytoplankton was collected using a plankton net with 200 meshes to the inch. Surface water samples were taken using a clean polythene bucket, rinsed twice with loch water before filling. Five-litre samples were transferred to a clean, narrow necked 5 litre polythene bottle which was rinsed twice with sample before filling.

Depth samples of water and phytoplankton were collected using a 6 litre closing samples of the Van Dorn type (Van Dorn, 1956). In Loch Lomond the samples were lowered from a hydrographic winch fitted with a meter, in the other four lochs a cord marked at suitable intervals was used. When the sampling device had reached the desired depth closure was effected by a drop-weight "messenger" which slides down the supporting wire. This type of sampler has the advantage of being free-flushing during descent and non-contaminating (due to its chemically neutral polythene tube). The plastic caps drawn around to the side of the tube snap firmly to after being tripped by the messenger and make a watertight seal. The sampler can then be rapidly raised to the surface where a small volume of water is withdrawn to rinse a 5 litre polythene bottle which was then filled. On completion of water bottle sampling the oxygen-temperature profile was recorded and the weather conditions noted. Samples from rivers and burns were taken in the centre of the flow at a region of rapidly moving water and away from any source of localised pollution. All samples were taken using a clean polythene bucket rinsed twice in stream water. The running water was also used to wash a clean 5 litre narrow necked polythene bottle to which the bucket sample was then transferred.

Determination of orthophosphate

Almost all methods for the estimation of dissolved orthophosphate are colorimetric and most are based on the formation, under acid conditions, of the yellow colloidal phosphomolybdic acid and its subsequent reduction to a blue heteropoly compound. Under the conditions used, combined forms of phosphate do not react with molybdate, these include dissolved organically combined phosphate and polyphosphate. Particulate phosphorus is also un-reactive.

The procedure used here is that of Murphy and Riley (1962) with the acid and molybdate concentrations given by Stephens (1963) as described by Strick-land and Parsons (1968).

The sample is treated with a single reagent containing acidified ammonium molybdate, ascorbic acid and antimony. All reagents used were of analytical quality. The ammonium molybdate solution was made up freshly each week, ascorbic acid solution was kept frozen at $-20^{\circ}C$ between analyses but was never kept more than one month. The concentrated sulphuric acid and the solution of potassium antimonyl tartrate were made up in large volumes, sufficient for 3 months.

Samples were analysed within 2-4 hours of completion of sampling, large pieces of debris and zooplankton were removed by filtering through a fine (25 μ) nylon mesh.

100 ml aliquots of each sample were dispensed into 250 ml polythene bottles; and analysed in duplicate while standards and blanks were analysed in triplicate. The sample aliquots for analysis were placed in a water bath for 30 minutes at $20-25^{\circ}C$; 10 ml of freshly prepared mixed reagent were

added with mixing. After 1 hour the extinction of the blue colour was read at 885 mμ on an SP 600 spectrophotometer in 4 cm cells. Each set of analyses was accompanied by standards and blanks, the standard being a solution of KH_2PO_4 (3 μg atoms P/l.). This was prepared from a concentrated standard (kept frozen at $-20^{\circ}C$), the blanks being distilled water. The equation used for calculation the calibration factor is $F = \frac{3}{Astd - A_{Blank}}$. For full description of the method see Appendix (i).

The single reagent method described above is the result of development and improvement made by many authors over a period of years. The addition of sulphuric acid gives an optimum pH for the reaction of orthophosphate with molybdate even in the presence of a large excess of silicate (Burton ~~et al.~~, 1973). The use of ascorbic acid as a reductant in the analysis of fresh was has been recommended by Strickland and Parsons (1968), Goltermann (1969), standard method of A.P.H.A.(1971) and Burton (1973). This has many advantages over stannous chloride (Olsen, 1967) as a reducing agent, the blue colour is stable for many hours, there is no temperature effect between 15-30°C and there is no interference with arsenic, silicate, copper or iron. The ease and rapidity of use of a single reagent solution also recommends it. On the other hand, stannous chloride which is recommended by Mackath (1963) is unsuitable where many analyses have to be carried out. The colour must be measured between 10-12 minutes after adding the second reagent. The method is very temperature dependent and the addition of two solutions is involved, there is also greater sensitivity to interfering ions (Olsen, 1967; Burton, 1973).

The addition of antimonyl ions to the single solution (Murphy and Riley, 1962) considerably improved the rate of colour formation, which previously took 24 hours at room temperature (Murphy and Riley, 1958).

Extraction of the highly coloured blue complex into an organic layer increases the sensitivity of the method considerably, but the disadvantage of this procedure for the analysis of many samples lies in the demand on glassware, reagents, space and time (Olsen, 1967).

The most recent method of phosphate analyses described by Hasakaw and

Ohsima (1973) utilise a single reagent which is stable in air for many months. Colour development takes 20 minutes at 100°C, is stable for a few months and does not suffer from As or Si interference. No indication is given of the accuracy of the method.

Determination of silicate

What is commonly termed soluble silica or silicate is almost always determined by a colorimetric method involving the formation of a silicomolybdate complex. The yellow colour of this complex may be measured directly or the silicomolybdate complex may be reduced to a heteropoly blue. The blue colour is more intense than the yellow colour and provides increased sensitivity. According to Martin (1972) the method depends on the reaction of orthosilicic-acid H_4SiO_4 with molybdate in the ratio 12:1 to give silico molybdic acid:- $H_4SiO_4 + 2H_3\ (H_3Mo_6O_{21}) \rightleftarrows H_4(SiMo_{12}\ O_{40}) + 6H_2O$. Dienert and Wandenbulcke (1923) also claim that the reaction is given only with silicic acid. However Goltermann (1969) states that "the formula of the compounds of silicon which are determined by the chemical methods is not known and the terms silica and silicate are used only as convenient descriptions". Strickland and Parsons (1968) consider that the term "reactive silicate" should be used since not all the silicic acid present was reactive, while Burton and Leatherland (1970) found no unreactive silicate in river water samples even with concentrations up to 5000 μg Si/l. Lund (1964) made the important conclusion that the "orthosilicate silicon" or the "silica" estimated by the standard molybdate method are available to diatoms, while the more highly polymerized forms are not.

The procedure used in the present investigation is a modification of the method of Mullin and Riley (1955) as described by Strickland and Parsons (1968).

The silicate samples for analysis were returned to the laboratory in polythene containers within 2-3 hours of the completion of the sampling. The analysis was commenced immediately, duplicate 25 ml aliquots of each sample being dispensed into 250 ml narrow necked polythene bottles. These were then allowed to equilibrate in a water bath for about 30 minutes at a temperature between 18-25°C, after which 10 ml at acidified molybdate solution was added. The mixture was allowed to stand for 10 minutes followed by immediate addition of 15 ml of reducing agent consisting of metol-sulphite solution, oxalic acid solution and sulphuric acid.

The solution was allowed to stand for 2-3 hours to allow the complete reduction of the silico molybdate complex. The extinction was then measured in a 4 cm Unicam glass cell against distilled water. The readings were made on a Unicam Sp 600 spectrophotometer using a red filter at 810 mμ. Each set of analyses was accompanied by standards and blanks three of each being carried through the above procedure. The silicate standard used was sodium silico fluoride (Na_2SiF6); this is an easily prepared, long-lasting standard which is stored as a concentrated solution and diluted to give a standard solution of 4 μg atoms Si/l. for immediate use. The blanks used were silicate-free distilled water.

All reagents used were of analytical quality, all solutions were kept in polythene bottles and the distilled water for making up solutions was stored in polythene containers. The acidified molybdate solutions were made up freshly each week, as a white precipitate tends to form if kept longer. The metol-sulphite solution was also found to deteriorate on keeping and was freshly prepared each week. The other reagents, oxalic acid and sulphuric acid, were made up in bulk, sufficient for three months.

The theoretical basis of this determination of silicate has been considered in detail by many authors, the main difference between the methods lying in the type of reductants employed and the use of oxalic acid. According to the standard methods of the A.P.H.A. (1967) ammonium molybdate reacts at pH 1.2 with silica and also with any phosphate present to produce a heteropoly acid. The molybdophosphoric acid and any (arsenomolybdic acid) are destroyed by adding oxalic acid. This is, generally, included with the reducing agent (Goltermann, 1969 used H_2SO_4 instead).

Metol-sulphite solution is commonly used as a reductant in the silicate analysis of fresh water (Mullin and Riley, 1955; Mackereth, 1963; Strickland

and Parsons, 1968), while stannous chloride is recommended by Goltermann (1969). According to Mullin and Riley (1955) metol sulphite was chosen on the grounds of cost, accuracy, high stability of the reagent and stable colour formation. The addition of sulphite is necessary for rapid and efficient reduction of the silicomolybdate. The sulphuric acid prevents the reduction of the excess molybdate which has not been complexed with silica and is also essential for reduction of silicomolybdate to take place. Although stannous chloride reducing agent has a slightly greater sensitivity the molybdenum-blue colour is unstable and must be read between 10 and 15 minutes after adding the reagents. The colour with the metol sulphite reductant is stable for up to 24 hours, and the interference from other ions (Cu^{2+}, Fe^{2+}, Ca^{2+}, Ni^{2+}) is likely to be low (Mackereth, 1963).

This procedure is suitable for samples with silicate concentration in the range 0.1-140 µg atoms Si/l. (Strickland and Parsons, 1968) for higher concentrations the molybdinum yellow method should be used (A.P.H.A., 1967).

For complete details of the method see Appendix (ii).

Determination of Nitrate

A large variety of methods have been used in the estimation of nitrate in natural waters, though these may be divided into three main categories. Colorimetric methods reacting with nitrate directly, methods relying on the reduction of nitrate to either nitrite, ammonia, or nitrosyl chloride, and methods giving a direct reading, including specific ion-electrodes and u.v. absorption.

The colorimetric methods are based on the formation of various coloured products when nitrate is allowed to react with various organic reagents such as Brucine (A.P.H.A., 1967) and Strychnidine (Cooper, 1932) in acid solution or with phenoldisulphonic acid (Mackereth, 1963) in alkaline solution. The brucine and strychnidine methods suffer from sensitivity to temperature, pH and impurities in the reagent (Martin, 1972; A.P.H.A., 1967). The phenodisulphonic acid procedure involves the time consuming process of evaporating 100 ml of sample to dryness before adding the reagent. All these procedures suffer from chloride and nitrite interference (Martin, 1972; A.P.H.A., 1967;

Mackereth, 1963).

The reduction of nitrate to nitrite or nitrosyl chloride is now commonly used in determination of nitrate, though Goltermann (1969) describes a method in which nitrate is reduced to ammonia. This is a lengthy procedure involving distillation of the ammonia followed by Nesslerization, the drastic reducing conditions used result in the reduction of organic nitrogen compounds.

The reduction of nitrate to nitrosyl chloride in the presence of sulphuric acid was used by Armstrong (1965) in his method of nitrate estimation. The nitrosyl chloride was measured from its u.v. absorption at 230 mμ, this method is applicable for only high nitrate concentrations and the method is temperature dependent (Martin, 1972).

A sensitive method involving the reduction of nitrate to nitrite was described by Mullin and Riley (1955). Hydrazine acted as the reducing agent in strongly alkaline solution, the reaction being catalysed by copper ions (Cu^{2+}). This procedure is very temperature dependent, and requires 24 hours for complete reduction to take place; the nitrite is then assayed by the Bendschneider and Robinson technique. The use of zinc powder for the reduction of nitrate to nitrite (Chow and Johnstone, 1962) gives only 85-90% reduction and each sample has to be centrifuged and filtered. Morris and Riley (1963) described a method using cadmium as a reducing agent. This provides reproducible reduction of $91 \pm 1\%$ nitrate to nitrite after the samples had been passed through a column of amalgamated cadmium filings. A later modification lengthened the reducing column and included an alkaline ammonium chloride wash to complex the oxidised Cd ions. In a further refinement Strickland and Parsons (1965) replaced ammonium chloride by the tetrasodium salt of ethylenediaminetetraacetic acid. Wood, Armstrong and Richards (1967) replaced mercury as a cathode by copper providing a reproducible, quantitative reduction of nitrate to nitrite $99 \pm 1\%$. This method was used in the present investigation as a rapid and reproducible technique with high sensitivity over the range 0-60 μg atoms N/l. The reaction is as follows:-

$$NO_3^- + Cd + EDTA^{4-} + H_2O \rightarrow NO_2^- + Cd - EDTA^{2-} + 2OH^-$$

The addition of EDTA complexes the Cd^{2+} ions and this prevents the precipitation of $Cd(OH)_2$ and $CdCo_3$ which reduce the column efficiency and decreases the column life (Wood, Armstrong and Richards, 1967).

Analysis of samples was commenced immediately on return to the laboratory and within 3 hours of completion of sampling. 50 ml aliquots of each sample were measured into two 50 ml graduated measuring cylinders; the column was then washed with 3-4 ml of sample, followed by the addition of the remaining sample to the column reservoir, the graduated cylinder being placed under the column discharge tap. The flow rate was controlled at 10-12 ml/minute and 15 ml of column effluent was collected in the cylinder. After dilution to 30 ml with distilled water the solution was assayed for nitrite estimation as described by Bendschneider and Robinson (1952) using 1 cm Unicam glass cell. All samples were analysed in duplicate.

The method was calibrated using a nitrate standard of 20 µg atoms N/l. prepared by diluting 1 ml of concentrated standard solution (5 µg atoms/ml of potassium nitrate to 250 ml with distilled water. Three standard solutions and three distilled water blanks were carried through the entire procedure with each set of determinations. The calibration factor, F, was calculated from the expression

$$F = \frac{20}{E_{std} - E_{blank}}$$

The concentration of nitrate in any sample was then found by multiplying the corrected mean extinction of the sample by the calibration factor and subtracting the nitrite concentration in µg atoms N/l.

For full details of the method see Appendix (iii).

Determination of Nitrite

All estimation of nitrite are based on a diazotization process. Under acid conditions the nitrite ions react with an aromatic amine ($R - NH_2$) to form a diazo compound which is coupled with a second aromatic amine ($Ar\ NH_2$) to form a red azo dye (Martin, 1972). The intensity of the final colour is proportional to the amount of nitrite present.

The earlier method of Griess-Ilosvay (A.P.H.A., 1967) recommended by Mackereth (1963) used sulphanilic acid as the diazotising agent and 1-naphthylamine hudrochloride as the coupling agent. This method suffers from interference with metal ions (Fe^{2+}, Ca^{2+}, etc.) which catalyse the decomposition of the diazonium salt, and is generally slow and inconsistent(A.P.H.A., 1967).

Bendschneider and Robinson (1952) adopted a sulphanilamide solution and N-(1-naphthyl)-ethylenediamine dihydrochloride solution in their improved method, which was described in detail by Strickland and Parsons (1968) and used throughout the present investigation.

The reaction is as follows:-

$$NH_2.C_6H_4.SO_2\ NH_2 + N\bar{O}_2 + 2\overset{+}{H} \rightarrow \overset{+}{N} \equiv N\ C_6H_4.SO_2\ NH_2 + H_2O$$

diazonium ion

$$NH_2\ CH_2\ CH_2\ NH.C_{10}H_7 + \overset{+}{N} \equiv N\ C_6H_4.SO_2\ NH_2 \rightarrow$$

$$NH_2\ CH_2\ CH_2NH\ C_{10}H_6.N = N.\ C_6H_4.\ SO_2\ NH_2 + H^+$$

pink azo dye

The absorbance of the pink azo dye is measured at 543 mμ. This procedure has the advantage of being 5% more sensitive, independent of temperature over a wide range, not as sensitive to interference by metal ions and more rapid (Martin, 1972).

Analysis was carried out within three hours, on fresh s amples, 50 ml aliquots of which were measured into graduated cylinders. 1 ml of sulphanilamide was added to each sample aliquot and mixed, after 2 to 6 minutes 1 ml of coupling reagent (N-(1-Naphthyl)-ethylenediamine dihydrochloride solution was added and mixed. The colour developed was measured after 10 minutes in a 4 cm Unicam glass cell at 543 mμ. A Unicam SP600 spectrophotometer was used throughout the investigation.

A standard nitrite solution, prepared from A.R. sodium nitrite, was diluted to a concentration of 2 μg atoms N/l. for calibration purposes. Recalibration was found to be necessary except when reagents were changed although distilled water blanks were run with each set of determinations.

The calibration factor was determined from the expression

$$F = \frac{2}{Estn - E_{blank}}$$

the nitrite concentration of any sample being found by multiplying F by the corrected extinction at 543 mμ.

For full details of method see Appendix (iv).

pH determination

pH is the logarithm of the reciprocal of the hydrogen ion concentration. The pH expectation for most natural waters lies between 6.5 and 8.5 (Welch, 1952) though the majority of waters are slightly basic due to the presence of carbonate and bicarbonate ions (Ruttner, 1963).

pH can be measured colorimetrically or electrometrically. The colorimetric method suffers from interference from colour, colloidal matter, and various oxidants and reductants. No single indicator covers the entire range of interest and this procedure is suitable for rough estimations only. The electrometric method is considered standard and has high precision (Welch, 1952).

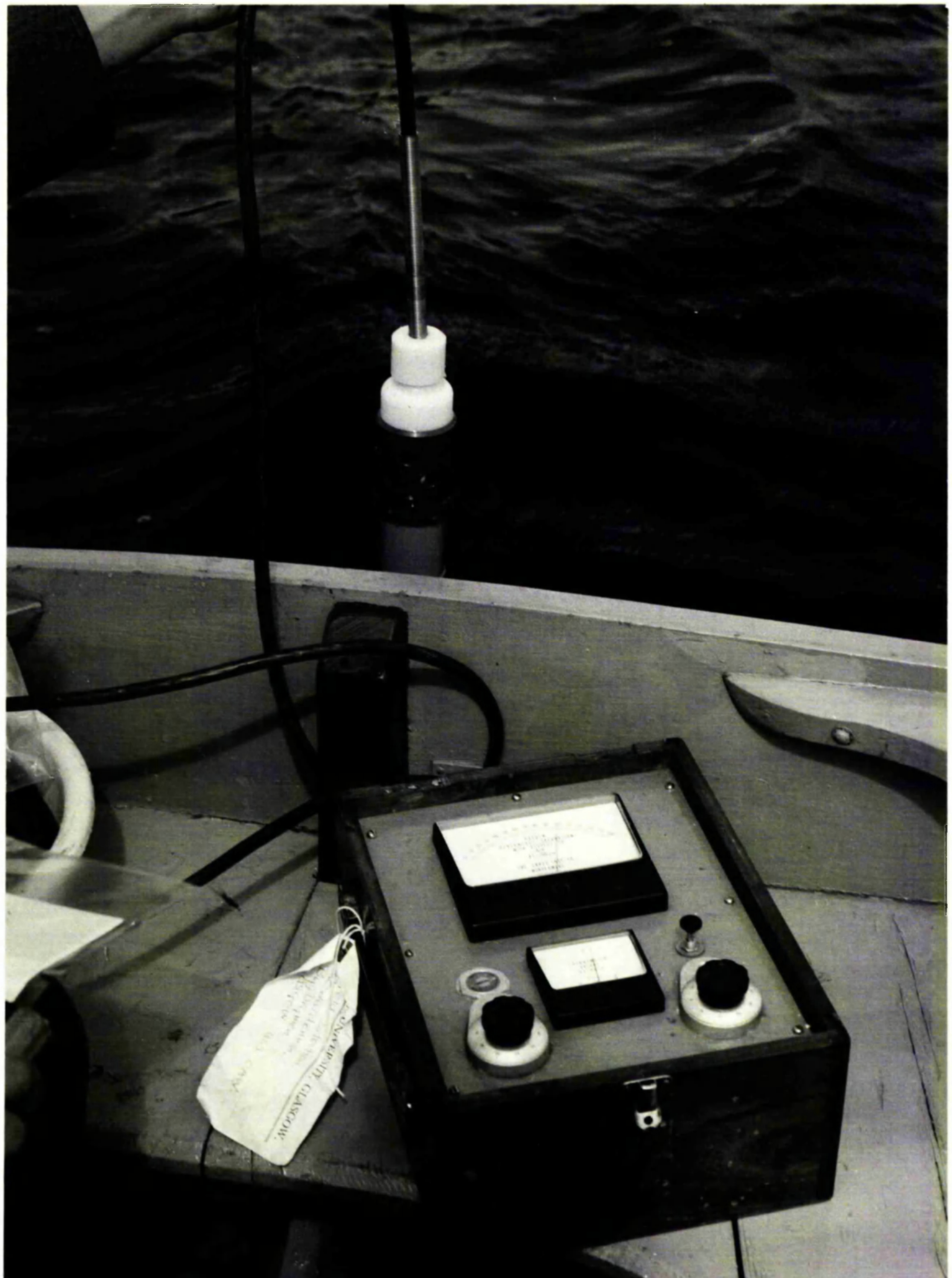
In this investigation the pH of unfiltered samples was measured immed-iately on return to the laboratory using a Pye Model 292 pH meter. The electrodes used with the meter were a glass indicator electrode in combination with a saturated calomel electrode. The glass electrode is free from interference, covers the range 0 to 14 and has an error of $\pm$ 0.02. The electrode was standardized on each occasion using a buffer solution near to the expected pH of the sample (in this case pH 7). Since the current from the glass electrode is temperature dependent, the temperature of the buffer was measured to 1°C and the instrument set accordingly. The pH of the samples were measured within 3°C of this temperature.

For full details of the pH determination see Appendix (v).

Alkalinity determination

Alkalinity is the concentration of weak acid salt, largely bicarbonate, in natural waters. The hydrolysis in solution of the bicarbonate ion results

Fig I



in the production of hydroxyl ions:-

$$M^{+} + HCO_3^{-} + H_2O \rightleftarrows M^{+} + H_2CO_3 + OH^{+}$$

By titrating the sample with standard acid (thereby removing the hydroxyl ions) the concentration of bicarbonate in solution can be determined. When the equation has moved completely to the right, only undissociated carbonic acid and free carbon dioxide will be present. This happens below pH 4.5 and an indicator was chosen which changes colour at this pH.

The method recommended by Mackereth (1963) was used. To each 100 ml aliquot of sample 5 drops of B.D.H. 4.5 indicator was added followed by titration against standard N/100 hydrochloric acid from a 10 ml burette. The sample was mixed continuously using a magnetic stirrer and titration was continued till the colour of the solution changed from blue-grey to grey. Recognition of the end point was facilitated by comparison with a standard end point colour. The alkalinity of duplicate aliquots of each sample was determined.

From a knowledge of the normality of the acid, the mean titration volume and the volume of sample, the total alkalinity can be determined. The alkalinity of a sample is often expressed in terms of dissolved calcium carbonate, by multiplying the value for meq HCO_3^-/l. by the equivalent weight of calcium carbonate (50) and expressed as mg $CaCO_3$/l.

Full details of the method and calculation are given in Appendix (vi).

Oxygen and temperature measurement

Oxygen saturation and temperature profiles were recorded at all stations using the improved dissolved oxygen meter described by Mackereth (1964). The instrument used was supplied by The Lakes Instrument Company, Windermere, Westmorland (see Figure 1).

The galvanic cell is protected from the external medium by a 0.003 inch thick polythene membrane which is permeable to gases but very little else. When the silver and lead electrodes are connected, via the external circuit, the current flowing is a function of the rate of oxygen supply to the electrode which is dependent on the external concentration of the gas. The output current is measured on deck with a microammeter and the temperature is measured by balancing the thermistor resistance and noting the potentiometer reading. The galvanic cell has an output of hundreds of microamps compared with earlier models which produced very low current and the sensitivity is stable over a long period.

Two probes were used with the meter, one with a cable length of 150 m and the other of 20 m each was calibrated individually. Before use the probe was connected to the meter and immersed in the water for at least 10 minutes. This allowed any oxygen within the electrode to be consumed and the output to stabilise. After anchoring the boat at a sampling station in Loch Lomond the long probe (150 m) was lowered by means of a hydrographic winch fitted with a depth meter. The oxygen temperature depth profile was plotted at 1 m intervals in the epilimnion and thermocline regions while 5 m intervals were taken in the hypolimnion. At sampling stations in the other lochs the 20 metre length probe, marked at metre intervals was used, measurements were made at each metre interval. At each new depth the probe was allowed to reach a new steady state, the response time being generally less than one minute. On completion of the readings, the oxygen probe was wrapped in a wet cloth, which rapidly became deoxygenated and prevented the build up of oxygen in the galvanic cell.

The procedure for taking oxygen and temperature readings and calibration of the probe is fully described in the Appendix (vii).

Determination of Chlorophyll a

Of the spectrophotometric methods available for the estimation of chlorophyll, modification of Richards and Thompson's (1952) procedure, based on extraction in 90% acetone have been most widely followed (Talling and Driver, 1963). According to "Recommended procedures for measuring productivity" Anon (1969), 90% acetone is favoured because the extinction coefficient is higher than for other organic solvents, pure chlorophyll,a is more stable in acetone and the absorption band in the red is sharper. The advantages of using methanol in the extraction of chlorophyll when certain green and blue-green algae are involved has been disputed by Talling and Driver (1963) who state that 90% methanol has not been obviously more efficient than 90% acetone in this respect.

The procedure used in the present investigation is based on Richards and Thompson (1952) as modified by Parsons and Strickland (1963) and described in Strickland Parsons (1968). The volume of sample was generally 1 litre which was filtered without application of suction (Lund and Talling, 1957). Glass fibre filters (Whatman GF/C) were used as recommended by Strickland and Parsons (1968). These filters give practically no turbidity blank and are advantageous if a grinding step is included. Magnesium carbonate was added at the filtration stage, to prevent the chlorophyll from becoming acid and the resulting decomposition to phaephytin pigment (Strickland and Parsons, 1968).

On completion of filtration the filter was ground with 2 ml of ice cold 90% acetone to break up the cells and to improve the extraction. A laboratory tissue grinder was used, running for 2 minutes at 500 r.p.m. in subdued light. The contents of the grinder tube were transferred to a stoppered centrifuge tube making sure that the total volume did not exceed 10 ml. 15 to 20 hours were required for pigment extraction (Strickland and Parsons, 1968) which was carried on in the dark at $1^{\circ}C$. After this period the extract was made up to 12 ml with 90% acetone and centrifuged for 10 minutes at between 3,000 and 4,000 r.p.m. Because of the photosensitivity of pigment extracts exposure to light was as brief as possible.

The measurement of extinction was made against 90% acetone at 750, 665, 645 and 630 mμ using a Unicam SP600 spectrophotometer. 645 and 630 mμ represent the absorption peaks of chlorophyll b and c respectively. Since small extinctions had to be measured, optical inequalities between cells were corrected by determining the cell to cell blank at all wave lengths used. Turbidity blanks were measured from the reading at 750 mμ where the absorption of light by plant pigment is absent (Strickland and Parsons, 1968). All readings were corrected for turbidity by subtracting the value at 750 mμ.

Since the glass fibre filters retain a proportion of the acetone, it was necessary to use 12 ml of solvent to obtain sufficient extract to fill a spectrophotometer cuvette. Therefore the observed extinction values were normalised to the values expected for 10 mls of extract by multiplying them by a factor of 1.2. Chlorophyll a was then calculated from the equation:

$$\mu g \text{ chlorophyll a}/l = \frac{c}{v}$$

where (v) equals volume of water filtered in litres and (c) is a value obtained from the revised trichromatic equation of Parsons and Strickland (1963). Their equation was based on a re-evaluation of the specific absorption coefficients of chlorophylls a, b and c. They showed that the values on which Richards and Thompson (1952) based their equations were too low and that pigment concentrations had been overestimated by 25%. Their revised equation for 90% acetone extract is as follows:-

$$Ca = 11.6\ D665 - 1.31\ D645 - 0.14\ D630$$

where D is the corrected extinction at each wavelength measured in a 1 cm cell.

For full details of chlorophyll a estimation see Appendix (viii).

Enumeration of phytoplankton

Direct microscopical examination is necessary both for taxonic work and for the quantitative assessment of phytoplankton in term of cell numbers (Margalef, 1971). For this purpose algae have to be concentrated. In general the methods used involve either filtration, sedimentation or centrifugation. The examination of water samples may be made using a haemocytometer. The choice of a counting method for the present investigation was based on a practical examination of the advantages and disadvantages of each procedure.

Concentration of phytoplankton by centrifugation is used both for small volumes (10 to 20 ml) and for larger volumes (1 litre or more) if a continuous centrifuge is available. This procedure allows the observation of living flagellates but its applicability is limited by the buoyancy of certain components of the phytoplankton (Margalef, 1971).

Ferguson-Wood (1962) describes a quantitative method involving the filtration of 5 litre of water sample through a continuous centrifuge. The material concentrated in 10 ml is stained with acridine orange and examined under ultra-violet light in a petroff-Hauser bacterial counting chamber. A quantitative transfer of the concentrated phytoplankton to a counting chamber can be made, providing that certain precautions are taken (Lund and Talling, 1957). Mulligan and Kingsbury (1968) have demonstrated that the centrifugation technique is 90% effective in removing phytoplankton in general and only 5-10% efficient in bringing down particles of 2-4 μ diameter. The errors inherent in the use of haemocytometers and other counting chambers have been considered in detail by Lund and Talling (1957) and by Lund, Kipling and le Cren (1958). Replicate series of counts were always found to show significantly different deviations, probably owing to the large size of some organisms, haemocytometers being devised for small cells (Lund, Kipling and Cren, 1958). McNabb (1960) states that the use of such chambers yields inconsistent results due to the non-random distribution of organisms on the mounts. Sub sampling errors are considerable and replicate series of counts must be made for a relatively precise estimate (Edmondson, 1971). The combined working depth of the liquid and the thick, optically flat cover-glass is such that immersion lenses cannot be used for critical examination (McNabb, 1960). In general, this method is more useful for cultures of algae than for natural populations (Lund and Talling, 1957).

The inverted microscope technique (Utermöhl, 1936; Lund, Kipling and Cren, 1958) has been widely used for the enumeration of samples sedimented with lugols solution. As some small plankton sink slowly, the sedimentation time in hours must be at least three times the height of the cylinder in centimetres (Margalef, 1971). Even allowing for this some colonial forms (especially Myxophyceae) were not sedimented in a reasonable time. *Oscillatoria erythraea* is an example of this and can neither be sedimented nor centrifuged when in the bloom stage (Ferguson-Wood, 1962). The practical disadvantages in this well-proven method lie in the space needed for the storage of sedimenting samples, the length of sedimentation time and the large number of cylinders which would have been required for the present study.

Partial filtration and re-suspension of the retained material in a small volume of water has been frequently used but separation of the organisms from the filter may be difficult in some cases (Margalef, 1971). Cole and Knight-Jones (1949) were apparently the first to describe the technique using membrane filtration in the enumeration of phytoplankton. The material retained by the filter was resuspended in 1 ml of water and then counted in 3 haemocytometers.

McNabb (1960) described a technique for the enumeration of fresh water phytoplankton concentrated on a molecular filter. Samples preserved with formalin (4 parts per 100 parts samples) were filtered through a millipore HA filter. Clearing the filter was carried out in immersion oil which replaced the water in the interstices of the filter in twenty-four hours at room temperature. Algae were found to be randomly distributed on the filter. Individuals of each species are not counted but are recorded by presence or absence in each field. The scoring of 30 random fields was stated to be sufficient for this procedure. The percentage frequency can be converted to the theoretical density according to the table given by the author. McNabb (1960) and Legendre and Watt (1972) demonstrated that the theoretical density closely approximates the actual density calculated from the more time consuming process of counting the number of individuals.

Holmes (1962) proposed a modification of McNabb's method, adding a staining step in which the filter and retained material was dehydrated with increasing of ethanol and finally stained in alcoholic fast green. The filter was cleared in xylene or beechwood creosote and preservation was generally good for diatoms, dinoflagellates and chrysophyceae while naked flagellates and thin wall diatoms were poorly preserved. In contrast with McNabb(1960) Holmes found that the organisms were non-randomly distributed on the filter. De Noyelles (1968) devised a modified procedure based on McNabb's method using a microfiltration unit through which 1 to 5 ml of samples were filtered. Phytoplankton on the filter surface were stained directly with aniline blue and eosine y, both stains being made up in aqueous solution. This treatment was said to slectively stain the cytoplasm, leaving the debris unstained. The filter was enumerated without clearing although an optional clearing step was included. The phytoplankton were randomly distributed on the filter and were enumerated either by scoring presence or absence or by direct counting of individuals.

Method

The membrane filtration technique of McNabb (1960) was used in the present study with a few modifications. Fresh samples rather than preserved ones were used, filtration being completed with a short time of sampling. The scoring of individuals by presence or absence suggested by McNabb gives an estimate of the actual density, called the theoretical density (Legendre and Watt, 1972) for the present study however algae were counted as numbers of individuals per field, a more time-consuming but more accurate process. Several types of immersion oil were compared for clearing efficient, the final choice being 'Uvinert' immersion oil.

The sample volume filtered was 250 ml (occasionally 100 ml) which was passed through a 25 mm diameter Millipore H.A. filter with a 0.45 μ per pore size. Clearing in 'Uvinert' immersion oil was complete in 24 hours at 25°C in the dark. After mounting on a slide the number of each organism in 30 random fields was counted. For full details see Appendix (ix).

A Nikon model LBR-Ke microscope was used throughout the investigation, for the identification of net-phytoplankton and the enumeration of organisms on filters. A x20 bright field objective was used for counting purposes (occasionally a x40 objective was used) while high power (x40) and oil immersion objectives were used, when necessary, for identification.

The number of algae per litre were calculated from the following equation (Edmondson, 1971; De Noyelles, 1968; McNabb, 1960):-

$$\text{No. of algae per litre} = \frac{\text{Area of filter x total count in 30 fields}}{\text{Total area of 30 fields x volume of sample in litres}}$$

McNabb (1960) and De Noyelles (1968) demonstrated that the distribution of phytoplankton on the filter was random. This was confirmed in the present investigation. The chi squared values calculated for 5 sets of 30 counts fell between 14.2 to 18.1. This indicates a high probability of the distribution being random ($p < 0.02$) (see Bishop (1971) Table (80)). The non-random distribution of organisms described by Holmes (1962) may have resulted from the redistribution of organisms during the dehydration and staining steps involved in this method.

The enumeration of organisms on the filter is subject to the same statistical requirement as the scanning of sedimented organisms with the inverted microscope (Margalef, 1971). The statistical basis of the counting procedure was considered in detail by Lund, Kipling and Cren (1958) who gave 95% confidence limit for various counts. This is applied to counts in the present investigation in the following table:-

Table 3. Size of count and accuracy for present investigation using x20 objective with 250 ml of sample filtered

Approximate 0.95 confidence limits			
No. of organisms counted	Cells/litre	Accuracy expressed as percentage of the count	Range
4	183	± 100%	0 - 366
16	733	± 50%	366 - 1100
100	4582	± 20%	3666 - 5498
400	18330	± 10%	16500 - 20164
1600	73323	± 5%	69657 - 76989

McNabb (1960) investigated the errors of the technique and stated that the sub sampling error and the difference between separate sets of enumeration from the same filter were not significant. This was confirmed by Legendre and Watt (1972). The counting procedure applies to complete organisms which may be cells, filaments or colonies. *Staurastrum*, *Peridinium*, *Ceratium* and *Cyclotella* were recorded as cells, *Melosira*, *Tabellaria fenestrata*, *Asterionella* and filamentous blue-green algae were recorded as chains, the total being multiplied by the mean number of cells per chain. The 95% confidence limits are applicable to these cases (Lund, Kipling and Cren, 1958), while larger, colonial algae, Fragilaria, Botryococcus, Coelosphaerium, Microcystis, Dinobryon, Dictyosphaerium and T. flocculosa were recorded as colonies.

The advantages of the technique of membrane filtration are considerable, a semi-permanent, easily stored filter retaining even the smallest organisms, in such a manner that they are randomly distributed, can be prepared for enumeration in 24 hours or less. On the other hand sedimentation takes several weeks for all the algae in 1 litre sample (de Noyelles, 1968) and makes no provision for the easy preparation of a permanent slide. The recent split-tube technique (Evans, 1972) partially overcame this problem, allowing the counting chamber to be covered and stored. Living and dead phytoplankton are easily distinguished by their natural pigmentation even after periods in excess of 22 months (McNabb, 1960). Furthermore there is no problem with buoyant phytoplankton or nanoplankton, the latter being easily identified using oil immersion lens. Various organisms and groups of organisms respond differently to the treatment but generally the following groups are very well-preserved: Bacillariophyceae, Dinophyceae, Chrysophyceae, Cyanophyceae and Chlorophyceae.

CHAPTER 3

RESULTS

(1) Orthophosphate Phosphorus

(a) Loch Lomond

Loch Lomod is generally low in phosphate. For most of the year the concentration at all depths sampled was less than 0.2 μg at. P/l., with the exception of South Balmaha, the only lowland station. The changes in phosphate concentration follow the general pattern of nutrient cycling with high levels in winter and low levels in summer. This pattern is very clear in the South Station (see Figure 2 and Appendix Table 1), which displayed marked summer minima of 0.02 μg at. P/l. in both 1972 and 1973 and a prominent winter peak of 0.2 μg at. P/l. This represents a ten-fold range between maximum and minimum values of orthophosphate.

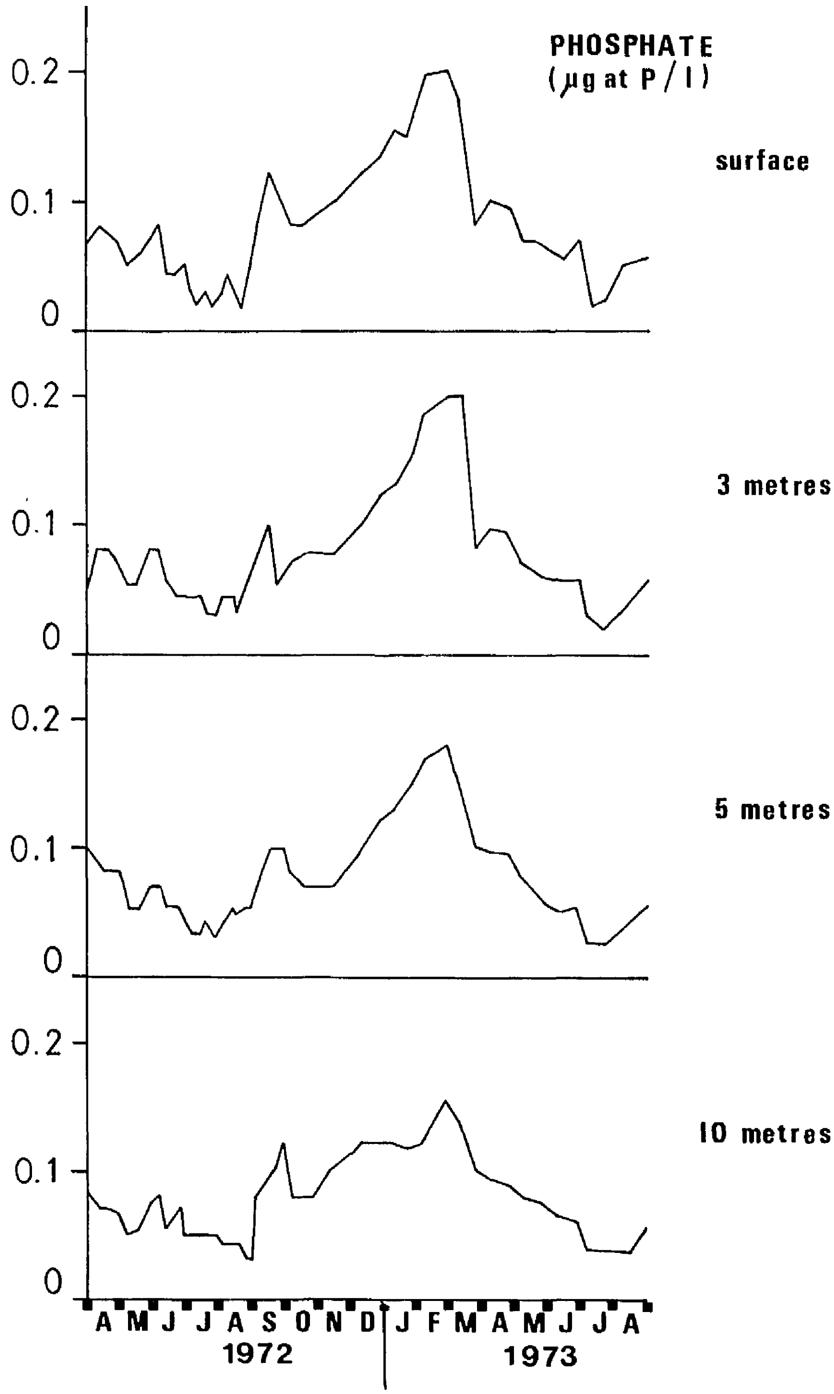
The minimum spring value at the South Station in 1972 occurred on 4 May when levels of phosphate fell to around 0.05 at surface and depth. This level remained till 17 May after which a small increase was apparent at all levels reaching a maximum at the surface of 0.08 μg at. P/l on 5 June, 1972. A decline followed with levels fluctuating slightly, to reach a minimum of 0.02 μg at. P/l. at the surface on 10 July. Phosphate values at 3 m and 5 m depth were also reduced reaching a minimum at both levels of 0.03 μg. at. P/l. on 26 July while the minimum level at 10 m (0.03 μg at. P/l.) was not reached until 22 August, 1972.

Surface concentration of phosphate fluctuated between 0.02 to 0.04 μg at. P/l. until 22 August after which levels suddenly increased to give a significant peak at surface, 3 m and 5 m (0.12, 0.10, 0.10 μg at. P/l. respectively) on 12 September. This was followed a week later by a similar increase at 10 metres depth. A decline in phosphate level followed with a level of 0.07 μg at. P/l. being reached at 5 m depth towards the end of October.

The winter increase started in November and attained maximum level in February when phosphate concentrations were 0.2, 0.2, 0.18 and 0.16 μg at. P/l. at surface, 3 m, 5 m, and 10 m respectively. The rapid downward trend started

LOCH LOMOND SOUTH BASIN

Fig 2



at the beginning of March, falling to a spring minimum at surface and 3 m of 0.08 μg at. P/l. at the end of March. A more gradual phosphate reduction at 5 m and 10 m depth gave a final concentration of 0.1 μg at. P/l. Phosphate levels declined again from 12 April to the beginning of May, surface, 3 m and 5 m depth showing similar rapid reduction to about 0.06 μg at. P/l. while the downward slope at 10 m was less steep (0.09 to 0.075 μg at. P/l.). The subsequent plateau in phosphate concentration terminated at the end of June when levels of this nutrient dropped to trace level (0.02 μg at. P/l.) at surface and 3 m. Phosphate remained almost undetectable till the end of July when a corresponding increase at all depths raised levels to around 0.06 μg at. P/l. During the summer months the phosphate concentrations at 10 m depth were higher than the surface while during the winter the reverse obtained.

The pattern of variation in the Middle Station of Loch Lomond (see Fig. 3 and Appendix Table 2) exhibits some similar features to the South Station. The 1972 spring minimum (0.04 μg at. P/l.) occurred at the surface and 3 m on 27 April following a steep decline in phosphate levels. A similar decrease at 5 m and 10 m resulted in concentrations of 0.055 and 0.065 μg at. P/l. respectively. This was followed during May by an increase in phosphate concentration to a level not exceeding 0.08 μg at. P/l. at surface and 0.085 at 10 m. The subsequent decline to a summer minimum reduced phosphate to 0.04 μg at. P/l. during July, a level which was maintained till the beginning of September.

The striking increase which occurred at the beginning of September occurred at all depths reaching a maximum of 0.11 at surface, 0.1 at 3 m and 5 m and 0.095 μg at. P/l. at 10 m. This upward trend of nutrient concentration was coincident with the September increase in the North and South Station. By 25 October levels had dropped to an autumn minimum of 0.07 μg at. P/l. at surface, 3 m, 5 m and 10 m respectively (on 15 February). Thus the maximum quantity of phosphate is greater than that of the North and less than that of the South Station.

A spring minimum occurred on 28 March, 1973 when phosphate concentration

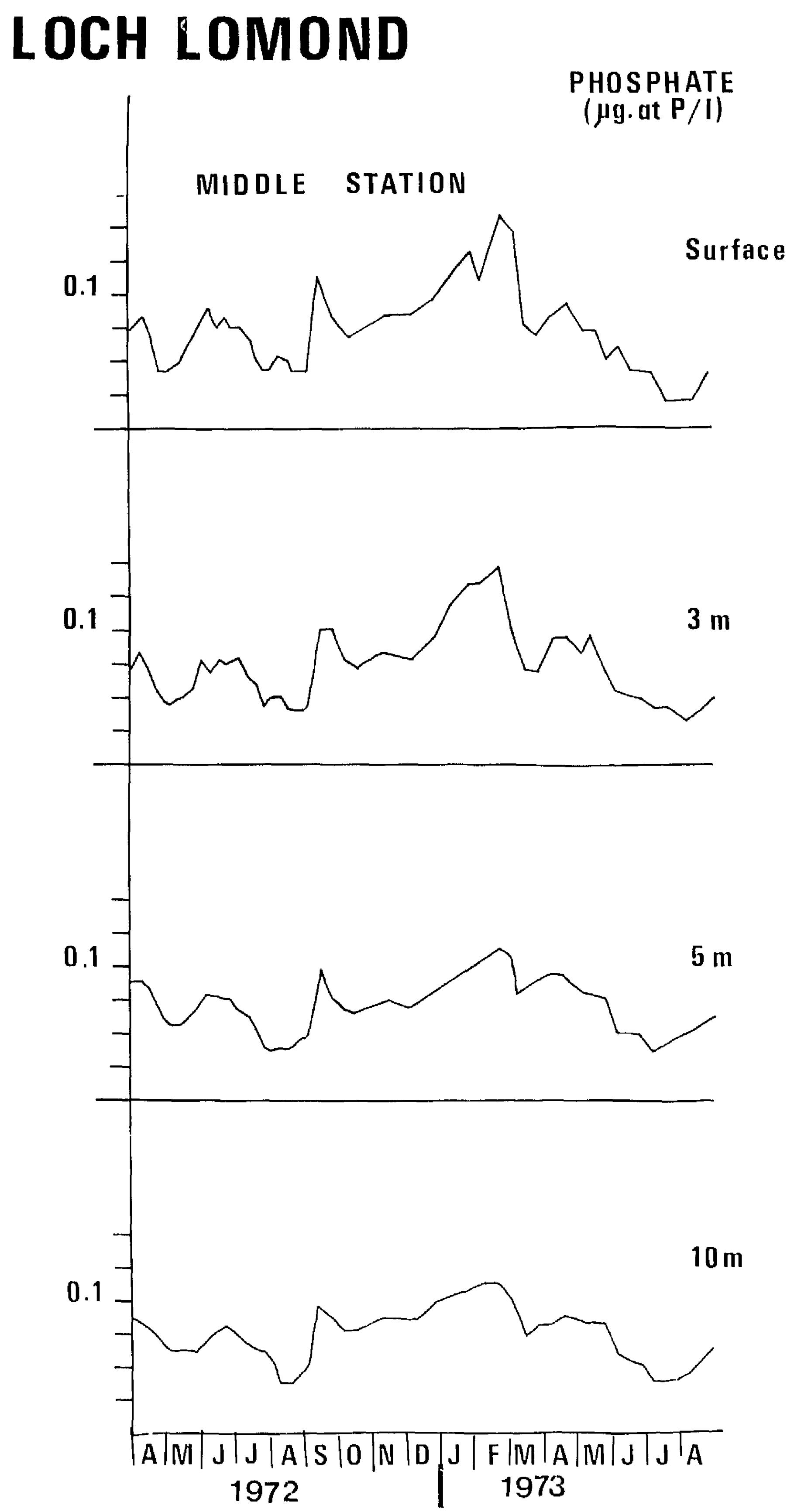

LOCH LOMOND
PHOSPHATE
(µg. at P/l)
MIDDLE STATION
Surface
0.1
3 m
0.1
5 m
0.1
10m
0.1
A M J J A S O N D J F M A M J J A
1972
1973

Fig 3

plunged to 0.065 μg at. P/l. at surface. A small increment in nutrient levels occurred towards the end of April when phosphate did not exceed 0.09 μg at. P/l. at any depth. Depletion to nearly undetectable levels (0.02 μg at. P/l.) was reached during July. The summer minimum on 24 July, 1973 was half that of the previous year, when levels of 0.04 μg at. P/l. was recorded at all depths. The winter maximum in 1973 decreased from surface to depth (10 m) whereas the summer minimum showed the reverse gradient.

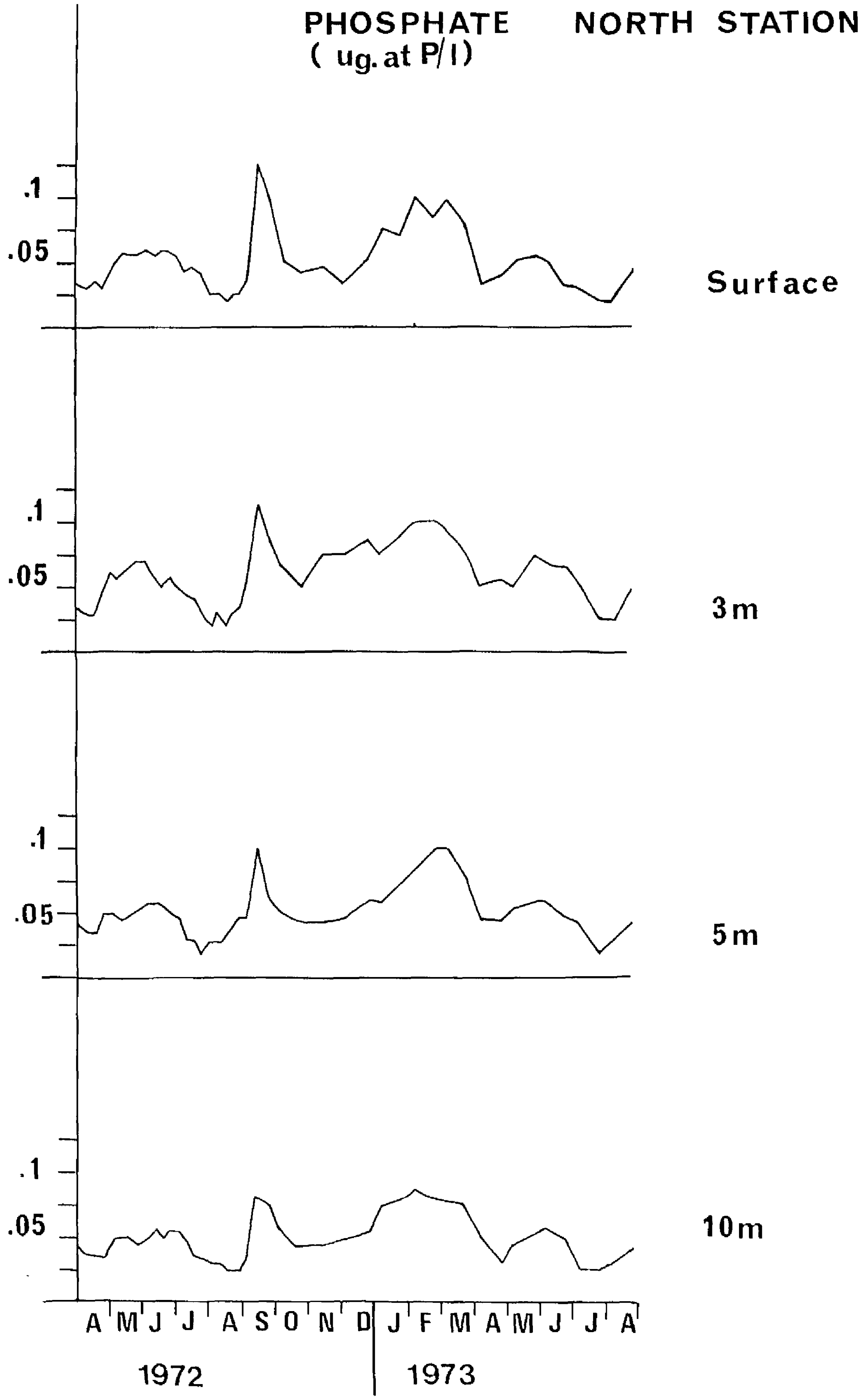
In the North Station (see Figure 4 and Appendix Table 3) in 1972 a spring minimum was maintained throughout the month of April with phosphate concentration not descending below 0.03 μg at. P/l. This minimum was succeeded by a small increase in phosphate to a level not exceeding 0.07 μg at. P/l. at any depth on 5 June, 1972. These levels were maintained till the first week in July when the gradual downward course towards the summer minimum began. By 1 August phosphate was present in trace amounts at all depths (less than 0.03 μg at. P/l.); little change occurred until 12 September when a simultaneous, abrupt increase in phosphate concentration took place at all depths, reaching a maximum of 0.125 μg at. P/l. at the surface, declining to 0.08 at 10 m depth.

A steep fall in phosphate levels during the ensuing weeks reduced the quantity of phosphate to trace level on 25 October. These levels persisted with small variations till the end of December, 10 m depth concentrations being higher than surface concentrations throughout this period.

The winter increase began on 4 January and attained its maximum on 1 February when phosphate was present at a concentration of 0.1 μg at. P/l. at surface and 3 m depth. A rapid fall in nutrient levels resulted in a vernal minimum on 12 April when the surface concentration was 0.035 μg at. P/l. The small phosphate increase following this minimum raised levels to between 0.05 to 0.075 μg at. P/l. on 24 May. The subsequent decline in phosphate concentration began a month later (24 June) at the surface followed (on 6 July) by a decrease at all depths, reaching almost undetectable levels

LOCH LOMOND

Fig 4



24 July.

The summer phosphate minimum in the north was the same in 1972 and 1973 but was reached earlier in the former year. Although phosphate levels were generally higher in winter than in summer the abrupt increase in September, 1972 resulted in concentrations exceeding the winter maximum at surface and 3 m depth. Comparisons between the other two stations so far described, show that the winter maximum was lower in the North than in the Middle which in turn was lower than the South Station. The winter maximum was reached earlier in the North.

The results from the North Inversnaid station (Table 4) show that the ~~su~~ sudden phosphate increase during September occurred concurrently with that of other stations in Loch Lomond. Maximum levels reached on 12 September were 0.214 at surface and 0.185 µg at. P/l. at 3 m depth recorded. Following on this nutrient peak, levels fell to around 0.1 µg at. P/l. at the surface and 3 m depth on 11 October. The winter nutrient increase commenced towards the end of November attaining a summit on 4 January (0.161 µg at. P/l. at surface and 0.130 µg at. P/l. at 3 m depth). A sustained downward slope then foll-owed till the surface and 3 m depth concentration reached almost undetectable levels (0.02 to 0.01 µg at. P/l.) on 12 April. After these low phosphate values the levels fluctuated until a sudden peak occurred on 24 June reaching 0.126 at the surface and 0.133 µg at. P/l. at 3 m depth. By the 24 July the quantity of phosphate had declined to 0.02 µg at. P/l., subsequently rising to a high value of 0.146 at surface and 0.093 µg at. P/l. at 3 m depth on 17 August, 1973.

The North Falloch station (see Table 4) exhibited a larger September increase than North Inversnaid station reaching 0.22 µg at. P/l. After this came an abrupt drop in phosphate concentrations descending to around 0.026 µg at. P/l. on 4 January at surface and 0.05 µg at. P/l. at 3 m depth. The maximal winter levels were observed on 1 February, these being 0.1 and 0.13 µg at. P/l. at surface and 3 m respectively. The spring minimum occurred at surface and 3 m on 12 April when only trace levels were recorded. Irreg-

Table 4.

	Phosphate (µg. at.-P/l.)						Silicate (µg. at./l.)					
	South Balmaha		North Inversnaid		North Falloch		South Balmaha		North Inversnaid		North Falloch	
Date	Surface	3 m	Surface	3 m	Surface	3 m	Surface	3 m	Surface	3 m	Surface	3 m
8. 8.72	0.05	0.06	-	-	-	-	5.2	5.3	-	-	-	-
15. 8.72	-	-	0.071	0.077	0.084	0.098	-	-	9.01	9.64	9.86	9.64
6. 9.72	0.287	0.28	-	-	-	-	5.53	5.4	-	-	-	-
12. 9.72	-	-	0.214	0.185	0.221	-	-	-	8.05	8.14	9.41	9.14
11.10.72	-	-	0.101	0.095	0.05	0.06	-	-	9.04	9.4	9.1	9.2
25.10.72	0.063	0.1	-	-	-	-	5.98	6.1	-	-	-	-
23.11.72	0.082	0.101	0.13	0.11	0.05	0.06	11.27	11.16	11.3	11.2	11.3	11.3
7.12.72	0.12	0.13	0.12	0.11	0.066	0.07	13.8	13.2	13.69	14.3	13.41	12.8
21.12.72	0.28	0.29	-	-	-	-	18.3	18.8	-	-	-	-
4. 1.73	0.23	0.24	0.161	0.13	0.026	0.05	21.3	21.4	15.88	14.6	14.64	13.5
17. 1.73	0.26	0.23	-	-	-	-	23.3	22.4	-	-	-	-
1. 2.73	-	-	0.12	0.15	0.1	0.13	-	-	14.92	14.3	14.55	14.22
15. 2.73	0.31	0.30	-	-	-	-	25.3	24.6	-	-	-	-
1. 3.73	-	-	0.083	0.08	0.069	0.09	-	-	14.91	14.1	15.54	15.1
15. 3.73	0.11	0.16	0.055	0.043	0.065	0.05	21.93	20.8	14.69	13.8	15.26	15.6
28. 3.73	0.07	0.05	-	-	-	-	19.17	-	-	-	-	-
12. 4.73	0.13	0.12	0.02	0.01	0.01	0.039	8.52	8.6	13.33	12.68	14.48	13.32
26. 4.73	0.146	0.13	0.079	0.139	0.039	0.052	16.8	15.9	14.46	15.2	14.46	13.06
24. 5.73	0.073	0.093	0.046	0.079	0.066	0.079	15.99	16.53	15.85	15.76	15.99	15.31
7. 6.73	0.087	0.058	0.019	0.046	0.058	0.058	10.83	11.52	13.26	-	13.39	13.01
24. 6.73	0.06	0.05	0.126	0.133	0.126	0.113	5.32	5.85	5.9	5.03	5.64	5.7
6. 7.73	0.04	0.03	0.05	0.06	0.05	0.06	5.2	5.1	4.6	4.8	4.3	4.5
24. 7.73	0.05	0.06	0.02	0.03	0.03	0.02	2.3	2.4	3.2	3.3	3.2	3.8
2. 8.73	0.063	*0.093	0.079	0.039	0.086	0.099	3.28	2.08	6.64	6.69	6.81	6.47
17. 8.73	0.146	0.10	0.146	0.093	0.106	0.106	5.0	5.06	6.58	6.62	7.79	7.6

ular nutrient changes followed until 24 June when a sudden increase coincident with that of North Inversnaid took place. Here the phosphate level reached 0.126 at the surface and 0.113 μg at. P/l. at 3 m depth. During the subsequent summer depression phosphate levels fell to 0.02 μg at. P/l. on 24 July. By the 17 August phosphate was on the increase with concentrations reaching 0.146 μg at. P/l.

The South Balmaha station (Table 4) shows a large upsurge in phosphate concentration between the 8 August (0.05 μg at. P/l.) and 6 September, 1972 (0.287 μg at. P/l.) at the surface. This increase in phosphate levels occurred a week earlier and was greater than the similar increase which occurred throughout the loch in September. The late autumn decline reduced levels to 0.06 μg at. P/l. at the surface on 25 October. The highest winter values were recorded on 15 February when phosphate levels increased to 0.31 μg at. P/l. By 28 March the quantity of phosphate had decreased reaching 0.05 at 3 m and 0.07 μg at. P/l. at surface; this coincided with spring minimum in the South and Middle stations. A peak of 0.146 μg at. P/l. was attained at the surface on 26 April. A gradual decline followed with the phosphate values reducing to 0.04 μg at. P/l. at surface on 6 July, 1973. The paucity in phosphate was maintained till the beginning of August when an upsurge in the nutrient took place, raising the levels to 0.146 μg at. P/l. at surface and 0.10 μg at. P/l. at 3 m depth.

The annual range of phosphate concentration is greater at South Balmaha station (0.04 to 0.31) than at any other station in Loch Lomond. The range at the surface decreases from South Balmaha (0.27) to the South Station (0.18), decreases still further to the Middle Station (0.14) reaching a minimum at the North Station (0.11), continuing n orthward the range increases to North Inversnaid (0.19) and further still to North Falloch (0.21).

The annual minimum of phosphate at each station shows a progressive decrease from the most southerly station in Loch Lomond (0.04 μg at. P/l.) to the most northerly (0.01 μg at. P/l.). The annual maximum at the surface is greatest at the most southerly station, South Balmaha, where a peak of 0.31 μg at. P/l. was recorded. The peak was less at South Station (0.20 μg at. P/l.) decreasing still further to the Middle Station (0.16 μg at. P/l.) with the lowest annual maximum being recorded at the North Station (0.12 μg at. P/l.); passing northward the maximum phosphate values increases to 0.214 at North Inversnaid station, a value which was just exceeded by North Falloch station where 0.22 μg at. P/l. was recorded.

Typically the pattern of seasonal variation at depth resembles that at the surface although there may be a brief lag, not exceeding a week between them. The magnitude of the changes is reduced at depth, giving the curves a smoother, more regular outline.

The winter maximum is reached concurrently in the North, North Inversnaid, and North Falloch Stations on 1 February, 1973, while the winter peak in the remaining stations Middle, South and South Balmaha is reached a fortnight later (15 February, 1973).

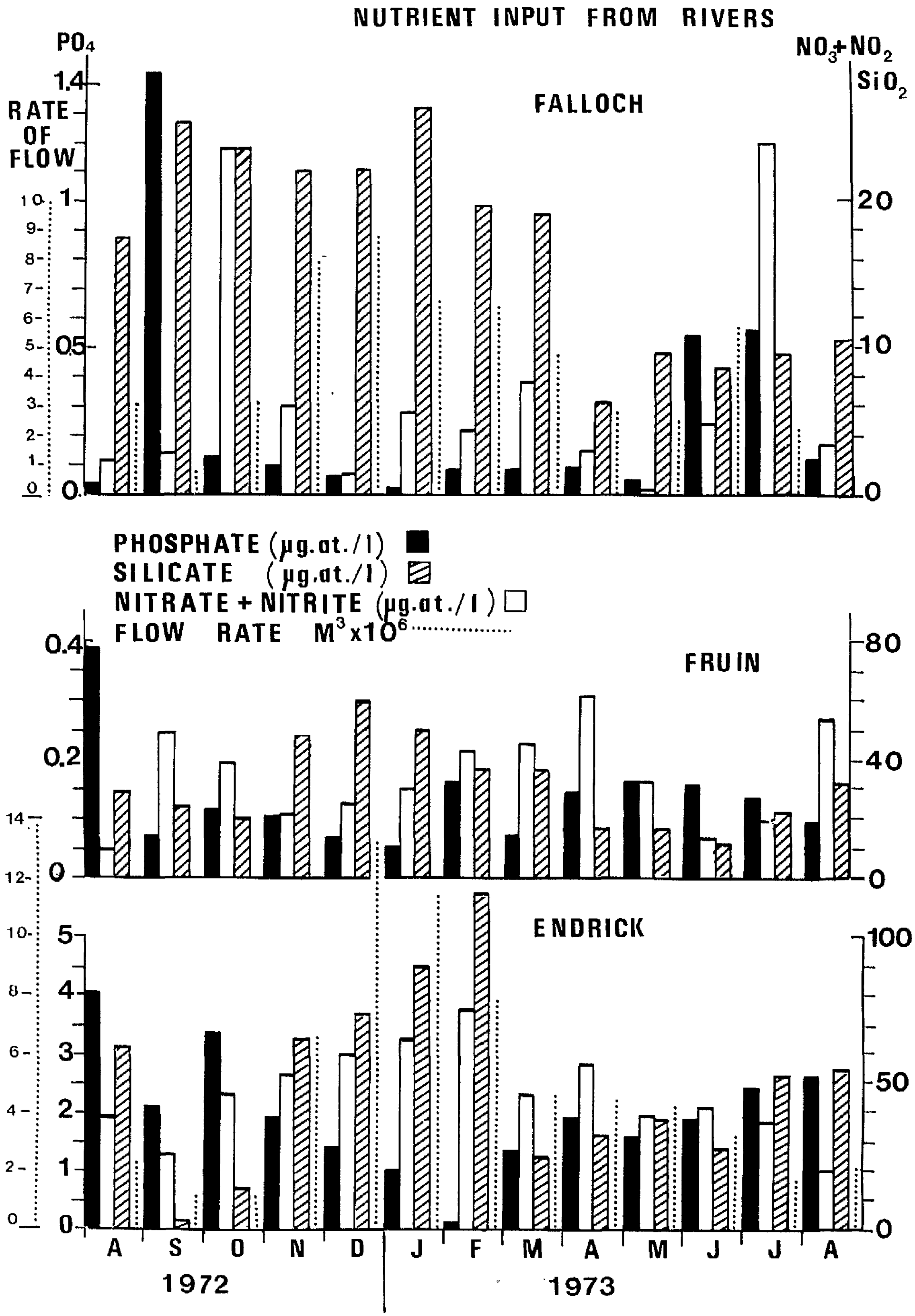
In 1972 the minimum phosphate level at the surface occurred on 10 July at South Station. The summer minimum at the Middle Station was found on 26 July while the lowest level in the North Station was not evident till 15 August. In 1973 the summer minimum at South Balmaha and South Station occurred on 6 July while the other four stations displayed minimal levels on 24 July.

(b) Rivers and burns flowing into Loch Lomond

In contrast to the Loch itself the phosphate levels in the inflows (see Tables 5, 6 and 7 and Figures 5, 6 and 7) were irregular and varied, ranging from an extreme concentration of 4 μg at. P/l. in the River Endrick (8 August, 1972) to trace levels found occasionally in the Falloch and several of the small burns. It is evident that on 8 August, 1972 phosphate levels were generally high in the rivers and burns south of Inverbeg bar; the Fruin, Finlas, Douglas Water and Blair Burn having values of 0.39, 0.35, 0.49 and 0.38 μg at. P/l. respectively. However, in some of the smaller inflows in this region the level ranged from 0.189 and 0.15 μg at. P/l. in Cashell and Coille Mhor Burn to 0.08 in Coille Mhor Loch water and Luss.

LOCH LOMOND

FIG 5



The lowest phosphate value recorded on this date was 0.02 μg at. P/l. in the Ardess burn while the Endrick showed the highest value for any inflow during the entire year - 4.04 μg at. P/l.

On 15 August the inflows contributing to Loch Lomond, north of the Inverbeg bar were examined and phosphate was found to be generally lower than in inflows to the south. The maximum concentration of phosphate was recorded in the Inversnaid Water (1.25 μg at. P/l; all other streams except for Cailness (0.54 μg at. P/l.) having levels below 0.1 μg at. P/l. (Falloch, Inveruglas, Rubha Ban, AlltArdvorlich, and Stuckindroin).

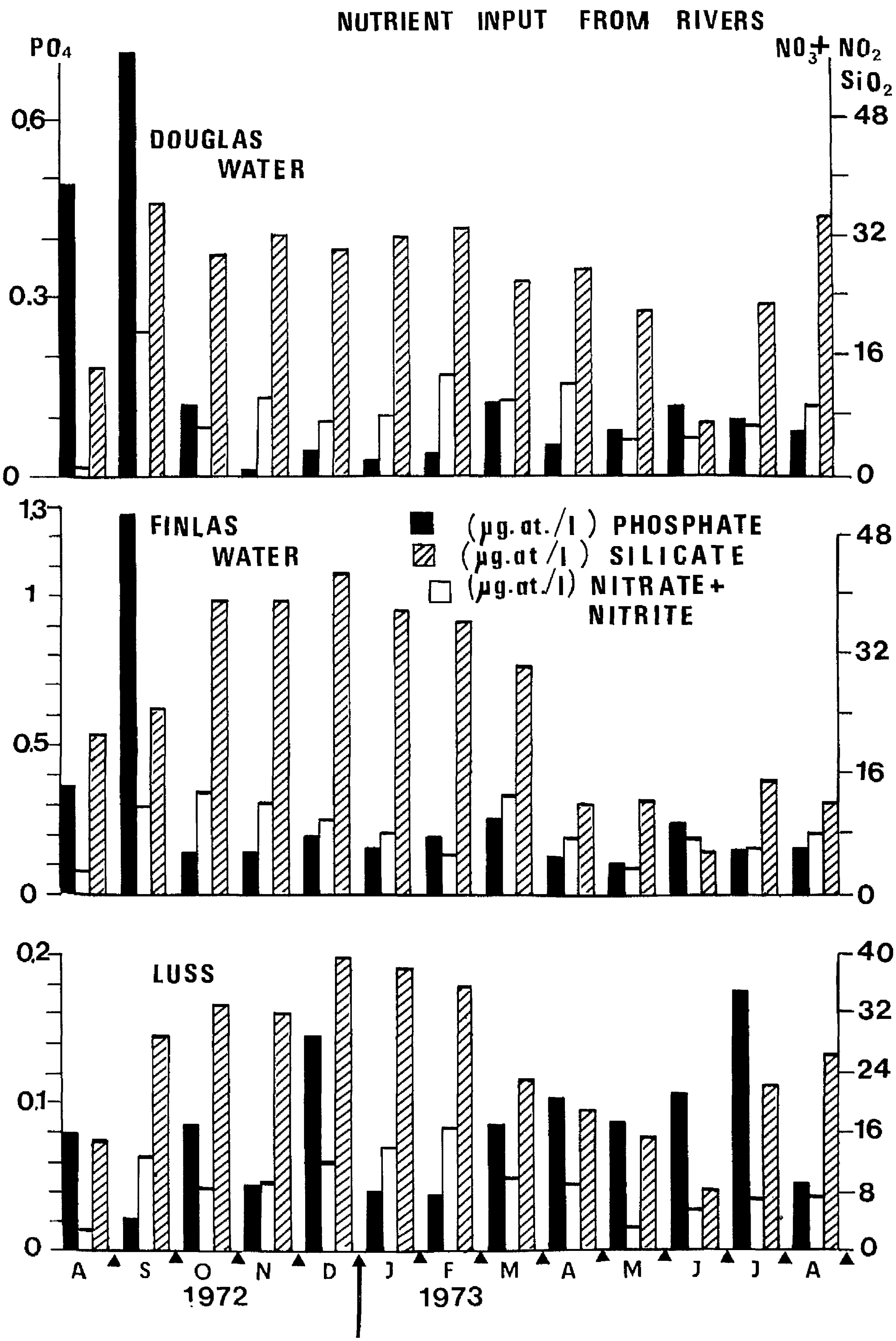
On 6 September, 1972 when the rivers below the Inverbeg bar were sampled, the Endrick still showed a noticeably higher concentration of phosphate than the other inflows. The Finlas had increased by four-fold reaching its maximum level for the year of 1.27 μg at. P/l.; Douglas Water and Coille Mhor Burn increased to 0.728 and 0.18 μg at. P/l. respectively. Cashell and Blair Burns remained at the same level while the Fruin, Luss and Ardess Waters all showed reductions to 0.07, 0.02 and 0.014 μg at. P/l. respectively.

The rivers and burns above the Inverbeg bar all showed prominent increases on 12 September except for the Inversnaid Water which declined to 0.264 μg at. P/l. The River Falloch showed a remarkable 25-fold increase reaching its maximum recorded level of 1.43 μg at. P/l. AlltArdvorlich Burn showed a 30-fold increase reaching its recorded maximum of 1.882 μg at. P/l. and the nearby Stuckindroin Burn exhibited a ten-fold increase to 1.06 μg at. P/l. The Inveruglas water displayed a three-fold increase whereas Cailness and Rubha Ban doubled in phosphate concentration reaching 1.92 and 0.182 μg at. P/l. respectively.

All seventeen rivers and burns flowing into Loch Lomond were sampled on 11 October and then south of the Inverbeg bar were examined again on 25 October, 1972. The data indicate that nearly all the rivers and burns which showed marked increases in phosphate in September were now drastically reduced while those inflows which decreased in September showed an upward

LOCH LOMOND

FIG 6



trend in October. The Falloch and Cailness inflows both show a large reduction in phosphate level, 0.126 and 0.05 µg at. P/l. respectively, while Ardess and Luss Water display phosphate increase to 0.183 and 0.113 µg at. P/l. respectively.

The examination of all rivers and burns on 23 November indicated that phosphate levels were further diminished. In general quantities of phosphate were less than 0.14 µg at. P/l. although Endrick exhibited its usual high level (1.9 µg at. P/l.).

On 7 December the inflows to the north of Inverbeg bar were examined while on 21 December the inflows to the south were investigated. The variation in phosphate level showed no consistant pattern. However, Luss Water showed a distinct increase to 0.145 µg at. P/l. whereas Rubha Ban reached its lowest recorded level - 0.02 µg at. P/l.

An investigation of all the inflows on 4 January, 1973 clearly showed that a general decline in phosphate concentration had taken place. The Endrick, Finlas and Ardess were reduced to 1.0, 0.125 and 0.13 µg at. P/l. respectively, all other inflows to the loch were less than 0.1µg at. P/l. with Falloch, Douglas and Inversnaid input reaching almost undetectable levels. During the first two weeks of February all inflows were examined and a slight upward trend was apparent in most. The Endrick, however, showed a small decline in phosphate concentration to reach its lowest recorded level of 0.096 µg at. P/l.

On 1 March rivers and burns to the north of Inverbeg bar were sampled; on 15 March all inflows were examined and on 26 March most of the inflows were examined. In general the main inflows to the Luss and Fault basins (Endrick, Fruin, Luss, Finlas and Douglas) were higher in phosphate than in February whereas the major inflows to the upper loch (Falloch, Inveruglas, Inversnaid and Cailness) showed insignificant increases. However, two small burns inflowing to the upper loch increased markedly; Rabha Ban reached its maximum level (0.97 µg at. P/l.) and Ardess rose to 0.21 µg at. P/l. In contrast Stuckindroin, Allt Ardvorlich and Blair burn were reduced

LOCH LOMOND

FIG 7

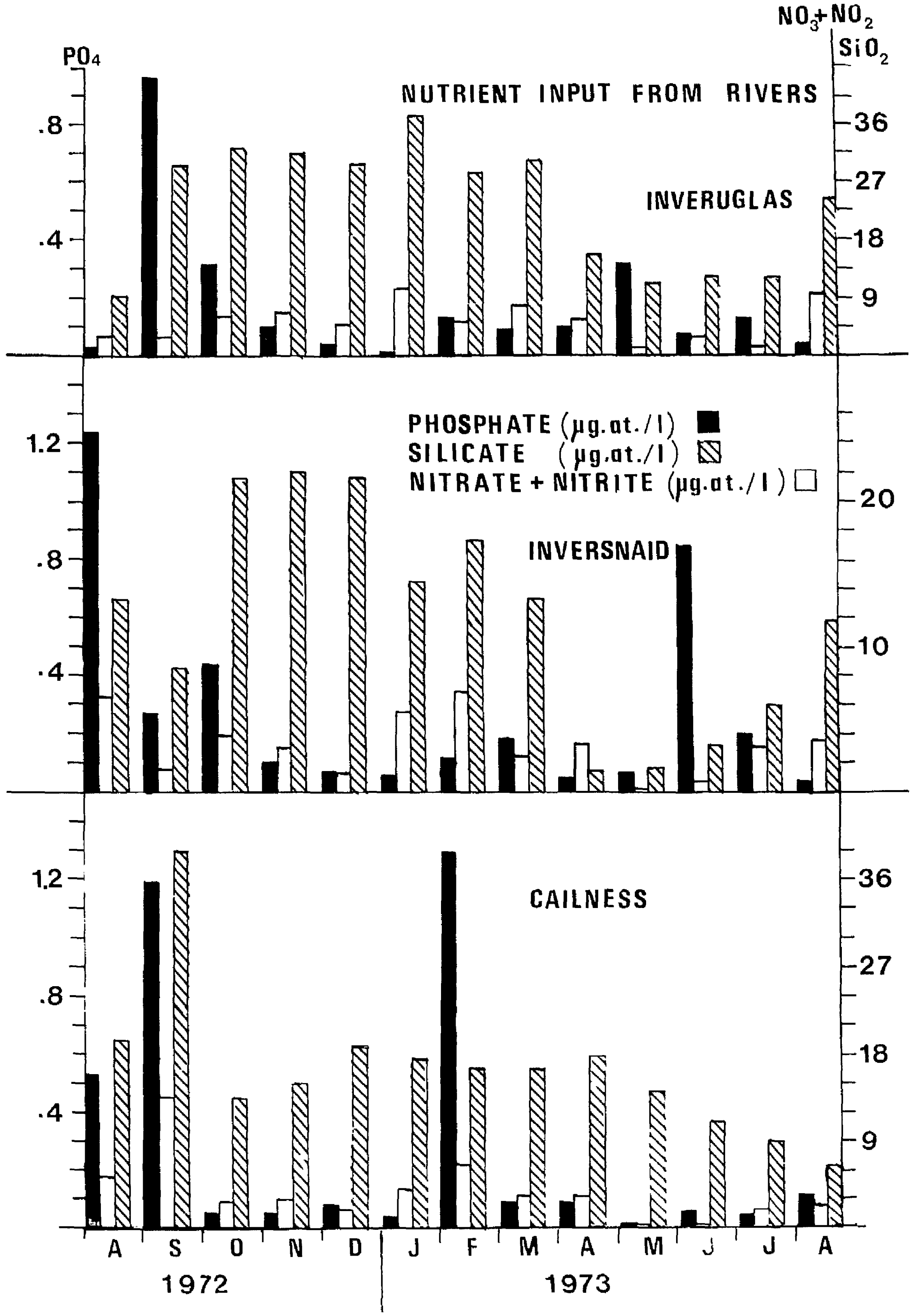


Table 5. Phosphate (μg. atom P/l) of the rivers and streams inflowing to Loch Lomond.

Date	Endrick	Fruin	Luss	Finlas	Douglas	Falloch	Inveruglas	Inversnaid	Cailness	Coille Mhor Burn	Cashell	Rubha Ban
8. 8.72	4.04	0.39	0.08	0.35	0.494	-	-	-	-	0.15	0.189	-
15. 8.72	-	-	-	-	-	0.049	0.035	1.24	0.535	-	-	0.091
6. 9.72	2.1	0.07	0.021	1.27	0.728	-	-	-	-	0.18	0.182	-
12.99.72	-	-	-	-	-	1.43	0.96	0.262	1.19	-	-	0.182
11.10.72	3.27	0.107	0.113	0.10	0.12	0.126	0.303	0.442	0.05	0.126	0.164	0.189
25.10.72	3.28	0.126	0.063	0.17	-	-	-	-	-	-	0.113	-
23.11.72	1.9	0.101	0.044	0.139	0.019	0.1	0.1	0.1	0.05	0.025	0.025	0.07
7. 2.72	-	-	-	-	0.04	0.052	0.040	0.067	0.08	-	-	0.02
21.12.72	1.415	0.06	0.145	0.199	-	-	-	-	-	0.042	0.054	-
4. 1.73	1.0	0.05	0.04	0.125	0.025	0.013	Trace	0.059	0.048	0.08	0.03	0.052
1. 2.73	-	-	-	-	-	0.08	0.14	0.11	0.14	-	0.077	0.07
15. 2.73	0.096	0.158	0.038	0.193	0.038	-	-	-	-	0.064	0.077	-
1. 3.73	-	-	-	-	-	0.139	0.125	0.11	0.181	-	-	0.97
15. 3.73	1.32	0.139	0.083	0.432	0.09	0.041	0.112	0.251	0.048	0.076	0.11	0.12
26. 3.73	1.32	0.03	0.09	0.07	0.15	0.08	0.03	-	0.048	0.03	Trace	-
12. 4.73	1.59	0.13	0.026	0.13	0.01	Trace	0.01	0.026	0.026	-	0.01	0.026
26. 4.73	2.39	0.152	0.199	0.199	0.09	0.199	0.199	0.079	0.133	0.186	0.192	0.146
10. 5.73	2.32	0.152	-	-	0.11	-	-	-	-	0.059	-	-
24. 5.73	0.85	0.184	0.086	0.099	0.046	0.046	0.312	0.062	0.013	0.059	0.066	0.079
7. 6.73	1.97	-	-	-	-	0.97	0.058	1.55	0.039	-	-	0.077
21. 6.73	1.72	0.159	0.106	0.239	0.106	0.095	0.106	0.186	0.113	0.119	0.106	0.113
6. 7.73	2.47	0.133	0.172	0.146	0.09	0.172	0.133	0.2	0.05	0.15	0.15	0.12
2. 8.73	2.73	0.093	0.046	0.15	0.07	0.119	0.046	0.033	0.113	0.20	0.22	0.079

Table 6. Chemical data for three inflows to Loch Lomond

	Coille Mhor Loch Water					AlltArdvorlich Burn					Ardess Burn	
Date	PO_4	SiO_2	p^H	NO_3+NO_2	$CaCO_3$	PO_4	SiO_2	p^H	NO_3+NO_2	$CaCO_3$	p^H	NO_3+NO_2
8. 8.72	0.08	12.3	6.1	6.4	3.0	-	-	-	-	-	6.2	10.3
15. 8.72	-	-	-	-	-	0.06	22.3	6.4	12.3	8.0	-	-
6. 9.72	0.18	25.0	6.0	18.3	2.5	-	-	-	-	-	6.4	12.24
12. 9.72	-	-	-	-	-	1.882	33.93	6.5	5.58	7.25	-	-
11.10.72	0.12	18.15	6.2	6.97	3.75	0.148	28.3	6.45	2.66	4.0	6.7	8.61
25.10.72	0.06	34.4	6.7	13.4	4.5	-	-	-	-	-	6.3	8.3
23.11.72	0.069	31.75	6.1	11.87	3.0	0.102	24.3	6.3	2.3	3.5	6.15	5.22
7.12.72	-	-	-	-	-	0.08	21.25	5.8	1.22	2.5	-	-
21.12.72	0.084	35.17	5.6	15.8	2.0	-	-	-	-	-	6.1	8.3
4. 1.73	0.14	32.3	5.4	17.2	1.5	0.065	25.62	5.8	3.27	3.0	5.6	12.3
1. 2.73	-	-	-	-	-	0.093	21.26	5.6	3.51	2.0	-	-
15. 2.73	0.335	30.88	5.65	16.98	3.25	-	-	-	-	-	5.7	15.0
1. 3.73	-	-	-	-	-	0.195	18.85	5.4	2.16	2.0	-	-
15. 3.73	0.094	33.65	6.3	20.01	6.0	0.096	28.54	5.8	4.37	2.5	5.6	10.53
28. 3.73	0.06	18.3	6.4	19.3	6.5	Trace	38.34	6.3	5.24	3.5	5.6	9.43
12. 4.73	0.01	5.96	6.4	16.3	6.5	0.01	2.77	6.7	5.3	4.2	5.6	10.3
26. 4.73	0.066	29.77	6.7	8.2	7.0	0.066	23.18	7.6	6.66	28.0	5.7	4.04
10. 5.73	0.053	22.3	6.4	5.6	4.0	0.067	22.1	7.0	4.32	12.5	5.4	6.54
24. 5.73	0.039	18.49	6.1	3.27	3.0	0.059	20.99	7.1	5.68	14.0	5.2	8.05
7. 6.73	-	-	-	-	-	0.058	32.58	7.6	1.13	40.0	-	-
24. 6.73	0.186	5.85	5.6	3.33	4.0	0.126	11.07	7.0	4.8	15.0	5.0	1.86
6. 7.73	0.186	6.4	5.6	3.5	4.0	0.039	22.78	7.2	5.11	18.00	5.0	6.34
24. 7.73	-	-	-	-	-	-	-	-	-	-	-	-
2. 8.73	0.093	9.3	5.8	3.67	4.5	0.099	31.95	7.4	10.24	32.0	5.2	9.2

Table 7. <u>Chemical data for three inflows to Loch Lomond</u>

	Blair Burn					Stuckindroin					Ardess Burn	
	PO_4	SiO_2	pH	NO_3+NO_2	$CaCO_3$	PO_4	SiO_2	pH	NO_3+NO_2	$CaCO_3$	PO_4	SiO_2
8. 8.72	0.379	20.08	6.1	0.045	7.0	-	-	-	-	-	0.02	18.3
15. 8.72	-	-	-	-	-	0.084	32.8	7.9	9.75	48.0	-	-
6. 9.72	0.21	39.97	6.5	14.3	6.0	-	-	-	-	-	0.014	5.02
12. 9.72	-	-	-	-	-	1.06	29.86	7.9	13.28	6.7	-	-
11.10.72	0.316	45.63	5.7	1.68	4.25	0.113	37.94	7.95	14.96	45.0	0.183	24.2
25.10.72	0.151	60.79	6.4	0.13	5.5	-	-	-	-	-	0.12	28.2
23.11.72	0.025	43.8	4.8	4.92	3.0	0.06	30.3	7.8	10.2	40.0	0.05	40.51
17.12.72	-	-	-	-	-	0.026	25.51	7.8	9.03	44.0	-	-
21.12.72	0.075	40.42	5.8	18.3	4.5	-	-	-	-	-	0.121	29.4
4. 1.73	0.06	45.8	5.6	25.4	4.0	0.032	28.9	7.5	10.67	23.0	0.13	28.3
1. 2.73	0.096	58.2	5.8	43.2	4.0	0.01	26.7	7.35	9.16	14.0	-	-
15. 2.73	0.096	115.0	5.9	75.88	3.0	-	-	-	-	-	0.077	25.56
1. 3.73	-	-	-	-	-	Trace	16.72	6.7	3.6	5.5	-	-
15. 3.73	0.083	42.6	5.4	2.02	2.0	0.041	31.3	7.5	11.12	23.0	0.11	23.04
28. 3.73	Trace	40.47	5.3	2.28	2.5	Trace	23.43	7.6	7.06	26.0	0.21	15.65
12. 4.73	0.01	2.33	5.3	2.0	2.0	0.093	18.31	7.7	9.2	28.0	Trace	5.94
26. 4.73	0.133	2.55	5.9	1.66	3.5	0.864	24.24	7.8	11.66	33.0	0.192	5.38
10. 5.73	0.039	15.08	5.2	1.6	3.0	0.23	14.3	6.9	8.5	10.0	0.039	1.36
24. 5.73	0.026	21.54	5.5	0.15	8.5	0.059	3.7	5.6	0.355	5.0	0.046	14.62
7. 6.73	0.058	21.3	5.0	9.56	3.0	0.097	15.29	7.8	0.25	80.0	-	-
24. 6.73	0.139	7.5	5.0	1.47	3.0	0.099	3.62	5.6	1.47	3.0	0.066	2.13
6. 7.73	0.16	8.3	5.1	3.4	3.5	0.066	6.81	6.1	0.58	3.5	0.12	8.6
24. 7.73	-	-	-	-	-	-	-	-	-	-	-	-
2. 8.73	0.23	6.3	5.8	14.2	6.5	0.06	23.2	7.4	5.3	22.0	0.47	27.15

to trace levels on 28 March. A high level of 0.43 μg at. P/l. was recorded in the Finlas water on 15 March while the Endrick remained constant at 1.32 μg at. P/l. and the Falloch was generally around 0.05 μg at. P/l.

During April samples were taken from all rivers and burns on 12 and 26 of the month. Results indicate that the inflows to the lower loch were still increasing in phosphate content. The Falloch and Inveruglas rose from almost undetectable phosphate concentration on 12 April to reach almost 0.2 μg at. P/l. on 26 April. Luss Water attained its maximum recorded level of 0.199 μg at. P/l.

Samples taken during May showed general reduction in phosphate content, the Endrick declined to 0.85 μg at. P/l. Nevertheless Fruin and Inveruglas showed peaks at 0.184 and 0.312 μg at. P/l. respectively while AlltArdvorlich increased to 0.06 μg at. P/l. from trace amounts.

In June samples were taken on 7 and 21 of the month. The Falloch showed a marked increase to 0.97 and Inversnaid Water reached its maximum recorded phosphate level of 1.55 μg at. P/l; the Endrick increased two-fold to 1.97 μg at. P/l. Data for July shows a further increase in Endrick, Luss and Falloch to 2.47, 0.172 and 0.172 μg at. P/l respectively and in most other inflows. A small reduction in phosphate levels was observed in Fruin, Douglas and Finlas. Samples taken on 2~~n~~August show only small fluctuations in phosphate concentration from the July values.

There are at least three generalizations which can be made concerning the seasonal variation in phosphate content in the inflows to Loch Lomond. First, in all the large inflows the level of phosphate is lower during the winter than at any other time of the year. Second, most major inflows showed prominent phosphate maxima during August and September including Endrick, Fruin, Finlas, Douglas, Falloch, Inveruglas and Inversnaid. The Falloch showed a second peak in June. Third, the phosphate level in the Endrick was typically higher than in any of the other rivers and burns investigated.

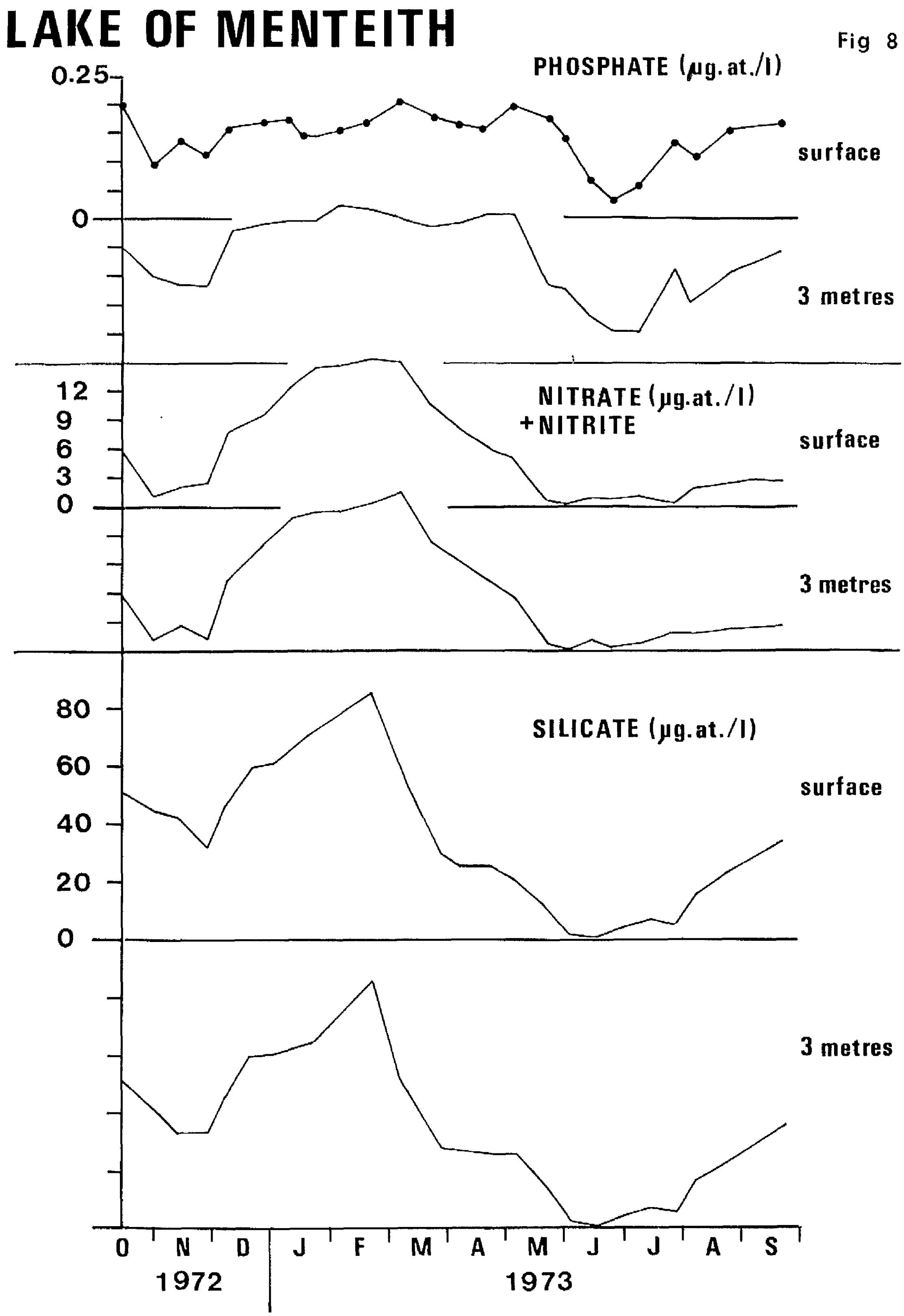
(c) The four lochs

(i) Lake of Menteith

The variation in the levels of dissolved phosphate (Figure 8 and Appendix Table 4) in Lake of Menteith shows a clear parallel between surface and 3 m depth. The winter maximum is higher at 3 m depth (0.274 µg at. P/l.), thus at the surface (0.2 µg at. P/l.) while the summer minimum is 0.05 µg at./P/l. at 3 m depth and 0.03 µg at. P/l. at the surface. The autumn minimum at 3 m depth followed a gradual decline in the quantity of phosphate from 0.19 on 18 October to 0.13 µg at.P/l. on 29 November, 1972; in contrast the surface minimum reached 0.093 µg at. P/l. on 1 November after a rapid decline. The winter increase started suddenly at 3 m depth on 13 December reaching a peak on 7 February, 1973 while the surface showed a gradual rise in phosphate attaining a maximum on 8 March.

The vernal minimum is clear at the surface where levels of dissolved phosphate declined to 0.15 µg at. P/l. on 20 April. This decrease is not clearly shown at depth although a slight dip occurred on 26 March. This was followed by an upward trend with surface phosphate reaching a concentration equal to that of the winter maximum (0.2 µg at. P/l.). A parallel increase took place at 3 m depth reaching a peak of 0.25 µg at. P/l. on the same date as the surface (3rd May, 1973).

A gradual decrease in phosphate at surface and 3 m took place from the beginning of May reaching minimum level on 28 June. The initial rate of decline at 3 m depth was greater than that at the surface with the phosphate concentration dropping from 0.25 on 3 May to 0.14 µg at. P/l. on 17 May. The subsequent increase in phosphate levels was more rapid at 3 m (0.053 to 0.159 µg at. P/l.) than at the surface (0.053 to 0.137 µg at. P/l.) attaining a maximum on 26 July. At the beginning of August a small depression occurred with the phosphate concentration falling to 0.107 and 0.10 µg at. P/l. at surface and 3 m respectively. This reduction was short-lived being followed by a steady increase at surface and depth to reach respective phosphate concentrations of 0.16 and 0.19 µg at. P/l. on 20 September.


LAKE OF MENTEITH
Fig 8
PHOSPHATE (µg.at./l)
0.25
0
surface
3 metres
NITRATE (µg.at./l)
+NITRITE
12
9
6
3
0
surface
3 metres
SILICATE (µg.at./l)
80
60
40
20
0
surface
3 metres
O N D J F M A M J J A S
1972
1973

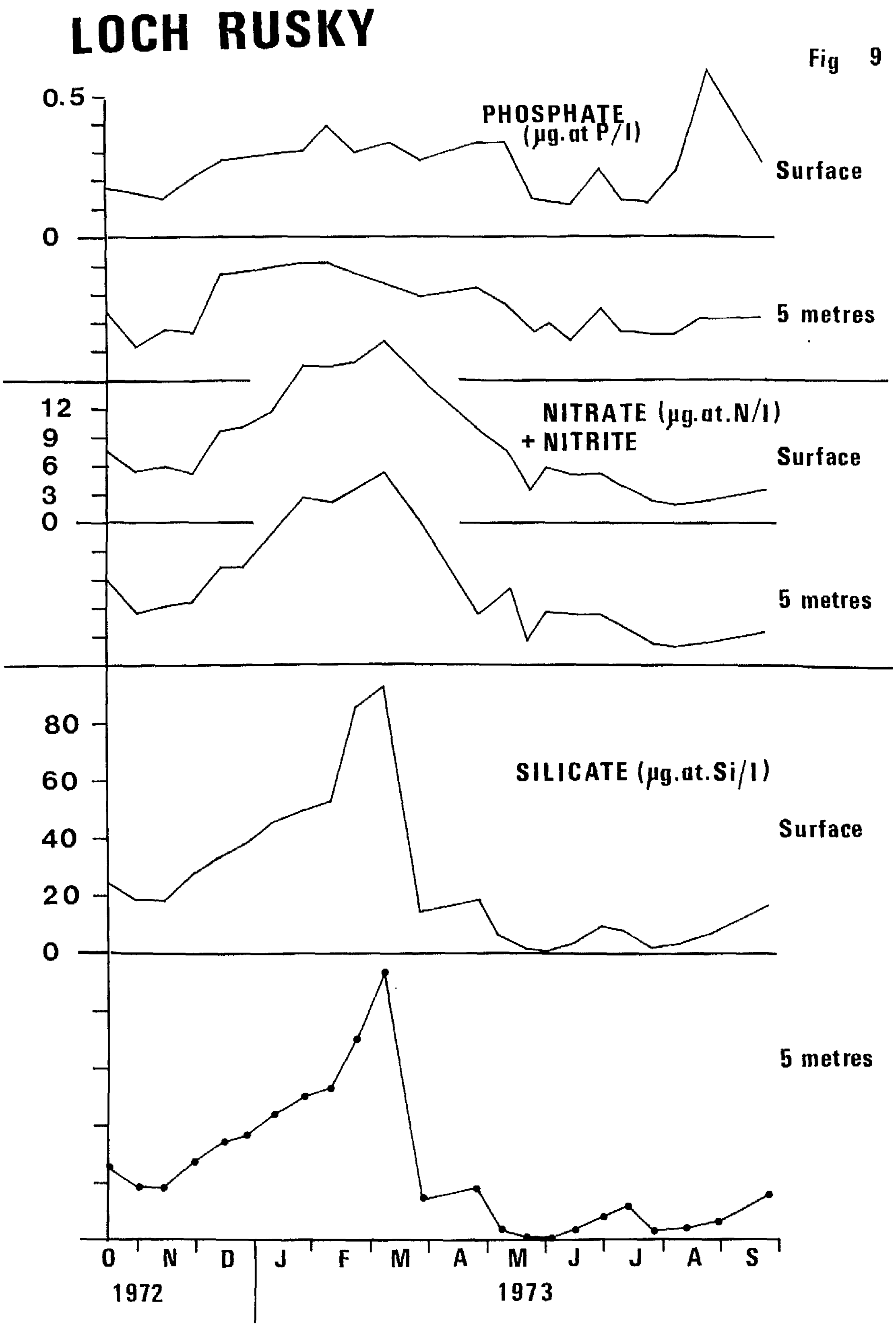
The phosphate level in the Burn of Menteith (Table 8(b) and Figure 4) was generally more than 0.1 µg at. P/l. The maximum recorded concentration was 0.85 µg at. P/l.) on 3 May while the minimum, 0.08 µg at. P/l., was found on 7 June. The only distinctive feature of the phosphate variation in the burn was that the content of this nutrient decreased towards the winter falling from 0.72 on 18 October to 0.14 µg at. P/l. on 24 January. Concentrations fluctuated around this level until 8 March when a steady rise in dissolved phosphate occurred, culminating in a peak of 0.85 on 3 May. A rapid decline in phosphate reduced levels to 0.15 µg at. P/l. on 17 May after which concentrations fluctuated between 0.1 and 0.2 µg at. P/l. until 11 July. The sustained increase in phosphate content following this period resulted in a concentration of 0.63 µg at. P/l. on 20 September, 1973.

Generally the phosphate levels at 3 m depth in Lake of Menteith were higher and the maximum range of phosphate concentration was greater (0.22) than those at the surface (0.17).

(ii) <u>Loch Rusky</u>

The phosphate content in Loch Rusky is generally higher than any station Loch Lomond or any of the other Lochs studied. There is (Figure 9 and Table 4) no clear pattern of seasonal variation could be observed. The surface shows an annual maximum on 23 August of 0.59 µg at. P/l. The pattern of phosphate variation at 5 metres is more regular with a distinct winter maximum on 24 January. However, there is no distinct relationship between surface and 5 m depth, the phosphate concentration being irregularly greater at one or the other. Occasionally, increases which are apparent at the surface are absent at 5 m depth, the large peak in August being a case in point.

The surface phosphate concentration showed a gradual increase from a minimum of 0.14 on 15 November to a winter maximum of 0.39 µg at. P/l. on 7 February. This is contrasted with an abrupt increase at 5 m depth from 0.16 to 0.36 µg at. P/l. between 29 November and 11 December followed by a slight gradient to reach a winter maximum of 0.41 µg at. P/l. The surface



LOCH RUSKY
Fig 9
PHOSPHATE (µg.at P/l)
Surface
5 metres
NITRATE (µg.at.N/l) + NITRITE
Surface
5 metres
SILICATE (µg.at.Si/l)
Surface
5 metres
0.5
0
12
9
6
3
0
80
60
40
20
0
O N D J F M A M J J A S
1972
1973

phosphate level then fluctuated around a value of 0.3 μg at. P/l. until 3 May when a very steep decline occurred. However, during this period the dissolved phosphate at 5 m depth declined steadily from 7 February until 14 June when the levels at surface and depth were 0.105 and 0.13 μg at. P/l. respectively.

On 28 June a small peak in phosphate occurred raising the level to 0.22 at surface and 0.25 μg at. P/l at depth. This was followed by a slight depression after which a dramatic rise in phosphate levels occurred at the surface to give a value of 0.59 μg at. P/l. which exceeded the winter maximum. This increase was totally absent at 5 m depth.

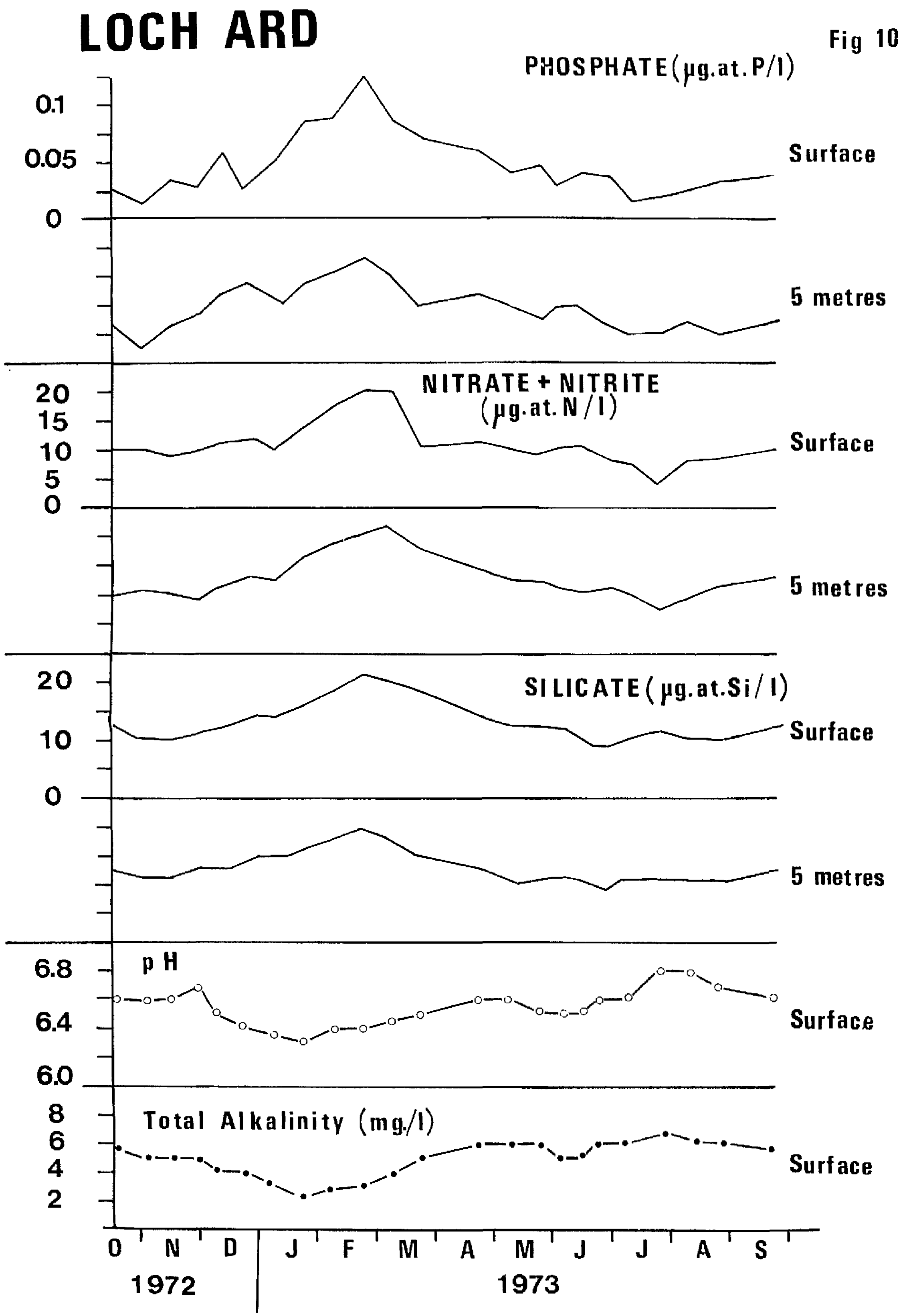
The range of phosphate in the Letter burn (Table 8b) was from a maximum of 0.8 μg at. P/l. on 29 November falling to 0.036 μg at. P/l. on 20 April. The level of dissolved phosphate was generally higher in winter than during the rest of the year. This is in contrast with most of the inflows studied, when the minimum values were found in winter. Variation in this nutrient was -irregular, fluctuating between 0.1 and 0.2 μg at. P/l. from 21 February onward.

(iii) Loch Achray

In Loch Achray (Figure 11 and Appendix Table 4) the patterns of phosphate variation at surface and 5 m depth are similar, showing a winter peak and summer depression. The highest value reached at the surface (0.24 μg at. P/l) is only slightly less than the 5 m maximum (0.25 μg at. P/l.) whereas the minimum recorded value is the same in each case (0.03 μg at. P/l.).

A steep decline in dissolved phosphate took place in autumn 1972 falling at the surface from 0.152 on 18 October to 0.04 μg at. P/l. on 1 November. This was followed by fluctuating levels of phosphate with a rapid rise being evident on 27 December reaching a maximum on 7 February at the surface and 5 m depth.

The spring minimum (0.08 μg at. P/l.) was manifest at the surface on 8 March following a steep drop in dissolved phosphate while at 5 m depth this depression appeared a fortnight later. The subsequent slight increase



LOCH ARD
Fig 10
PHOSPHATE(µg.at.P/l)
0.1
0.05
0
Surface
5 metres
NITRATE + NITRITE (µg.at.N/l)
20
15
10
5
0
Surface
5 metres
SILICATE(µg.at.Si/l)
20
10
0
Surface
5 metres
pH
6.8
6.4
6.0
Surface
Total Alkalinity (mg/l)
8
6
4
2
Surface
O N D J F M A M J J A S
1972
1973

at the end of April raised the phosphate values at surface and 5 m depth to 0.14 and 0.17 µg at. P/l. respectively.

The steep decline to 0.07 µg at. P/l. at the surface on 17 May was not apparent at 5 m depth though a rapid reduction occurred here on 14 June to reach 0.03 µg at. P/l. The downward curve continued until 11 July when surface and depth concentration of phosphate were reduced to their lowest values. The summer minimum was succeeded by a gradual upward trend in levels of this nutrient reaching 0.16 µg at. P/l. on 23 August, 1973.

Results from the main inflow, Achray Water, (Table 8b) shows that the phosphate content was at its lowest during the winter and at its peak in summer and autumn. From 1 November until 17 May phosphate levels did not exceed 0.1 µg at. P/l. During the last two weeks in May levels rose rapidly to 0.3 µg at. P/l. on 1 June and attained a maximum recorded concentration of 0.33 µg at. P/l. on 28 June. A continuous reduction in phosphate level took place during July and by 8 August the phosphate concentration had fallen to 0.047 µg at. P/l. An increase followed raising the level of phosphate to 0.275 and 0.232 µg at. P/l. on 23 August and 20 September, 1973 respectively.

In summary, the phosphate level in Loch Achray ranged from 0.03 in July to 0.24 µg at. P/l. on 7 February whereas in the Achray Water this nutrient ranged from almost undetectable in November to 0.33 µg at. P/l in June, 1973.

(iv) Loch Ard

The levels of dissolved phosphate in Loch Ard (Figure 10 and Appendix Table 4) are lower than Loch Achray, Rusky and Lake of Menteith. However, the pattern of variation is broadly similar, with a winter peak and a summer depression both at surface and 5 m depth.

The phosphate level during October, November and December, 1972 and from May to October, 1973 was almost undetectable. The winter increase commenced on 10 January while in all other lochs studied including Loch Lomond it began earlier. The phosphate maximum in Loch Ard was 0.125 µg at. P/l. at the surface on 21 February, later than in Loch Achray and Loch Rusky. A slightly lower winter peak (0.09 µg at. P/l.) was reached at 5 m depth on the same date.

LOCH ACHRAY

Fig 11

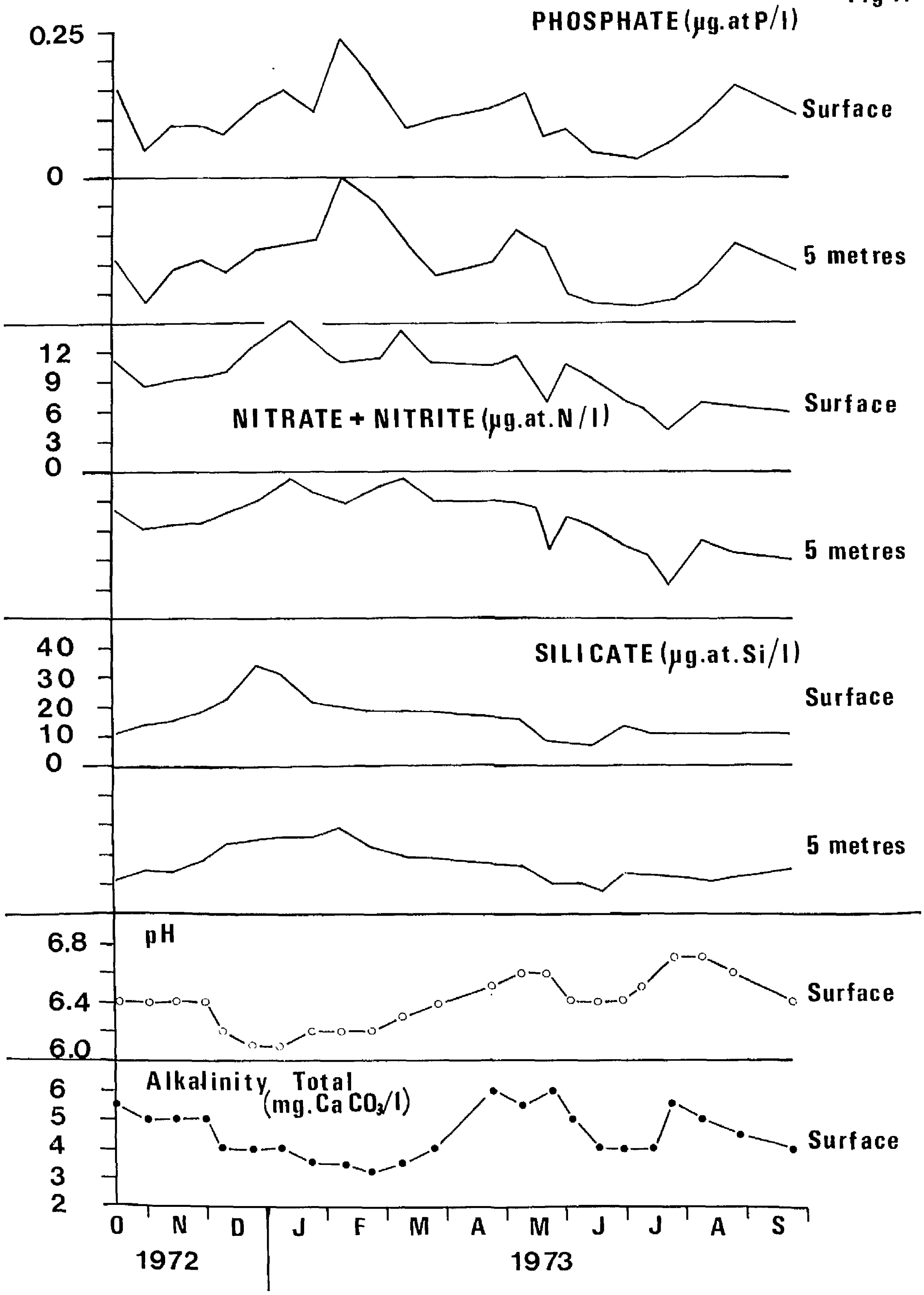


Fig 12

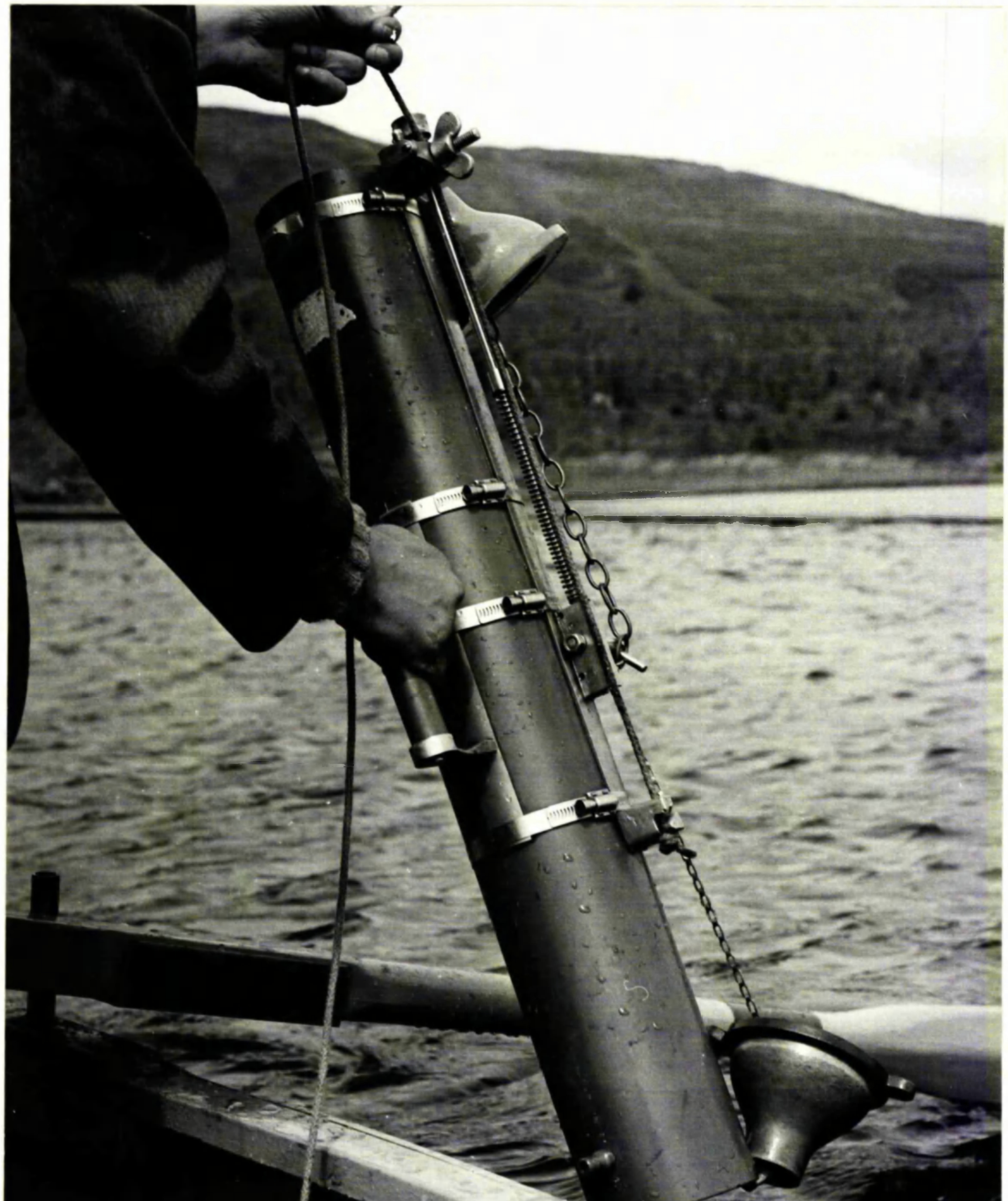


Table 8a. Nutrient input and other data for the four lochs other than Loch Lomond.

Date	Burn of Menteith		Letter burn		Achray Water		Ledard Burn		Water of Chon	
	NO_3/N	NO_2/N	NO_3/N	NO_2/N	NO_3/N	NO_2/N	NO_3/N	NO_2/N	NO_3/N	NO_2/N
18.10.72	0.79	0.042	1.65	0.034	0.71	0.034	1.22	0.042	3.45	0.02
1.11.72	4.2	0.034	6.0	0.08	9.2	0.044	4.0	0.06	7.43	0.02
15.11.72	7.6	0.044	12.06	0.15	11.5	0.063	8.4	0.05	8.6	0.02
29.11.72	3.7	0.08	18.0	0.32	5.4	0.025	7.35	0.04	10.63	0.03
13.12.72	3.6	0.017	16.5	0.059	8.53	0.008	8.32	0.003	13.34	0.06
27.12.72	4.8	0.09	17.4	0.08	10.43	0.074	7.41	0.03	15.65	0.07
10. 1.73	5.3	0.13	18.3	0.32	18.32	0.083	8.54	0.03	14.43	0.06
24. 1.73	6.32	0.16	17.13	0.28	24.48	0.065	9.83	0.05	12.32	0.23
7. 2.73	3.7	0.13	14.22	0.23	11.4	0.074	7.53	0.034	10.30	0.12
21. 2.73	3.88	0.2	14.46	0.2	12.85	0.075	9.8	0.37	9.97	0.11
8. 3.73	4.1	0.042	10.25	0.051	13.18	0.034	10.89	0.034	12.16	0.025
28. 3.73	6.35	0.03	3.6	0.04	7.23	0.02	10.83	0.033	11.23	0.026
20. 4.73	7.6	0.094	2.3	0.051	11.17	0.034	8.0	0.034	9.95	0.05
3. 5.73	4.97	0.12	1.02	0.05	5.79	0.07	4.11	0.05	7.56	0.05
17. 5.73	0.53	0.034	0.49	0.035	3.21	0.35	2.42	0.023	9.41	0.015
1. 6.73	0.98	0.033	0.97	0.033	6.8	0.068	2.8	0.016	6.9	0.016
14. 6.73	3.2	0.025	0.67	0.017	5.58	0.054	4.3	0.021	8.6	0.025
28. 6.73	7.3	0.054	2.61	0.067	8.04	0.041	6.51	0.037	9.61	0.047
11. 7.73	6.7	0.063	2.3	0.084	6.3	0.043	4.3	0.045	8.64	0.034
26. 7.73	6.99	0.088	2.21	0.11	6.5	0.068	5.8	0.061	5.32	0.035
8. 8.73	4.22	0.35	2.57	0.065	6.39	0.045	2.37	0.082	4.88	0.014
23. 8.73	0.22	0.23	0.09	0.043	0.061	0.053	0.054	0.083	4.35	0.023
20. 9.73	0.54	0.086	1.3	0.052	0.83	0.045	0.12	0.041	5.34	0.025

Table 8b. Nutrient input and other data for the four Lochs other than Loch Lomond

	Burn of Menteith		Letter burn		Achray Water		Ledard Burn		Water of Chon	
	PO_4^{-3}/P	SiO_2	PO_4^{-3}/P	SiO_2	PO_4^{-3}/P	SiO_2	PO_4^{-3}/P	SiO_2	PO_4^{-3}/P	SiO_2
18.10.72	0.72	86.6	0.143	78.3	0.158	10.51	0.095	40.74	0.102	17.82
1.11.72	0.63	92.3	0.262	66.3	Trace	22.83	0.018	33.26	0.086	16.43
15.11.72	0.19	55.75	0.451	55.7	0.046	26.27	0.052	43.4	0.074	14.41
29.11.72	0.149	64.3	0.804	54.2	0.060	25.56	0.153	34.8	0.043	16.42
13.12.72	0.151	63.3	0.357	78.6	0.082	23.43	0.027	30.08	0.05	18.33
27.12.72	0.134	74.3	0.367	86.4	0.053	22.4	0.053	33.8	0.12	20.12
10. 1.73	0.142	68.6	0.510	92.3	0.042	28.3	0.082	36.3	0.094	23.21
24. 1.73	0.146	62.4	0.536	78.8	0.02	15.76	0.114	23.43	0.063	28.32
7. 2.73	0.155	53.32	0.394	63.99	0.023	15.99	0.048	34.12	0.047	25.59
21. 2.73	0.201	68.16	0.203	76.68	0.075	18.53	0.375	34.71	0.1	23.04
8. 3.73	0.187	93.3	0.214	68.4	0.053	20.87	0.013	30.67	0.053	22.15
26. 3.73	0.49	55.38	0.17	67.45	Trace	14.26	0.04	28.73	0.07	27.05
20. 4.73	0.68	30.88	0.036	42.17	0.050	11.28	0.137	31.95	0.065	12.78
3. 5.73	0.851	29.77	0.199	42.54	0.032	17.44	0.166	29.35	0.086	14.88
17. 5.73	0.15	38.34	0.097	38.34	0.084	1.34	0.084	28.75	0.058	16.99
1. 6.73	0.078	53.6	0.101	25.98	0.297	3.49	0.053	19.59	0.025	2.10
14. 6.73	0.15	59.8	0.124	0.298	0.239	2.50	0.04	14.6	0.045	3.38
28. 6.73	0.231	64.8	0.199	60.48	0.325	16.72	0.173	13.21	0.13	7.92
11. 7.73	0.21	43.4	0.18	48.5	0.183	8.73	0.03	12.63	0.12	8.32
26. 7.73	0.206	27.69	0.166	21.93	0.099	5.53	0.119	15.95	0.093	12.35
8. 8.73	0.267	43.4	0.147	42.7	0.047	6.32	0.04	20.02	0.067	16.57
23. 8.73	0.52	58.6	0.123	53.63	0.275	11.58	0.137	38.34	0.137	15.76
20. 9.73	0.63	84.3	0.163	68.44	0.232	10.8	0.112	36.3	0.13	16.6

Table 8c. Nutrient input and other data for the four Lochs other than Loch Lomond

Date	Burn of Menteith		Letter Burn		Achray Water		Ledard Burn		Water of Chon	
	p^H	$CaCO_3$	p^H	$CaCO_3$	p^H	$CaCO_3$	p^H	$CaCO_3$	p^H	$CaCO_3$
18.10.72	7.7	80.5	7.5	47.25	6.9	4.75	7.5	32.5	6.3	2.5
1.11.72	7.6	62.0	7.2	38.5	6.7	4.5	7.1	26.5	6.6	5.5
15.11.72	7.7	54.5	6.9	9.6	6.6	4.0	7.2	24.0	6.4	4.5
29.11.72	7.5	38.0	6.2	4.5	5.1	1.5	6.5	8.0	6.7	8.0
13.12.72	7.4	88.5	6.1	2.5	5.3	1.5	6.4	6.5	6.8	8.5
27.12.72	7.3	26.0	5.8	2.0	5.4	2.0	6.5	4.5	7.1	14.5
10. 1.73	7.2	14.5	5.4	2.0	5.8	5.0	6.4	4.0	7.1	15.0
24. 1.73	7.2	10.0	5.5	3.7	6.1	4.0	6.5	5.0	7.0	15.0
7. 2.73	7.35	28.0	6.3	4.5	6.2	8.5	6.8	6.5	5.3	1.0
21. 2.73	7.6	35.0	6.7	11.5	6.4	2.5	7.0	14.0	5.5	1.5
8. 3.73	7.55	42.0	6.8	10.0	6.45	4.0	7.1	15.5	5.7	1.5
28. 3.73	7.6	43.5	6.9	11.5	6.2	3.5	6.5	4.5	6.2	6.0
20. 4.73	7.8	61.5	7.4	24.0	7.0	6.0	6.2	3.5	7.0	14.0
3. 5.73	7.8	48.5	7.1	14.5	6.3	3.5	6.3	3.0	6.4	2.5
17. 5.73	7.8	48.0	6.95	20.0	6.4	2.0	6.9	24.0	6.3	3.0
1. 6.73	7.7	48.0	6.8	12.0	6.7	3.5	6.7	12.0	6.4	3.0
14. 6.73	7.65	44.0	6.9	12.5	6.45	3.0	6.95	16.5	5.9	1.5
28. 6.73	7.8	63.0	7.3	32.0	5.8	3.5	6.8	5.5	6.0	2.0
11. 7.73	7.8	65.0	7.4	30.5	6.3	3.0	6.6	3.5	6.3	2.5
26. 7.73	7.9	74.0	7.5	38.5	6.9	4.5	6.4	3.0	6.1	2.0
2. 8.73	7.7	42.0	6.8	15.0	6.4	4.0	7.2	14.0	6.3	2.5
23. 8.73	7.65	42.0	7.3	28.5	6.4	3.5	7.33	16.5	6.65	3.5
20. 9.73	7.5	58.0	7.3	28.0	6.8	6.5	7.3	16.0	6.2	2.0

From 8 March a continuous downward movement of phosphate was apparent at the surface and a similar but more irregular change at 5 m depth. A minimum value was reached on 1 June, 0.03 and 0.04 μg at. P/l. being recorded at surface and 5 metres respectively.

The two main inflows to Loch Ard, Ledard Burn and Water of Chon (see Table 8(b)) showed no marked seasonal pattern of phosphate variation. Although both are typically low in phosphate. Dissolved phosphate ranged from 0.01 to 0.38 in Ledard Burn and from 0.03 to 0.14 μg at. P/l. in Chon Water.

The Ledard Burn exhibited phosphate concentrations not exceeding 0.15 μg at. P/l. from 18 October to 7 February while Water of Chon generally varied around 0.1 μg at P/l. A phosphate maximum in Ledard Burn was recorded (0.38 μg at. P/l.) on 21 February while Water of Chon continued at a low level, reaching a peak (0.13 μg at. P/l.) on 28 June following the maximum. Ledard Burn showed erratic variations in phosphate levels, rising on two occasions to 0.17 μg at. P/l.

(2) Silicate

(a) Loch Lomond

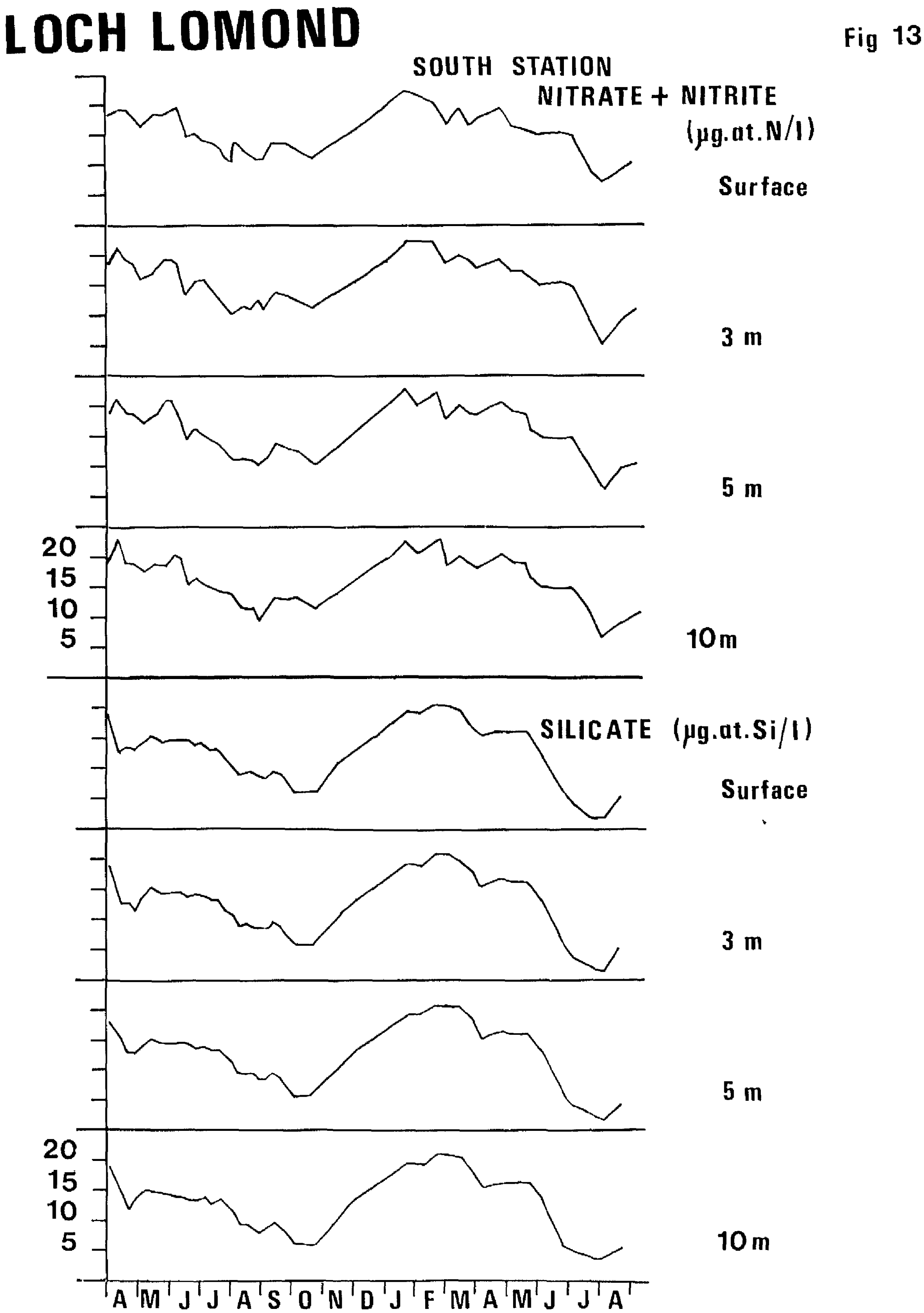
All six stations in Loch Lomond clearly show a winter maximum and summer minimum both at the surface and at various depths. The surface silicate maximum ranged from 25.3 μg at. Si/l. at South Balmaha to 15.88 μg at. Si/l. in North Inversnaid station while the minimum for the year varied from 5.04 in the north station to 2.3 μg at. Si/l. at South Balmaha and South station. The annual range of silicate varied from about 10 μg at. Si/l. in the North Station to about 21 μg at. Si/l. at South Balmaha station. The changes of silicate levels at depth may differ from those at the surface by up to two weeks. A subsidiary maximum occurred in May at all stations examined in 1973 and at the three stations investigated at this period in 1972.

In the South Station in 1972 when the winter maximum was not recorded (Figure 13 and Table 5 in Appendix) the annual variation of silicate ranged from 18.2 on 7 April to 6.1 μg at. Si/l. on 11 October at the surface. In 1973 the range was from 21.9 on 15 February to 2.3 μg at. Si/l. on 24 July.

Three marked depressions in silicate levels occurred in 1972. The spring minimum followed a steep decline from 7 April to 14 April at all depths. Surface and 3 m silicate concentrations fell from 18.2 to 12.3 μg at. Si/l., a drop of almost 6 μg at. Si/l. in a week. At 5 and 10 m depth the same decrease in level took two weeks (from 18.6 to 12.0 μg at. Si/l. at 10 m depth).

The increase towards the end of April was initiated at 10 m depth while the surface values were still falling, a rise in silicate at all depths was evident a week later. Surface and 3 m levels reached 15.2 μg at. Si/l. on 17 May. A second decrease in silicate ensued from 4 July to 8 August when surface and 3 m values fell from 14.3 to 8.9 μg at. Si/l. At 5 and 10 m depth the concentration of silicate did not fall below 9.5 μg at. Si/l. This decline coincided with the minimum levels of phosphate recorded in 1972. The downward curve of silicate continued till the minimum value for the year (6.05 μg at. Si/l.) was reached on 11 October. Preceding this a sudden small increase in dissolved silicate occurred at all,depths on 12 September with levels reaching 9.3, 9.7, 9.4 and 9.4 μg at. Si/l. at surface, 3 m, 5 m, and 10 m depth respectively. This peak occurred simultaneously with the phosphate maximum recorded at all stations in Loch Lomond on this date.

A sustained rise in silicate levels from 6.2 μg at. Si/l. at all depths on 25 October resulted in a winter maximum of around 22 μg at. Si/l. at all depths on 15 February. The subsequent decline in the silicate concentration led to a spring minimum of around 15.9 μg at. Si/l. at all depths on 12 April. This represents a decrease of about 6 μg at. Si/l. and occurred concurrently with the decline in phosphate concentrations. Till 10 May levels remain fairly constant although a slight upward trend was apparent at 3 m and 5 m on 26 April. Thereafter the silicate levels fell dramatically to reach a summer minimum of 2.27 μg at. Si/l. at the surface and 3.7 at 10 m depth on 24 July, 1973. This was the largest single decrease recorded at this



LOCH LOMOND
Fig 13
SOUTH STATION
NITRATE + NITRITE
(µg.at.N/l)
Surface
3 m
5 m
10m
SILICATE (µg.at.Si/l)
Surface
3 m
5 m
10m
20
15
10
5
A M J J A S O N D J F M A M J J A

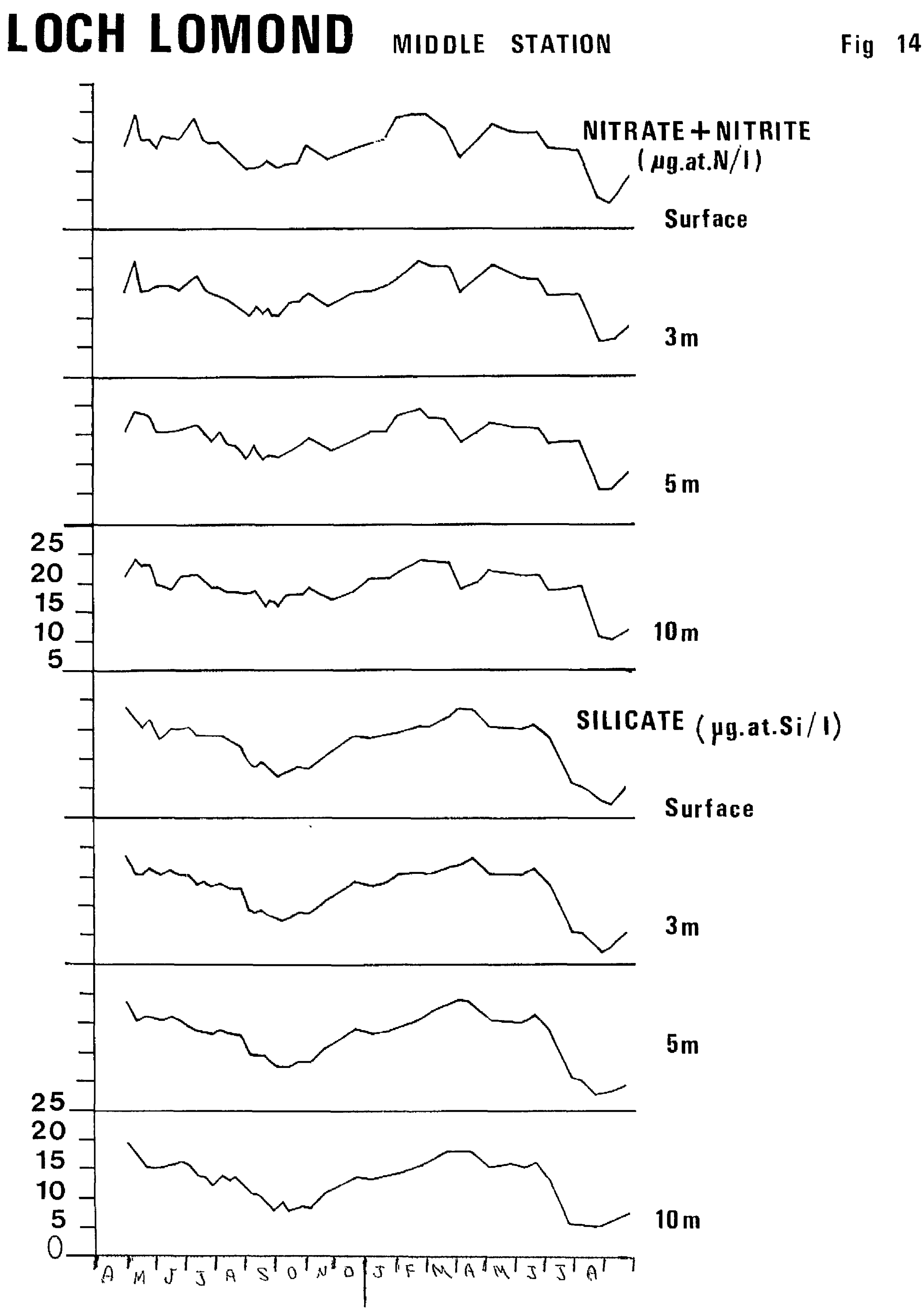
station (14.2 µg at. Si/l.) and occurred at the same time as the decline in phosphate. The subsequent increase in silicate levels during August occurred a week later than the phosphate increase.

The levels of silicate at the Middle Station (Figure 14 and Appendix Table 6) varied from 18.45 on 7 April to 7.42 on 6 September at the surface in 1972, having a range of 11 µg at. Si/l. In 1973 the surface silicate 1 levels ranged from 17.89 on 1 March to 2.47 on 2 August that is a range of 15.42 µg at. Si/l. The pattern of variation was similar at all depths though the summer minimum at 10 m depth (5.1) was more than twice that at surface and 3 m depth (2.5 µg at. Si/l.) during 1973.

From 7 April, 1972 to 4 May silicate levels decreased at all depths, falling from 18.45 to 13.66 at the surface, 18.2 to 15.3 at 3 m, 18.26 to 16.13 at 5 m and 19.65 to 15.54 µg at. Si/l. at 10 m. This was followed by a small increase in levels, reaching 15.45 µg at. Si/l. at the surface on 29 May. The silicate concentration remained around this value till 10 July when a gradual decrease began. An abrupt drop in silicate from 12.2 to 9.2 µg at. Si/l. occurred between 18 July to 1 August at the surface, whereas a decline from 13.8 to 10.12 µg at. Si/l. took place at 10 m depth.

A steady decline ensued, reaching a minimum of about 7.5 µg at. Si/l. on 6 September at the surface, 3 m and 5 m, while at 10 m depth the lowest value was reached a week later. Silicate levels did not show any further decrease but remained around 8.5 µg at. Si/l. at all depths until 25 October. This marked the beginning of the winter increase which reached a maximum of 17.89, 18.38, 18.31 and 17.89 µg at. Si/l. at surface, 3 m, 5 m and 10 metres respectively. This was 2 weeks later than phosphate maximum.

A f all in silicate of about 3 µg at. Si/l. occurred from 15 March to 12 April reaching about 15.5 µg at. Si/l. at all depths. A slight upward trend in silicate was evident from 2 May to 24 May rising to a peak value of 16.7 at 3 m depth and 16.0 µg at. Si/l. at the surface. A decline to about 13.5 µg at. Si/l. on 7 June was followed by a steep reduction in silicate concentration reaching 5.6 µg at. Si/l. at the surface on 24 June. Values



LOCH LOMOND MIDDLE STATION
Fig 14
NITRATE + NITRITE (μg.at.N/l)
Surface
3m
5m
10m
SILICATE (μg.at.Si/l)
Surface
3m
5m
10m
25
20
15
10
5
0
A M J J A S O N D J F M A M J J A

lying between 5 and 6 μg at. Si/l. persisted at all depths till 6 July. Following this a further decline was apparent at surface, 3 m, and 5 m depth reaching 2.8, 2.4, and 3.0 μg at. Si/l. respectively on 24 July. This decrease was absent at 10 m depth. A summer minimum was reached at the surface on 2 August (coinciding with minimum levels of phosphate) while all other depths registered an increase. By 17 August silicate was increasing at all depths.

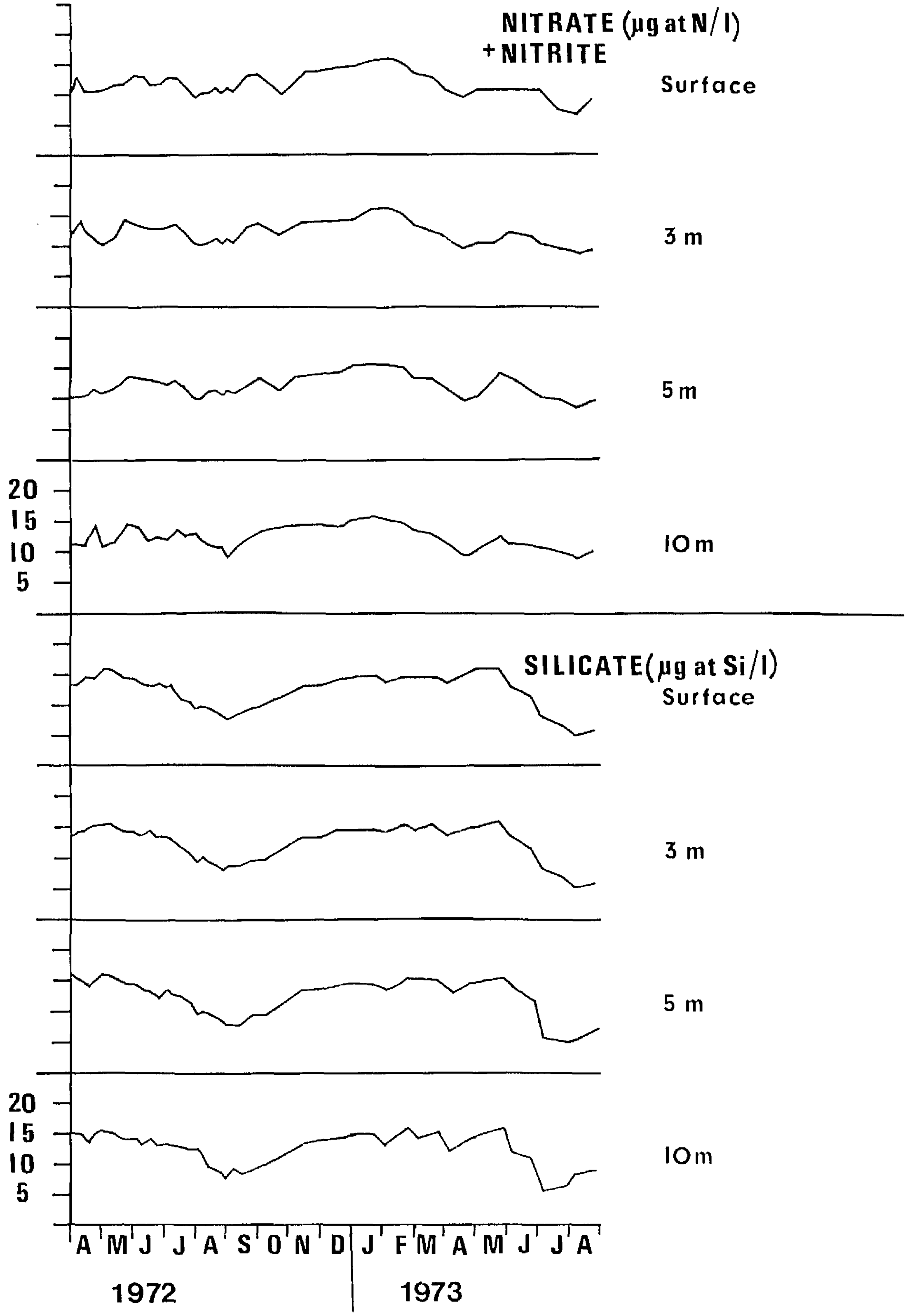
Silicate levels in the North Station (Figure 15, Appendix Table 7) show a smaller seasonal range than that of the Middle or South though the winter maximum and summer minimum were clear at all depths. The annual range in 1972 was about 9 μg at. Si/l. while in 1973 it was 11 μg at. Si/l.

In 1972 the spring minimum although not as distinct as at the other stations in the loch, can be discerned at 5 m and 10 m depth on 20 April. Subsequently silicate concentrations increased to reach a maximum on 4 May (16.02 at surface, 15.57 at 3 m, 16.36 at 5 m and 15.5 μg at. Si/l. at 10 m depth). These were the highest levels of silicate reached for the north. Fluctuating levels followed, showing a general downward trend in silicate values to reach about 13.5 μg at. Si/l. at all depths on 12 June. These concentrations persisted till 7 July.

A sustained fall ensued with the concentration of silicate decreasing from 13.3 at surface on 10 July to 9.37 on 1 August. A concomitant decrease at 3 m and 5 m was not apparent at 10 m depth.till a week later. The decline in silicate values continued reaching an annual minimum at the surface of 7.83 μg at. Si/l. on 6 September a week later than the minimum at other depths. A distinct upward curve was then evident, with levels rising steadily to around 13.5 μg at. Si/l. on 23 November. A further, more gradual increase raised the silicate content of the water to about 15 μg at. Si/l. at all depths on 4 January. These levels were maintained till the end of April, with a slight depression at surface and depth on 1 February and 12 April. The latter depression occurred at all depths sampled, the decrease from surface to 10 m being 1, 2, 5 and 3 μg at. Si/l. respectively; this fall in silicate concentration coincided with the spring phosphate

LOCH LOMOND

NORTH STATION Fig 15



decline. Following this depression silicate increased to a maximum on 24 May when levels were around 16 μg at. Si/l. at all depths.

By 24 June a decrease in excess of 3 μg at. Si/l. had taken place at all depths. A further decline at surface and 3 m depth reduced the silicate concentration to its annual minimum on 2 August (5.04 and 5.72 μg at. Si/l. respectively). At 5 m depth the pattern was noticeably different with levels abruptly falling between 24 June and 6 July to reach 5.15 declining still further to 5.00 μg at. Si/l. on 24 July. At 10 m depth the minimum, 5.85 μg at. Si/l. was reached on 6 July. The timing of these minimal silicate levels closely follows the minimum of phosphate. Increasing concentrations of silicate were first apparent at 10 m depth on 24 July, at 5 m depth on 2 August and at 3 m depth and surface on 17 August. Generally the maximum and minimum levels of silicate show no significant differences between depths although depth changes may differ from those at the surface by up to two weeks. The minimum silicate concentration recorded at all depths in 1973 was more than 2 μg at. Si/l. lower than in 1972. The maximum levels observed were the same in 1972 and 1973, occurring in May in both years.

During the months of August, September, and October 1972 the levels of silicate at the North Inversnaid station (See Table 4) remained between 8.1 and 9.7 μg at. Si/l. The winter increase was apparent on 23 November when levels had increased by almost 2 μg at. Si/l. reaching 11.3 at the surface. The winter maximum was reached on 4 January when the silicate content of the water was 15.9 μg at. Si/l. at the surface and 14.6 at 3 m depth.

The silicate concentration persisted around 14.9 μg at. Si/l. at the surface and slightly less at depth till 15 March. A small drop in silicate level followed reducing this nutrient to 13.3 at the surface and 12.7 μg at. Si/l. at depth on 12 April. This reduction accompanied the spring decrease in phosphate at this station.

The marked increase in silicate during May coincided with that at the other stations in Loch Lomond attaining a peak of 15.9 μg at. Si/l. at the surface and 15.8 μg at. Si/l. at 3 metres on 24 May. This peak exceeded the winter maximum. A subsequent shallow decline (of about 2 μg at. Si/l.) till 7 June was followed by a steep drop, reaching 5.9 at surface and 5.0 μg at. Si/l. at 3 metres on 24 June. A continued decline reduced silicate to 3.2 μg at. Si/l. at the surface on 24 July, the minimum recorded level. During August silicate showed an increase at all depths reaching 6.6 μg at. Si/l. on 17 August.

A close similarity exists between silicate levels at surface and 3 m depth, consequently the annual range was similar, 12.7 at surface and 12.5 at 3 m. During August 1972 the silicate content of the water was more than 3 μg at. Si/l. higher than in August, 1973.

The levels of silicate gradually declined from 9.9 μg at.Si/l. at surface at North Falloch station (see Table 4) in August to 9.1 on 11 October. The winter increase of silicate was first apparent on 23 November increasing steadily to reach a winter peak of 15.5 μg at. Si/l. at the surface on 1 March and 15.6 at depth a fortnight later. The time of maximal winter levels of silicate at this station coincides with the maximum at the North station but occurred two months later than the winter peak at North Inversnaid station (4 January).

A small depression in levels during April reached 14.5 and 13.1 μg at. Si/l. at surface and 3 metres respectively; this occurred concurrently with the spring phosphate decrease. The subsequent rise in silicate quantities during May raised levels of the silicate to 16 μg at. Si/l. at surface and 15.3 μg at. Si/l. at 3 m depth on 24 May. This exceeded the winter maximum by 0.5 μg at. Si/l.

A slight decline was evident during the next fortnight succeeded by a rapid fall to 5.6 μg at. Si/l. at surface and 5.7 at depth on 24 June. Throughout July levels continued to reduce with a recorded minimum of 3.2 at surface and 3.8 μg at. Si/l. at 3 m on 24 July. The summer minimum was coincident with the lowest levels recorded at all other stations in Loch Lomond. Silicate increased during August reaching 7.8 μg at. Si/l. on 17 August.

The extent of silicate variation at surface and 3 m depth was similar (12.7 and 11.8) with seasonal silicate variation closely following one another. Silicate concentrations in August, 1972 were higher than the same period in 1973 at this station.

Silicate concentrations in August, September and October at South Balmaha station (see Table 4) were manifestly lower than levels at other stations in Loch Lomond, ranging between 5.2 on 8 August and 6.1 μg at. Si/l. on 25 October. A doubling of silicate levels from the end of October to 23 November raised concentrations above 11 μg at. Si/l. to equal those at the other five stations in the Loch. The silicate levels continued rapidly upward to reach a winter maximum of 25.3 at surface and 24.6 μg at. Si/l. at 3 m depth on 15 February. This was the largest concentration of silicate recorded at any station in Loch Lomond, and occurred concurrently with the peak at South Station.

A gradual decline to a level of 19.2 μg at. Si/l. on 28 March was followed by an abrupt drop to 8.5 μg at.Si/l. at surface and depth on 12 April. This coincided with the general spring decrease in silicate throughout the loch and was by far the most marked (8.2 μg at. Si/l.).

A striking increase was evident by 26 April representing a doubling of the silicate concentration, to reach 16.8 at the surface and 15.9 μg at. Si/l. at 3 m depth. This occurred simultaneously with the silicate upsurge which occurred throughout the Loch in May and was by far the largest.

High levels of silicate persisted till 24 May and thereafter declined to 10.8 μg at. Si/l. on 7 June with a further large reduction to 5.3 at the surface on 24 June. Silicate further diminished to a summer minimum of 2.3 μg at. Si/l. at surface and 2.08 μg at. Si/l. at 3 m depth on 24 July. In August an increase was apparent at all depths, reaching around 5 μg at. Si/l. by 17 August.

In general the annual range of silicate at South Balmaha was 23 at the surface and 21.8 μg at. Si/l. at 3 m depth; this is greater than any of the other five stations in Loch Lomond. In contrast to North Falloch and North

Inversnaid levels of silicate in August 1972 and 1973 were the same.

To summarize the results of silicate in Loch Lomond, it is clear that the North Station possesses the lowest annual range of silicate. North and South of this station the annual range of surface concentrations increases. The range at North station was 11.04 increasing to 12.6μat North Inversnaid and reaching 12.79 at North Falloch. Passing southwards from the North Station the range rises to 15.4 at Middle station, increases still further to 19.6 at South station and reaches a maximum for the Loch of 23 μg at. Si/l. at the South Balmaha station.

The maximum silicate concentration recorded was at South Balmaha (25.3); this reduced towards the South station (21.93) and diminished further to the Middle station (18.45). The remaining three stations show similar maximum North station 16,08, North Inversnaid 15.88 and North Falloch 15.99 μg at. Si/l.

The minimum concentration of silicate was higher at the North Station (5.0) than elsewhere in the Loch; North Inversnaid and North Falloch both had similar minimum value 3.3 and 3.2 μg at. Si/l. respectively, while Middle, South and South Balmaha showed the lowest concentration of silicate, 2.4, 2.2 and 2.3 μg at. Si/l. respectively. The annual minimum at the North station occurs a week later than at all other stations.

The three stations studied in 1972 and 1973 show a higher minimum silicate concentration in the former year. The lowest recorded values in 1972 were 7.8, 7.4, and 6.1 μg at. Si/l. at North, Middle and South stations while in 1973 the minima were 5.0, 2.4 and 2.3 respectively.

The maximum for the year occurred in winter at South Balmaha, South and Middle stations while at North, North Inversnaid and North Falloch it occurred in May.

In general the variation in silicate concentrations in depth samples closely follows that of the surface with a maximum delay of a week or a fortnight.

(b) Rivers and burns flowing into Loch Lomond
(See Tables 6, 7 and 9, Figures 5, 6 and 7)

Rivers and burns to the South of Inverbeg bar were sampled on 8 August, 1972, while those to the north were investigated on 15 August. Overall, the inflows to the south were higher in silicate than those to the north. The Endrick had the highest silicate content during August (64.3 µg at. Si/l.) while 29.3 µg at. Si/l. was recorded in the Fruin. Of the northern inflows only the small streams exhibited high levels of silicate, Stuckindroin, Rubha Ban and AltArdvorlich having levels of silicate 32.8, 32.1, 22.3 µg at. Si/l. respectively. The remainder of the inflows had levels below 20 µg at. Si/l., the minimum concentration being recorded in the Inveruglas Water (8.1 µg at. Si/l.).

In September, 1972 all rivers and burns were sampled on two successive weeks, 6 and 9 September, an increase in silicate being apparent in most inflows. However, the Endrick and Fruin which were highest in August were reduced, the Endrick having its minimum silicate level for the year (3.72 µg at. Si/l. on 6 September, 1972). River Douglas reached its annual maximum of 36.9 µg at. Si/l. and Luss increased about two-fold to 29.4 µg at. Si/l. North of Inverbeg bar all rivers and burns showed an upward trend in silicate levels exceeding 25 µg at. Si/l. apart from the Inversnaid Water which became reduced to 8.4 µg at. Si/l.

During October all 17 inflows were sampled on 11th and only those to the south on 25th. Little difference between inflows north and south of Inverbeg bar was apparent and most were still increasing. Fruin showed an increase on 11 October to 36.9 and decreased to its annual minimum of 3.95 µg at. Si/l. on 25th. Cashell Burn showed a similar decline to 3.95 on 25th; on the other hand Coille Mhor Loch water decreased on 11 October rising to its annual maximum 34.4 µg at. Si/l. on 25 October. The Endrick remained constant between 14 and 15 µg at. Si/l. throughout the month, while the highest silicate content was observed in Rubha Ban, 51.3 µg at. Si/l. Generally the remaining inflows further increased during this period, and most exceeded 25 µg at. Si/l.

On 23 November the 17 rivers and burns were sampled and all were found to be on the increase. All inflows south of the Inverbeg bar exceeded 30 μg at. Si/l. and apart from Cailness all small tributaries to the north exceeded 30 μg at. Si/l., including Rubha Ban which exceeded 40 μg at Si/l. Larger inflows to the upper loch, Falloch and Inveruglas recorded levels of 22 and 28 μg at.Si/l. respectively while Inversnaid attained its annual maximum of 22 μg at. Si/l. To the south the Endrick increased six-fold to reach 65.7 (maximum of any river) and the Fruin rose to 48.18 μg at. Si/l. The lowest level of the north was 15.1 μg at. Si/l. in Cailness.

During the month of December inflows north of the Inverbeg bar were sampled on 7th and tributaries to the south on the 21st. All the main inflows to the south showed a further increase; Fruin, Luss and Finlas reaching their annual maximum of 60.4, 39.9 and 43.1 μg at. Si/l. respectively. All other inflows generally remained at a high level with the Endrick again exhibiting a higher silicate concentration than any other inflows (75.6 μg at. Si/l.).

Samples of all 17 inflows taken on 4 January show that high levels of silicate persisted throughout the catchment area. Generally the tributaries to the south exceeded 38 μg at. Si/l. while the Endrick showed a further increase to 90 μg at. Si/l., the greatest level of silicate recorded in January. In the north the Falloch and Inveruglas reached high levels, 26.2 and 33 μg at. Si/l. respectively, while in the south Cashell attained its maximum silicate concentration of 51.2 μg at. Si/l.

The rivers and burns were sampled on two occasions in February on 1st in north and 15th in the south. Silicate levels exceeding 35 μg at. Si/l. were maintained in the inflows to the south of Inverbeg bar. Silicate concentrations of 115 μg at. Si/l. were recorded for both River Endrick and Blair Burn. This was the maximum level of these or for any inflows to Loch Lomond. In contrast inflows to

Table 9. Silicate (μg.atom/l) of the rivers and streams inflowing to Loch Lomond

Date	Endrick	Fruin	Luss	Finlas	Douglas	Falloch	Inveruglas	Inversnaid	Cailness	Coille Mhor Burn	Cashell	Rubha Ban
8. 8.72	64.26	29.32	15.02	21.55	14.12	-	-	-	-	-	15.8	-
15. 8.72	-	-	-	-	-	17.64	8.12	13.11	19.6	26.8	-	32.08
6. 9.72	3.73	23.57	29.72	25.11	36.9	-	-	-	-	-	35.87	42.00
12. 9.72	-	-	-	-	-	25.34	26.24	8.4	36.2	35.6	-	-
11.10.72	14.35	36.9	37.94	37.94	29.73	23.58	28.5	21.53	13.94	30.25	30.55	51.27
25.10.72	14.96	3.95	28.92	40.49	30.34	-	-	-	-	32.37	3.95	-
23.11.72	65.7	48.18	32.85	39.42	32.85	22.0	28.0	22.0	15.1	38.32	37.23	>42.6
7.12.72	-	-	-	-	30.2	22.10	26.58	21.89	19.02	-	-	>42.6
21.12.72	75.55	60.37	39.9	43.05	-	-	-	-	-	34.02	49.35	-
4. 1.73	90.0	50.0	38.0	38.0	32.0	26.20	33.33	14.78	17.43	30.2	51.2	>42.6
1. 2.73	-	-	-	-	-	19.89	25.13	17.08	16.44	-	-	>42.6
15. 2.73	115.02	42.6	35.15	36.2	33.01	-	-	-	-	30.88	36.2	-
1. 3.73	-	-	-	-	-	12.07	16.72	13.09	11.28	-	-	38.34
15. 3.73	42.6	36.2	26.83	28.96	28.75	26.62	29.18	13.37	22.32	32.8	40.47	85.2
26. 3.73	17.64	36.21	19.17	31.95	25.56	11.28	38.34	-	-	25.56	-	-
12. 4.73	42.6	19.17	11.50	10.65	12.78	4.64	11.07	1.70	17.46	2.13	2.66	42.6
26. 4.73	23.88	16.42	26.8	13.18	27.22	8.4	17.07	1.27	20.14	2.97	7.86	63.81
10. 5.73	33.96	13.94	-	-	-	-	-	-	-	-	-	-
24. 5.73	39.88	24.86	15.08	12.51	22.59	9.62	10.30	1.70	14.03	13.49	3.93	56.71
7. 6.73	30.24	-	-	-	-	14.59	18.1	2.87	16.12	-	-	>42.6
21. 6.73	25.02	11.07	8.09	5.6	6.92	2.85	5.26	4.3	6.39	5.04	3.17	23.42
6. 7.73	53.67	22.57	22.17	15.33	23.0	9.6	11.07	6.0	9.0	13.8	22.3	28.2
2. 8.73	6.75	31.95	26.3	12.0	34.08	10.11	21.93	11.92	27.4	18.2	32.9	24.6

the north became reduced to levels below those of December. Falloch, Inveruglas, Cailness and AltArdvorlich showed reduction in silicate to 19.9, 25, 16.4 and 21.3 µg at. Si/l. respectively; nevertheless Rubha Ban maintained high levels exceeding 42.6 µg at. Si/l.

Three series of samples were taken on 1 March, and inflows to the north of Inverbeg bar were sampled on 15 March. All 17 inflows were examined while only those to the south were sampled on 28 March. In the south there was a general reduction in silicate levels. The Endrick decreased from its February maximum to 42.6 on 15 March and further to 17.5 µg at. Si/l. on 28 March. The Fruin showed a slight downward movement but stayed high; Luss, Douglas and Blair showed reduction to 19, 26 and 42.6 µg at. Si/l. respectively, the latter falling to half its February peak. In the north Falloch, Inveruglas and Rubha Ban were all reduced on 1 March. By 15 March Falloch and Rubha Ban were all reduced on 1 March. By 15 March Falloch and Rubha Ban increased to reach a maximum of 26.6 µg at. Si/l. and 85.2 respectively, while Inveruglas attained its maximum silicate level, 38.3 µg at. Si/l on 26 March. AltArdvorlich also reached its annual maximum on the 26th following a steady increase.

In April samples were taken from rivers and burns on 12th and 26th. Except for Endrick, Fruin, Inversnaid and Ardess, silicate concentrations in the inflows diminished until 12 April and then showed an upward trend to 26 April. A continuous decrease was shown by the Ardess burn which declined to 5.4 µg at. Si/l. on 26 April. The Inversnaid water fell from 13 in March to 1.7 µg at. Si/l. on 12 April and further still to reach a minimum of 1.27 on 26 April. The silicate content of the Fruin Water was reached 19 on 12 April followed by a further decline to 16 µg at. Si/l. on 26 April. The Endrick was the only inflow which increased during this period, reaching 42.6 on 12 April followed by a fall to 23.9 µg at. Si/l. on 26 April.

The series of samples were taken in May, the entire 17 inflows being sampled on 24 May. Silicate changes during this month was irregular and no distinct pattern was clear. The Endrick, Fruin, Falloch, Coille Mhor river, Blair Burn and Ardess increased while Luss, Douglas, Inveruglas, Cailness, Cashell, Rubha Ban, Stuckindroin and AltArdvorlich showed decreases in silicate levels. The other remained at their previous levels. The Ardess Burn reached its minimum on 10 May falling to 1.4 μg at. Si/l.

All rivers and burns were sampled on 21 June while only those to the south were examined on 7 June. Generally all displayed decrease in silicate levels and the following inflows reached their lowest silicate levels on 21 June; Luss (8.1), Finlas (5.6), Douglas (6.9), Falloch (2.85), Inveruglas (5.3), Rubha Ban (23.4), Cashell Burn (3.2), Coille Mhor River (5.0), Cailness (6.4), and Coille Mhor Loch water (5.9 μg at. Si/l.). Fruin fell to 11.1 and Endrick to 25.0 μg at. Si/l.

On 6 July the seventeen inflows were examined and all showed large increase in silicate levels, in most cases more than double. The Endrick reached 53.7, Fruin 22.6, Luss 22.1, Finlas 15, Douglas 23 and Falloch 9.6 μg at. Si/l.

Silicate levels in samples taken on 2 August, 1973 generally showed an upward movement although Blair Burn was reduced to its annual minimum 6.3 μg at. Si/l., Endrick was reduced to 6.8, and Finlas to 12 μg at. Si/l. The maximum silicate recorded on this occasion was Doublas Water with a value of 34.1 μg at. Si/l.

In summary rivers and burns showed a large range in silicate concentration especially when samples were taken on subsequent weeks. Silicate levels were usually at their minimum during June while maximum levels were found during the winter. The maximum concentration of silicate observed was 115 μg at. Si/l. in the Endrick and BlairBurn. While the minimum was 1.3 μg at. Si/l. recorded in the Inversnaid Water.

The maximum annual range of silicate occurred in the Endrick (111.3) and Blair Burn (112.7) followed by Fruin (56.4); Falloch showed a range of 23.7. The minimum silicate variation (21.7) occurred in the Inversnaid Water. Apart from Rubha Ban the inflows to the north contribute less silicate to the loch than those to the south.

In general the main rivers flowing to the lower loch, Endrick, Fruin, Luss and Finlas reached maximal silicate levels during the winter while of the main inflows to the upper loch, Falloch, Inveruglas, attain their maximum in the spring. Minimum levels of silicate were apparent during June for most rivers and burns, though those inflows with very high levels of silicate show low silicate levels during spring (Blair Burn) or of autumn (Endrick and Fruin).

(c) The four lochs

(i) Lake of Menteith

Silicate level in Lake of Menteith (Fig. 8 and Appendix Table 8) show clear seasonal variation having a distinct maximum in winter and definite minimum in summer. The annual range was about 85 μg at Si/l. From October 1972 to the end of November a decrease of more than 20 μg at.Si/l. occurred at surface and 3 m. This decrease in silicate (54.3 - 32.6 at surface) was coincident with the depression in phosphate levels during November. The winter rise in silicate commenced at the end of November steadily increasing to reach a peak of 85 μg at. Si/l. on 21 February, at the surface and 3 m depth.

A sudden drop in silicate values of around 30 μg at. Si/l. occurred between 21 February to 8 March and further decreased by 25 to reach 29.4 μg at. Si/l. on 26 March at the surface. A further decrease took place till 8 April reducing silicate level by 4 μg at. Si/l. at the surface and 3 μg at. Si/l. at 3 m depth. The concentration of silicate at 3 m depth remained constant (around 26 μg at. Si/l.) till 3 May while the surface showed a further decline of about 5 μg at. Si/l. after 20 April. From 3rd till 17th May surface and 3 m concentration were reduced to half (11.3 and 13.1 μg at. Si/l. respectively). A subsequent continuation of this decline in silicate reduced levels to 1.5 at surface and 2.2 μg at. Si/l. at 3 m depth on 1 June. A further decrease lowered the concentration to a critical level at 0.5 μg at. Si/l. at surface and 3 m depth on 24 June. This depression coincides with phosphate minimum and represents the annual silicate minimum for Lake of Menteith.

The subsequent upward movement of silicate levels reached 36.2 μg at. Si/l. on 20 September with a discontinuity on 26 July when a slight trough was evident. Concentration of silicate in Lake of Mentieth did not fall below 45.8 μg at. Si/l. during the winter months (December, January, February) or below 11.3 μg at. Si/l. throughout spring (March, April, May). During the summer months the minimum levels were 0.5 μg at. Si/l. at surface and 3 m depth while autumn values did not decline below 32.6 μg at. Si/l.

Surface and depth curves usually showed a great similarity in silicate concentration. However, on 1 November, 1972 the surface silicate exceeded depth values by 2 μg at. Si/l., on 15 November by 8 while on 29 November surface level fell below that at 3 m depth by 9 μg at. Si/l.

The only significant tributary to Lake of Menteith is the Burn of Menteith. There was no regular (Table 8(b)) seasonal pattern of silicate variation in this burn. The minimum silicate content of the inflow was 27.7 μg at. Si/l. on 26 July while the maximum level recorded was 93.3 μg at. Si/l. on 8 March. During winter levels did not fall below 53.3 The autumn minimum was 43.4, and the spring minimum was 29.8 and the summer minimum was 27.7 μg at. Si/l. Although these figures suggest a seasonal decline in silicate the maximum for each of these periods rises almost to winter level.

In general silicate levels were very high, showing the seasonal range less than that of the loch itself.

(ii) Loch Rusky

The general pattern of seasonal variation of silicate in Loch Rusky (Figure 9 and Appendix Table 8) was clear with a distinct winter maximum and a marked summer minimum when this nutrient was reduced to trace levels. The annual maximum was greater than for any of the other lochs studied. A remarkably close correlation exists between surface and depth concentration, the silicate values generally being identical.

A decline in silicate concentration at surface and 5 m depth from 18 October, 1972 to 1 November reduced silicate levels by about 6 g at. Si/l. to 18.5. This minimum corresponds with the depression in phosphate at this station, but precedes the silicate minimum in Lake of Menteith by almost 4 weeks. The minimum persists till 15 November, the winter increase first being evident on 29 November (2 weeks prior to the increase in Lake of Menteith). The upward trend in silicate levels was gradual till the 7 February when the concentration of silicate was 53 µg at.Si/l. at surface and depth. An abrupt rise in the level of dissolved silicate follows reaching a value of 85 µg at. Si/l. on 21 February and attaining a maximum of 93 µg at. Si/l. at surface and 5 m on 8 March. This was two weeks later than the maximum in Lake of Menteith.

Silicate levels then plunged by 78 µg at. Si/l. in two weeks, the largest single decrease recorded for any loch. The resulting concentrations were 15.0 at surface and 14.3 µg at. Si/l at 5 m depth on 26 March. A small increment in silicate levels of 3 µg at. Si/l. occurred on 20 April, following which silicate decreased to a summer minimum of 0.4 and 0.5 µg at. Si/l. at surface and 5 m depth respectively on 1st June. A sustained rise in silicate ensued reaching 9.2 µg at. Si/l. on 28 June, followed by a further decline to a late summer minimum of 2.3 and 3.1 µg at. Si/l. at surface and 5 m respectively on 26 July. These two summer minimum in silicate coincided with phosphate minimum at the same station. The subsequent rise in silicate levels reached more than 16 µg at. Si/l. at surface and 5 m depth on 20 September.

The main inflow to Loch Rusky is the Letter Burn which, unlike the Burn of Menteith, displays a fairly distinct seasonal cycle of silicate (Table 8(b). The maximum recorded silicate content (92.3 µg at. Si/l.) occurred on 10 January following a sustained increase from 15 November. Following this maximum, silicate showed a downward trend reaching a summer minimum of 0.3 µg at. Si/l. on 14 June. An abrupt increase took place during the next two weeks raising silicate level to 60.5 µg at. Si/l. on 28 June. This high level persisted throughout the late summer and autumn but fluctuated widely.

Winter silicate levels vary between 64 and 92 µg at. Si/l.; thus the summer maximum, 60 µg at. Si/l, is less than the winter minimum. The annual range of silicate concentration was 92 µg at. Si/l. which is almost exactly equal to that of the loch

(iii) Loch Achray

The variation in the level of silicate in Loch Achray (Figure 11 and Appendix Table 8) show a distinct seasonal cycle though the magnitude of the changes is less than in Loch Rusky and Lake of Menteith. The range of silicate concentration is only 24 µg at. Si/l. which is less than one-third the range of the previously described lochs. The silicate changes at surface and depth show little similarity at certain times of the year.

From 18 October, 1972 a gradual upward trend in silicate was apparent. A discontinuity in the pattern of increase occurred at surface and 5 m depth from 1 to 15 November, corresponding with the autumn minimum in phosphate. Surface silicate levels rose, first gradually and then steeply to reach an annual peak of 34.4 µg at. Si/l. on 27 December. This maximum preceded that in the silicate content of Loch Ard, Loch Rusky and Lake of Menteith by-2 months and was the first nutrient to reach a maximum level in Loch Achray. By 24 January surface levels declined to 21.3 and persisted around this level till the beginning of May.

An entirely different pattern can be discerned at 5 m depth. Here the silicate level rose rapidly from 14.1 on 15 November to 22.3 µg at. Si/l. on 13 December, followed by a gradual sustained increase to reach a maximum of 28 µg at. Si/l. on 7 February. This peak is about 6 µg at. Si/l. lower than the surface maximum and occurred six weeks later. A rapid decline brings the 5 m depth concentration of silicate into line with those at the surface (18.9 and 19.1 µg at. Si/l. respectively).

From 8 March levels showed a slight downward tendency until 3 May which was followed by an abrupt drop in silicate levels falling to 8.2 µg at. Si/l. at both surface and 5 m depth. The lowest point of the summer depression is reached on 1 June when silicate levels reach 7.4 µg at. Si/l. at surface. This coincided with the summer minima in Loch Rusky and Lake of Menteith. On 28 June concentrations doubled at both depths to reach 14 µg at. Si/l. and thereafter declined persisting around 11 µg at. Si/l. till completion of sampling.

The silicate levels in the main inflow to Loch Achray, Achray Water (see Table 8(b)) showed an irregular pattern of variation. The maximum level recorded in the inflow was 28.3 µg at. Si/l. on 10 January; this was less than the annual silicate maximum in Loch Achray, the minimum recorded silicate content was 1.34 µg at. Si/l. on 17 May, giving an annual range of 27, exactly the same as for the loch itself.

General features of silicate in Achray Water are: from 1 November to 10 January levels exceeded 20 µg at. Si/l., from 24 January to 3 May levels usually exceeded 15 µg at. Si/l., from 17 May onward silicate was less than 10 µg at. Si/l.

(iv) Loch Ard

The seasonal variation in silicate level in Loch Ard (Figure 10, Appendix Table 8) shows a single distinct feature, the winter maximum with a less distinct summer minimum. The annual range at this station was from 21.~~to~~ 9 µg at. Si/l. to 12 µg at. Si/l.; this is by far the smallest degree of variation shown for any of the four lochs.

An initial decrease occurred at surface and 5 m depth between 18 October and 1 November; this was coincident with the autumn minimum of phosphate. The gradual but sustained increase towards a winter maximum began on 29 November, increasing steadily to a peak value of 21 µg at. Si/l. at the surface and 20 µg at. Si/l. at 5 m depth on 21 February. This occurred simultaneously with the maximum in Lake of Menteith. Concentrations declined at the same rate as they increased. A short plateau occurred on 3 May following which silicate fell to a minimum of 9 µg at. Si/l. at the surface on 14 June and at 5 m depth on 28 June. Silicate then increased to reach a steady level around 10 rising further to 12.5 µg at. Si/l. on 20 September.

Silicate levels in the two main inflows to Loch Ard (Table 8(b)) were investigated. The Ledard Burn showed roughly double the silicate concentration of the Water of Chon. Neither displayed any consistent variation though both inflows maintained higher silicate levels from 18 October until 3 May. The values for the Ledard Burn lay between 30-40 µg at. Si/l.

while the Water of Chon recorded silicate levels between 15 and 25 µg at. Si/l. Ledard Burn reached maximum level of silicate (43.4) on 1 November while the Water of Chon showed a peak of 28.3 µg at. Si/l. on 24 January. The summer minimum were recorded on 1 June in Water of Chon (2.1 µg at. Si/l.) and on 11 July in Ledard Burn (12.6 µg at. Si/l.). The annual range of silicate levels in the two inflows is fairly similar, being 30.8 µg at. Si/l. in the Ledard Burn and 26.2 µg at. Si/l. in the Water of Chon.

3) Nitrate + Nitrite

(a) Loch Lomond

Nitrate plus nitrite in Loch Lomond was generally high throughout the year, never falling below a value of 4.0 µg at.N/l. The nitrite content of the water was always low and constituted only a small proportion of the total nitrate plus nitrite values. Any reference to nitrate in this section will be to the combined value of nitrate plus nitrite.

A clear seasonal cycle of nitrate with a distinct winter maximum and summer minimum was evident at the six stations in Loch Lomond. The maximum recorded nitrate concentration and the highest range of values were found at the South Balmaha station while the smallest maximum and least range of values occurred at the three northern stations. Events at surface and depth generally corresponded at all stations throughout the year.

In the South station of Loch Lomond in 1972 (Figure 13 and Appendix Table 9) nitrate fell from its April level (18.19 µg at. N/l.) to reach a spring depression at all depths on 4 May, 1972. This was coincident with the spring decrease at the North and Middle stations, although values here did not fall below 16 µg at. N/l. The subsequent increase in nitrate reached 21.8 µg at. N/l. at 5 m depth at the end of May while the highest surface value of 19.5 µg at. N/l. was not observed till 12 June. Nitrate concentration at this station then showed a fluctuating downward trend reaching an annual minimum of around 10 µg at. N/l. at surface and at 3 m depth on 1 August. This minimum was not found at 5 and 10 m depth until 29 August.

A distinct nitrate increase coinciding with increased phosphate and silicate was apparent on 6 September, 1972, rising to a maximum of 13.7 µg at. N/l. at the surface and 14.1 at 5 m depth on 12 September. This maximum preceded the September increase at the north and middle stations.

During October a fall in nitrate levels was obvious at all depths, reaching a minimum on 25 October. The winter increase, first became apparent at all stations on 23 November attaining a maximum of around 22.5 µg at. N/l. at all depths on 17 January. These high levels persisted for a month, followed by a decline to a spring minimum of about 17 µg at. N/l. at the surface on 28 March, and all depths a fortnight later. A subsequent upward trend in levels produced a transient peak of 20 µg at. N/l. on 26 April. Following this was a sudden drop to 16.0 µg at. N/l. at the surface on 2 May with a more gradual decline taking place at depth. Till 6 July levels fluctuated between 15 and 16 µg at. N/l. subsequently falling abruptly at surface and 3 m to 8.8 and 8.9 µg at. N/l. respectively on 24 July. A more gradual decline to the summer minimum occurred during the following two weeks to reach 7.7, 5.04, 6.2 and 7.2 µg at. N/l. at surface, 3 m, 5 m and 10 m depth respectively on 2 August. This was accompanied by a simultaneous minimum at all stations to the north. The increase during August raised levels of nitrate above 9.5 µg at. N/l. on 17th.

Minimum nitrate levels in 1972 were two-fold higher (10.1) than in 1973 (5.04 µg at. N/l.). Maximum nitrate level recorded during the period of sampling at South station was 22.7 µg at. N/l. giving an annual range of 17.7 µg at. N/l.

The annual variation in nitrate in the Middle station of Loch Lomond (Figure 14 and Appendix Table 10) showed the same general features as the South station, although the range of nitrate concentration (19.7-4.8 µg at. N/l.) was less; variations at each depth generally followed each other, even during the summer period.

The high nitrate levels recorded at all depths on 14 April, 1972 showed a marked decline by the following week, a reduction of 19.5 to 15.6 µg at. N/l. occurred at the surface and 19.7 to 14.8 µg at. N/l. at 3 m depth. A decrease in nitrate concentration at 5 m and 10 m depth was not evident till two weeks later, when a similar reduction occurred. The lowest value recorded at the surface (13.2 μg at. N/l.) occurred on 4 May accompanying the spring minimum of phosphate and silicate. From 4 May to 12 June an irregular rise in nitrate concentration occurred, this increase being most prominent at the surface where a maximum value of 18.2 μg at. N/l. was recorded. The change at 5 m depth was only marginal, rising from 15.3 to 16.9 g at. N/l., A sustained decline followed at all depths reaching a summer nitrate minimum of 10.5, 10.1 and 11.1 μg at. N/l. at surface, 3 m and 5 m on 1 August. The lowest recorded nitrate concentration at 10 m depth (11.7) was not attained till 15 August. In contrast the depression of silicate was noticeably later, not reaching its minimum till 6 September.

During September a general increase in nitrate values was obvious at all depths, reaching a maximum on 11 October when the greatest concentration recorded was 14.8 μg at. N/l. at the surface. This was later than the rise in nitrate at North and South stations. This peak was transient, and levels fell to 12.2 μg at. N/l. at all depths on 25 October.

A sustained increase followed, culminating in a peak on 17 January of 18.1, 19.2, 19.1 and 18.5 μg at. N/l. at surface, 3 m, 5 m, and 10 m depth respectively. This coincided with the winter maximum at the South and North stations. The subsequent decline in nitrate levels was first gradual and then steep, falling to a very distinct minimum of 12.4 μg at. N/l. at the surface on 1 March. A considerable increase followed at all depths rising to a maximum of 17.6, 18.1, 16.6 and 17.0 μg at. N/l. at the surface, 3 m, 5 m and 10 m depth respectively on 12 April. A period of sustained but gradual decline took place till 24 May, followed by a drop of 3 μg at. N/l. to reach 13 to 13.5 μg at. N/l. on 7 June. A plateau in nitrate values persisted till 6 July when concentrations fell to between 5.5 to 6.0 μg at. N/l. on 24 July, decreasing still further to 4.8 at the surface on 2 August. By 17 August nitrate was on the increase at all depths.

The minimum value of nitrate at this station was 10.1 μg at. N/l. in 1972 and 4.8 in 1973; in this respect the Middle station resembled the South though its annual maximum (19.7 μg at. N/l.) was less.

The seasonal changes in nitrate at the North station of Loch Lomond (Figure 15 and Appendix Table 11) were less considerable than the variation recorded at South and Middle stations. Nitrate concentrations never fell below 7 μg at. N/l. at any depth or rose above 16.1; nevertheless within this scope of variation, the annual pattern generally followed the changes described for the Middle and South stations. The week to week variation of nitrate at each depth sometimes showed little similarity with the surface, although the general pattern was similar.

Surface and 3 m depth sample showed a decline in nitrate concentration from 13.4 and 14.8 on 14 April, 1972 to 10.3 and 12.3 μg at. N/l. respectively on 20 April. The lowest value, recorded at 3 m depth (10.08 μg at. N/l.), occurred on 4 May, coinciding with the spring nitrate minimum at the South and Middle stations. A subsequent rise in levels was more gradual at the surface than depths, reaching the highest level at 3 m, 5 m and 10 m depth (14.6, 13.6 and 15.0 μg at. N/l. respectively) on 29 May. The surface maximum (13.1) was recorded a week later; although a small trough was evident at the surface between 19 and 27 June, the sustained decrease shown at the other stations after 12 June was absent. The actual decline toward a summer depression occurred between 10 July and 1 August falling by 2.9 μg at. N/l. to a nitrate minimum of 9.8 μg at. N/l. at surface on 1 August, 1972.

Till 12 September surface and depths nitrate values fluctuated between 10 and 11.5 μg at. N/l. followed by an increase on 27 September to 12.7 at the surface and 3 m, and to around 12.2 μg at. N/l. at 5 m and 10 m depth. An additional rise at 3 m, 5 m and 10 m on 11 October brought the nitrate concentration to 13.2 μg at. N/l. A marked decline occurred at surface, 3 m and 5 m depth on 25 October though the nitrate value at 10 m depth continued to rise. By 23 November an increase in nitrate levels was apparent at all depths, gradually reaching a winter maximum of 16.1 μg at. N/l.

at 3 m depth on 17 January, and 15.8 at the surface on 1 February.

Nitrate levels then showed a steady decline reaching a spring minimum of 9.7 at surface and 9.5 µg at. N/l. at depths on 26 April. This was considerably later than the spring decrease in nitrate at the South and Middle stations but coincided with the spring minimum at North Inversnaid and North Falloch. Concentrations at the surface subsequently showed a slight increase and then remained constant (10.4 - 11.0 µg at. N/l.) till 6 July, falling steeply thereafter to a summer minimum of 7.0 µg at. N/l. on 2 August. 5 m and 10 m depth samples exhibited a different pattern, rising steeply from the spring minimum to 14 at 5 m depth and 12.5 µg at. N/l. at 10 m depth on 24 May. A steady decline ensued reaching respective summer minima of 8 and 9 µg at. N/l. on 2 August. By 17 August nitrate was on the increase at surface and depths.

The minimum summer concentration of nitrate recorded in 1972 was 9.6 while this nutrient fell to 7.0 µg at. N/l. in summer 1973. The difference between the two years was not as marked as it was in the Middle and South stations.

Generally the North Inversnaid station (Table 11) showed close similarities to the North station of Loch Lomond, though its maximum and minimum nitrate values (15.3 and 5.4 µg at. N/l.) were slightly less than the corresponding values for the North station.

The nitrate levels at this station in August and September were only marginally different, remaining around 11 µg at. N/l. at surface and depth. A slight decline was evident on 11 October rising again on 23 November to 10.3 at surface and 10.6 µg at. N/l. at 3 m depth. This marked the commencement of the winter increase in nitrate. A sharp rise ensued during the next two weeks raising levels to 14 at the surface and 13.7 µg at. N/l. at depth. On 7 December a more gradual increase in nitrate levels continued till 1 March when the winter maximum of 15.2 µg at. N/l. at surface and 15.3 at 3 m depth was recorded. This was one month later than the maximum at North station.

Following this peak nitrate remained high till 15 March and then fell to 12.3 μg at. N/l. at the surface on 12 April. A further gentle decline reduced levels to 11.5 μg at. N/l. on 24 May after which values increased to a surface maximum of 12.9 μg at. N/l. on 7 June. A downward trend ensued with a sustained fall at surface and depth reaching respective summer minima of 5.6 and 5.4 μg at. N/l. on 2 August. This depression occurred concurrently with the summer minima at North, North Falloch, Middle and South stations. The range of nitrate values at this station was 9.9 μg at. N/l. showing a close similarity with the North and North Falloch stations.

The annual range of nitrate at North Falloch station (Table 11) was from 14.2 μg at. N/l. in March to 4.1 μg at. N/l. in August; this is slightly greater than that of North Inversnaid and North station. Levels of nitrate at this station increased from 9.5 μg at. N/l. on 15 August to 11.4 on 12 September; this coincided with the phosphate peak. A decrease ensued reducing surface concentrations of nitrate to 9 μg at. N/l. on 11 October. The sustained increase in nitrate, first apparent on 23 November, continued till 4 January when a value of 13.7 was recorded at the surface. A very gradual upward trend in nitrate values followed reaching a maximum value of 14.2 μg at. N/l. at surface and 13.8 at 3 m depth on 15 March. This peak was two weeks later than the winter maximum at the North Inversnaid station.

A rapid decrease in nitrate levels followed, reducing the surface level to 10.3 and depth to 10.4 μg at. N/l. on 12 April. A small depression of 1.5 μg at. N/l. occurred on 26 April, following which levels increased to 12.1 at surface and depth on 7 June. This maximum coincided with the highest June nitrate values in the North Inversnaid station. The subsequent decline was rapid till 24 June (7.3 at surface) followed by a shallow decrease reaching a minimum of 5.2 μg at. N/l. and 4.3 at surface and 3 m respectively on 2 August. This was concomitant with the summer minimum of nitrate throughout the loch. By 17 August nitrate was again showing an upward trend, reaching 7.2 μg at. N/l. on 17 August.

The nitrate concentrations recorded for the South Balmaha station (Table 11) exhibited a greater annual range than for any other station in Loch Lomond. The values varied from a maximum of 23.1 µg at. N/l. in February to a minimum of 4.3 in July, a difference of 18.8 µg at. N/l.

Nitrate concentrations of 7.4 µg at. N/l. at this station in August were noticeably lower than levels at any other stations in Loch Lomond and more than 5 µg at. N/l. lower than values for the South station. By 6 September concentrations had increased to 8.7 at the surface and 9.2 µg at. N/l. at 3 m depth. The gradual upward trend continued till 25 October raising levels to 12.4 µg at. N/l. at both depths to marginally exceed levels throughout the rest of the loch. On 23 November the concentration of nitrate was still rising steadily at 3 m depth though the surface concentration had only increased marinally. Nitrate values then climbed continuously at both depths reaching 19.8 and 21.2 µg at. N/l. at surface and depth respectively on 17 January. The subsequent increase produced a winter maximum on 15 February of 23.1 µg at. N/l. at the surface and 22.1 at depth. These are the highest nitrate values recorded at any station in Loch Lomond. These high concentrations remained till 15 March and were followed by a sharp decline to 16.7 µg at. N/l. at the surface and 16.3 at depth on 26 March. This downward movement continued, reaching about 13.2 µg at. N/l. at both depths on 12 April. This occurred simultaneously with the spring minimum of silicate at this station. An increase at 3 m depth on 26 April was followed by a similar increase at the surface two weeks later. The continual rise culminated in a surface maximum of 17.2 µg at. N/l. on 7 June with a maximum at 3 m (18.4) on the 24 June. This preceded the June peak in the South station by two weeks.

An abrupt decrease between 24 June and 6 July reduced nitrate concentration by almost a half, with a similar decrease taking place between 6 and 24 July. The nitrate reached its summer minimum on this date, 5.2 µg at. N/l. at the surface and 4.3 at 3 m depth. Both the timing of the decrease and the time of the minimum were 2 weeks earlier than for the South station.

In general, it is evident that the North station of Loch Lomond possesses the lowest annual range of nitrate. The difference between the nitrate maximum and minimum was 9.1 µg at. N/l. at North station which increased to 9.9 at the North Inversnaid station and reached 10.1 at North Falloch station. Passing southwards (Map 2) from the North station the range rose to 14.9 at the Middle station, increased still further to 17.7 µg at. N/l. at the South station, and reached a maximum of 18.8 at South Balmaha. This showed exactly the same pattern as silicate.

The maximum recorded level of nitrate at each station diminished passing from south to north. The highest nitrate value was observed at South Balmaha (23.1 g at. N/l.) while the maxima for subsequent stations were as follows: South (22.7), Middle (19.7), North (16.1), North Inversnaid (15.3) and North Falloch (14.2).

The minimum concentration of nitrate was highest at the North station (7.0 µg at. N/l.) less at the Middle and South stations (4.8 and 5 µg at. N/l.) and least at the South Balmaha (4.3). Passing northward from the North station the minimum was less at North Inversnaid (5.4) while at the North Falloch station the lowest nitrate value for any station (4.1 µg at. N N/l.) was recorded.

The three stations studied throughout 1972 and 1973 show lower minimum nitrate level in the latter year. The lowest recorded levels in 1972 were respectively 9.8, 10.1 and 10.1 µg at. N/l. in North, MIddle and South stations while in 1973 the minima were 7.0, 4.8 and 5.0 µg at. N/l.

The appearance of the winter increase was earliest at the South Balmaha station on 25 October. The summer minimum of nitrate occurred simultaneously at all stations in the Loch on 2 August.

(b) Rivers and Burns

Generally the rivers and burns flowing into Loch Lomond show a nitrate content at less than 15 µg at. N/l. except for the Endrick and Fruin which remain at high levels throughout the year. The recorded nitrate concentration in the inflows (Tables 6, 7, 10 and Fig. 5, 6, 7) range from a maximum of 75.9 µg at. N/l. in the Endrick and Blair Burn to trace quan-

Table 10. Nitrate + Nitrite (µg. atom N/l) of the rivers and streams inflowing to Loch Lomond.

Date	Endrick	Fruin	Luss	Finlas	Douglas	Falloch	Inveruglas	Inversnaid	Cailness	Coille Mhor Burn	Cashell	Rubha Ban
8. 8.72	39.72	9.8	3.7	3.36	1.86	-	-	-	-	6.4	0.07	-
15. 8.72	-	-	-	-	-	2.32	2.7	6.4	5.1	-	-	25.09
6. 9.72	26.97	49.68	12.77	11.76	19.26	-	-	-	-	12.2	6.69	-
12. 9.72	-	-	-	-	-	2.95	2.28	1.59	13.87	-	-	15.8
11.10.72	47.76	57.4	11.56	22.42	6.3	23.78	5,74	3.97	2.95	7.9	1.10	16.4
25.10.72	46.06	21.9	5.54	5.67	5.08	-	-	-	-	1.31	0.39	-
23.11.72	52.91	21.13	2.34	12.08	10.39	6.0	6.0	3.0	3.0	10.6	5.34	22.2
7.12.72	-	-	-	-	7.74	1.87	4.25	1.09	1.93	-	-	27.41
21.12.72	60.0	25.0	12.0	10.00	-	-	-	-	-	11.8	12.3	-
4. 1.73	65.0	30.0	14.0	8.00	8.00	5.7	9.3	5.52	4.29	13.3	14.6	10.22
1. 2.73	-	-	-	-	-	4.38	4.36	6.97	6.69	-	-	16.93
15. 2.73	75.88	36.12	16.32	5.29	13.67	-	-	-	-	16.1	20.73	-
1. 3.73	-	-	-	-	-	9.2	8.6	2.0	1.6	-	-	13.08
15. 3.73	57.72	49.88	13.95	15.45	14.91	5.47	8.61	2.55	5.19	15.23	4.28	16.68
26. 3.73	36.48	41.04	6.15	11.4	5.92	2.5	5.01	-	-	4.56	-	-
12. 4.73	-	-	-	-	-	-	-	-	-	-	-	-
26. 4.73	56.88	61.88	9.75	7.6	12.37	3.09	4.99	3.3	3.3	5.23	1.9	13.38
10. 5.73	48.3	27.82	-	-	5.53	-	-	-	-	0.30	-	-
24. 5.73	30.69	36.63	3.47	3.82	3.84	trace	1.05	0.1	trace	0.20	0.15	11.57
7. 6.73	33.2	-	-	-	-	6.45	3.52	0.20	0.15	-	-	13.88
21. 6.73	49.0	13.1	4.9	7.25	5.14	2.42	1.47	0.83	0.68	1.81	1.66	16.68
6. 7.73	36.52	19.62	7.2	6.18	6.67	24.59	1.46	3.0	2.0	2.1	2.3	12.3
2. 8.73	20.43	54.88	7.00	8.00	9.35	3.3	3.67	3.38	2.00	3.67	3.72	8.9

tities found occasionally in the Falloch and some other small burns. In general the small burns have the lowest nitrate levels, which usually lie below 5 and rarely rise a bove 10 µg at. N/1. The main inflows to the lower loch have slightly higher levels only falling below 5 µg at. N/1. for a brief period in the summer. The seasonal pattern was irregular, nevertheless there was a tendency for maximal nitrate value to occur in the winter and autumn with lower levels in summer.

During August 1972 samples were taken from rivers and burns south of Inverbeg bar on 8th while on 15th the inflows to the north of this bar were investigated. Nitrate levels were generally low throughout the catchment area. Five of the inflows showed their minimal recorded nitrate content: Fruin, 9.8, Finlas 3.4, Douglas 1.9 µg at. N/1; in Cashell and Blair Burn nitrate was almost undetectable. The Luss Water was slightly above its minimum nitrate level and the Endrick also exhibited a comparatively low nitrate value (39.7 µg at. N/1.). Main inflowing streams to the upper loch were also low in nitrate, the respective values for the Falloch, Douglas and Inveruglas being 2.3, 1.9 and 2.7 µg at. N/1.. However Allt Ardvorlich and Rubha Ban recorded their maxima (12.3 and 25.1 respectively). Two other burns, Stuckindroin and Ardess, also showed relatively high nitrate levels, 9.8 and 10.3 µg at. N/1. respectively.

In september the rivers and burns south of the Inverbeg bar were sampled on 6th and the inflows to the north were studied on the 12th. Generally an increase in nitrate was apparent during this month with Douglas and Cailness reaching their maxima (19.3 and 13.9 µg at. N/1. respectively). The increase in the other burns and rivers to the upper loch was only marginal. The main inflows to the lower loch increased by more than three fold; Fruin to 49.7, Luss to 12.8, Finlas to 11.8, Blair and Cashell Burn to 14.3 µg at. N/1. on 6 September. The Endrick showed a slight decrease to 27 µg at. N/1.

All 17 rivers and burns were investigated on 11 October while only those to the south of the Inverbeg bar were sampled on 25 October. On 11 October the main inflows to the lower loch were on the increase (Endrick

Table 11.

	Nitrate + Nitrite (µg. at. N/l.)						p^H					
	South Balmaha		North Inversnaid		North Falloch		South Balmaha		North Inversnaid		North Falloch	
Date	Surface	3 m	Surface	3 m	Surface	3 m	Surface	3 m	Surface	3 m	Surface	3 m
8. 8.72	7.4	-	-	-	-	-	7.3	7.4	-	-	-	-
15. 8.72	-	-	10.69	11.0	9.46	10.8	-	-	7.0	7.0	6.9	7.0
6. 9.72	8.7	9.2	-	-	-	-	7.5	7.4	-	-	-	-
12. 9.72	-	-	10.95	11.17	11.4	12.1	-	-	7.1	7.0	6.8	6.8
11.10.72	-	-	9.22	9.8	9.00	9.2	-	-	7.0	6.9	6.8	6.8
25.10.72	12.44	12.4	-	-	-	-	7.3	7.4	-	-	-	-
23.11.72	12.92	14.81	10.3	10.6	10.1	10.8	7.3	7.3	6.9	6.9	6.7	6.7
7.12.72	15.3	16.3	13.99	13.7	11.4	11.8	7.2	7.2	6.8	6.9	6.7	6.8
21.12.72	18.4	17.9	-	-	-	-	7.2	7.2	-	-	-	-
4. 1.73	-	-	14.11	14.3	13.7	13.9	-	-	6.7	6.8	6.6	6.6
17. 1.73	19.8	21.2	-	-	-	-	7.1	7.1	-	-	-	-
1. 2.73	-	-	14.54	14.8	13.55	13.4	-	-	6.7	6.6	6.4	6.5
15. 2.73	23.1	22.1	-	-	-	-	7.2	7.1	-	-	-	-
1. 3.73	-	-	15.2	15.3	13.4	12.6	-	-	6.6	6.6	6.3	6.3
15. 3.73	22.8	21.3	14.69	13.8	14.22	13.8	7.3	7.4	6.6	6.6	6.4	6.4
26. 3.73	16.73	16.3	-	-	-	-	7.5	7.4	-	-	-	-
12. 4.73	13.2	13.1	12.3	12.8	10.3	10.4	7.6	7.5	6.7	6.8	6.5	6.6
26. 4.73	13.13	17.65	11.9	11.63	8.9	9.7	7.3	7.3	6.8	6.9	6.8	6.8
24. 5.73	15.39	13.83	11.52	11.77	10.26	10.61	7.4	7.3	6.8	6.8	6.8	6.8
7. 6.73	17.2	16.8	12.9	12.1	12.1	12.1	7.3	7.3	6.7	6.7	6.6	6.6
24. 6.73	16.7	18.3	12.05	12.88	7.25	10.97	7.3	7.3	6.8	6.8	6.5	6.6
6. 7.73	10.3	8.9	9.8	9.3	6.7	7.3	7.4	7.4	6.9	6.9	6.7	6.6
24. 7.73	5.2	4.3	7.8	6.5	5.2	4.3	7.7	7.4	6.8	6.8	6.7	6.7
2. 8.73	7.05	7.49	5.56	5.43	5.29	4.06	7.6	7.5	6.9	6.9	6.7	6.8
17. 8.73	9.7	9.1	7.7	7.3	7.2	7.3	7.4	7.3	6.9	7.0	6.8	6.9

47.8, Fruin 57.4) or showed little change (Luss and Coille Mhor). The Finlas reached its annual maximum of 22.4 μg at. N/l., while Douglas Water declined to 6.3 and Cashell Burn to 1.1 μg at. N/l. On 25 October Finlas was drastically reduced to 5.7 μg at. N/l. while Cashell and Blair Burns fell to trace levels, Fruin and Luss were reduced to half and Endrick remained constant. The rivers and burns to the north increased considerably, Stuckindroin reaching its highest level of the year (15) and the Falloch increased from 3.0 μg at. N/l. to 23.8. Cailness, AlltArdvorlich and Ardess Burns decreased to 3.0, 2.7 and 8.6 μg at. N/l. respectively.

On 23 November all inflows to Loch Lomond were sampled. Those inflows to the lower loch either showed an increase or remained the same. Blair, Coille Mhor and Cashell showed a significant increase to 4.9, 10.9 and 5.3 μg at. N/l., Douglas and Finlas doubled in nitrate concentration while the Endrick and Fruin showed little change. Inflowing streams to the north either showed no change or exhibited a decreased nitrate content, the most marked being in the Falloch where levels fell from 23.8 to 6.0 μg at. N/l. Both AlltArdvorlich and Stuckindroin showed diminished levels of this nutrient and only Rubha Ban increased.

During December samples were taken from the inflows north of the Inverbeg bar on 7th and from those south of the bar on 21st. Most inflowing streams to the upper loch showed a distinct decrease in nitrate levels, Inversnaid to 1.1, Cailness to 1.9, Inveruglas to 4.3, Falloch to 1.9, Douglas to 7.7 and AlltArdvorlich to 1.2 μg at. N/l. Rubha Ban increased to 27.4 and Ardess to 8.3 μg at. N/l. In the catchment area of the lower loch an increase in nitrate was generally apparent. The Endrick and Fruin showed a further rise to 60 and 25 μg at. N/l. respectively, Luss increased to 12, Cashell to 12.3, Blair Burn to 18.3 and Coille Mhor Loch Water to 15.8 μg at. N/l.

On 4 January all rivers and burns were sampled and a general upward trend in nitrate levels was evident. The Inveruglas attained its annual maximum of 9.3 μg at. N/l. and only Rubha Ban decreased to 10.2 μg at. N/l.

During February inflows to the north of Inverbeg bar were examined on 1st while those to the south were sampled on 15th. The upward trend of nitrate levels continued throughout the month with many inflows reaching their annual maxima, Endrick (75.9), Luss (16.4), Inversnaid (6.97, Coille Mhor River (16.1),Cashell (20.7, Blair (75.9) and Ardess (15 µg at. N/1.).

On 1 March the rivers and burns to the north of Inverbeg bar were examined, on 15th all inflows were sampled and those to the south of Inverbeg bar were sampled again on 26 March. A general decline in nitrate levels was obvious, the greatest reduction being in Blair Burn which fell from 75.9 to 2.0 µg at. N/1. in four weeks. Considerable decreases in nitrate content were also apparent in Luss, Douglas, Falloch, Inveruglas, Coille Mhor River and Cashell Burn. Other inflows remained constant or fluctuated irregularly, Increases were recorded in the AlltArdvorlich, Fruin and Coille Mhor Loch Water which reached its annual maximum of nitrate, 20.0 µg at. N/1., on 15 March.

Some of the small burns were examined on 12 April and all inflows were sampled on 26 April. During this period Douglas Water increased to 12.4 µg at. N/1. The Endrick was still increasing (56.9) and the Fruin reached its maximum on 26 April (61.9 µg at. N/1.). Nearly all the other inflows remained constant or fluctuated about a mean level except for Coille Mhor Loch Water which decreased to 8.2 and Ardess to 4.0 µg at. N/1.

Some of the burns and rivers were investigated on 10 May while complete sampling of the inflowing streams was carried out on 24 May. A conspicuous feature of this month was the marked reduction in nitrate concentrations with nearly all inflows approaching their minimum levels. Concentrations of less than 1.0 µg at. N/1. were found in the Falloch, Inversnaid, Cailness, Coille Mhor River, Blair, Cashell and Stuckindroin Burn. The Endrick declined to 33.2 µg at. N/1. and the Fruin to 36.6. A marginal increase was recorded in Ardess and AlltArdvorlich Burns.

On 7 June rivers and burns to the north of Inverbeg bar were sampled and on 21 June samples were taken from all inflows. An overall rise in nitrate levels was clear during this month with the exception of the Coille Mhor Loch Water, Ardess, AlltArdvorlich and Stuckindroin Burns which reached their lowest nitrate values. The Fruin continued to decline while the Endrick reached a prominent peak at 49.0 μg at. N/l.

Samples were taken from all 17 rivers and burns on 6 July and 2 August. Generally nitrate levels showed a small upward movement although the Endrick and Rubha Ban fell to reach their annual minimum of 20.4 and 8.9 μg at. N/l. respectively. The Falloch reached a short-lived maximum on 6 July rising from 2.4 on 21 June to 24.6 μg at. N/l. and then decreased again to 3.3 on 2 August. Fruin and Blair Burn showed sharp rises to 54.9 and 14.2 μg at. N/l. respectively; Luss, Finlas and Douglas Water fluctuated between 6 and 9 μg at. N/l. while the small burns generally remained below 5.0 μg at. N/l.

In general the seasonal pattern of nitrate in the inflows from the Loch Lomond watershed showed a clear maximum in February and March. This is slightly later than the maximum observed in the North, Middle and South stations of the Loch. All inflows showed a depression in nitrate content in May and June with many reaching their minimum levels during this period.

The inflows to the upper loch, with the exception of Rubha Ban, possessed a lower average nitrate content than those to the south. Generally the levels were less that the corresponding levels in the loch itself, and rarely rose above 10 μg at. N/l. In the south the Endrick and Fruin usually exceeded the nitrate content of the loch, the Endrick being exceptionally high in this respect, never falling below 20 μg at. N/l.

(c) The four lochs

(i) Lake of Menteith

Nitrate levels in Lake of Menteith (Table 12 in Appendix and Figure 8) show a range between maximum and minimum values of 16.1 μg at. N/l; this is similar to the nitrate variation in the South station of Loch Lomond. The nitrate in Lake of Menteith, however, fell to almost undetectable levels during the summer, a phenomenon not observed in Loch Lomond.

The surface nitrate concentration on 18 October, 1972 was 5.7 μg at. N/l.; this diminished to low level on 1 November (1.4 μg at. N/l. at both depths). The marginal rise in nitrate at surface and 3 m depth on 29 November marked the commencement of the winter increase. An abrupt upsurge in the nitrate concentration followed, reaching 7.8 at the surface and 7.4 μg at. N/l. at 3 m depth by 13 December. Thereafter the rate of increase was more gradual reaching 14.1 μg at. N/l. at the surface on 24 January. A very slight rise in nitrate levels occurred during the ensuing six weeks reaching a surface maximum of 15.3 μg at. N/l. on 21 February and a maximum at 3 m depth of 16.5 μg at. N/l. on 8 March. This peak coincided with the maximum recorded phosphate levels and very low levels of silicate.

An initial marked fall in nitrate concentrations was evident at surface and depth on 26 March, showing a decrease of 4 μg at. N/l. at surface and 5 μg at. N/l. at 3 m depth. The rate of nitrate decrease then lessened slightly, falling to 6.0 μg at. N/l. at the surface on 20 April. A subsequent rapid decline reduced nitrate to low levels on 1 June when the surface nitrate concentration was 0.6 μg at. N/l. and the 3 m depth value was about 0.4 μg at. N/l. A slight rise in nitrate, raised concentrations of this nutrient to around 1 μg at. N/l. at surface and depth on 14 July. This was followed by a decline to 0.093 μg at. N/l. at 3 m depth on 28 June, the lowest level of nitrate recorded. A decrease at the surface subsequently occurred on 26 July, reducing nitrate to 0.78 μg at. N/l. Increases at surface and depth during August and September raised levels to 2.9 μg at. N/l. at surface and 2.7 at depth on 20 September.

The main inflow to Lake of Menteith, the Burn of Menteith (Table 8(a)) shows erratic variation in nitrate levels ranging from 7.6 to 0.22 μg at. N/l. A maximum was recorded on 15 November, following which levels remained above 3.5 μg at. N/l. till 24 January when a peak of 6.3 μg at. N/l. was recorded. Nitrate content ~~of~~ then fell to 3.7 μg at. N/l. followed by a steady increase to a peak of 7.6 on 20 April. Values declined to less than 1 μg at. N/l. on 17 May, subsequently rising to 7.3 on 28 June. A further fall ensued reaching levels of less than 1 μg at. N/l. on 20 September.

(ii) Loch Rusky

The observed nitrate concentration in Loch Rusky (Figure 9 and Appendix Table 12) ranged from 20.8 to 1.8 μg at. N/l. The largest variation found either in the four lochs or in Loch Lomond. There was generally a close correlation between nitrate concentration at surface and depth.

The initial level of nitrate, 7.5 μg at. N/l. at surface on 18 October, 1972, declined to 5.2 on 1 November and remained around this level till 29th. During this period concentration of nitrate at 5 m depth also stayed constant at about 6 g at. N/l. A sustained increase was evident on 13 December when levels had risen to 9.4 μg at. N/l. at the surface and 10.3 at 5 m depth. A plateau then followed with only a marginal inrement in nitrate levels, reaching 11.5 on 10 January. A further abrupt increase resulted in a surface nitrate concentration of 16.5 on 24 January, a level which persisted till 21 February. 5 m depth levels during this period remained at a slightly higher level (between 17.1 and 18.2 μg at. N/l.). A subsequent rise in nitrate values culminated in a winter maximum of 19.2 at the surface and 20.8 μg at. N/l. at 5 m depth on 8 March. This occurred concurrently with the winter maximum in Lake of Menteith.

A rapid decline at surface and depth reduced nitrate to 15.2 and 15.6 μg at. N/l. respectively on 26 March. This was followed by a more gradual decrease at the surface, lowering concentrations to 10.0 μg at. N/l. on 20 April and a further sharp decrease at 5 m depth in which nitrate fell to 5.9. The next fortnight saw continued decline at the surface and an increase to 8.0 μg at. N/l. at 5 m depth. A spring minimum was recorded at surface and depth on 17 May with concentrations of 3.3 and 2.8 μg at. N/l. respectively. This minimum coincided with a decrease in the levels of phosphate and silicate. 1 June saw an increase in nitrate levels to 5.8 μg at. N/l. at surface and depth; this was followed by a shallow decline to 3.8 μg at. N/l. at the surface and 4.5 at 5 m depth on 11 July, a period during which phosphate and silicate showed an increase. The downward trend then became more rapid, reducing nitrate to around 2 µg at. N/l. at surface and depth on 26 July. These levels persisted for a month during which the annual nitrate minimum was recorded (2.0 µg at. N/l. at surface and 1.8 at 5 m depth) on 8 August. This coincided with low levels of silicate, although phosphate appeared to be on the increase. From this period till the completion of sampling a slight rise in nitrate was apparent, reaching 3.3 at the surface and 3.6 µg at. N/l. at 5 m depth on 20 September, 1973.

The major inflow to Loch Rusky, the Letter Burn (Table 8(a), shows distinct seasonal characteristics. The nitrate levels were generally high from the end of November till the end of March and low for the rest of the year. Two large nitrate maxima were evident, one on 29 November when a value of 18.0 µg at. N/l. was recorded, and the other on 10 January when the value was 18.3 µg at. N/l. Between these two peaks the nitrate content of the water did not fall below 16 µg at. N/l. Following the January peak, nitrate levels showed a sustained downward trend falling to 10.3 µg at. N/l. on 8 March, then declining by almost 7 µg at. N/l. during the next fortnight to reach 3.6 µg at. N/l. An annual minimum of 0.5 µg at. N/l. was recorded on 17 May with levels remaining below 1 µg at. N/l. till 14 June; thereafter levels fluctuated between 1 and 3 µg at. N/l.

The annual range of nitrate concentration in this Burn was 17.8 compared with 19.0 µg at. N/l. for the Loch itself. The maximal levels of nitrate coincided with silicate and nitrate peaks at this station.

(iii) Loch Achray

The annual range of nitrate concentrations in Loch Achray (Figure 11 and Appendix Table 12) varied between 3.5 to 15.2 µg at. N/l. Levels of nitrate both at surface and depth showed considerable fluctuations tending to make the pattern of seasonal variation less distinct than in the other lochs investigated.

At the commencement of sampling on 18 October the levels of nitrate were 11.3 and 11.1 µg at. N/l. at surface and depth. On 1 November a decline to 9.0 μg at. N/l. had been recorded. This was followed by a gradual upward trend in nitrate levels, culminating in a peak of 15.2 at the surface and 14.5 μg at. N/l. at 5 m depth on 10 January. A decrease followed at surface and depth reducing nitrate values to 11.04 at the surface and 11.9 μg at. N/l. at depth on 7 February. The ensuing increase raised nitrate levels to 14.6 at the surface and 14.2 μg at. N/l. at 5 m depth on 8 March, 1973.

An irregular decline then took place with nitrate concentrations falling to 11.9 μg at. N/l. at surface and depth on 3 May. An abrupt drop reduced levels to 6.8 and 7.7 at surface and depth a fortnight later. This coincided with the rapid decline of phosphate and silicate. Subsequent to a short-lived increase (to 10.5 μg at. N/l.) on 1 June, levels declined still further, falling to a summer minimum on 26 July. Values of 4.3 and 3.5 μg at. N/l. at surface and depth respectively were recorded on this date, coinciding with low phosphate levels and a slight decline in silicate. By 8 August nitrate had risen by about 2 μg at. N/l. at surface and depth to give respective values of 6.4 and 6.2 μg at. N/l. Little change in nitrate levels was apparent till 20 September when the concentration was 6.0 μg at. N/l. at surface and depth.

The main inflow to Loch Achray is the Achray Water (Table 8(a). The nitrate content of this tributary showed a distinct seasonal pattern rising to a maximum in the winter period and falling to low levels in the summer. The trace level recorded in October was followed by a large nitrate rise to 9.2 μg at. N/l. at the beginning of November. The fluctuating upward trend reached 10.4 μg at. N/l. on 27 December followed by a large rise to 18.3 on 10 January. A continuation of this trend resulted in an annual maximum of 24.5 μg at. N/l. on 24 January. This peak was short-lived, the nitrate being reduced by half a fortnight later (11.4 μg at. N/l. on 7 February. Levels fluctuated till 20 April after which nitrate fell to 5.8 on 3 May. Levels generally remained between 6 and 8 μg at. N/l. till 8 August when nitrate fell to low levels. Nitrate was still less than 1 μg at. N/l. on 20 September when sampling was completed.

The range of nitrate values exhibited by this inflow, 24.4, was more than twice the range in the loch itself (11.7 µg at. N/l.).

(iv) Loch Ard

The observed seasonal variation of nitrate in Loch Ard (Table 12 Appendix and Fig. 10) lay between the values of 21.1 and 4.1 µg at. N/l. Within this range the pattern of variation was clear, with a distinct winter maximum and a well-defined depression in summer.

From 18 October to 15 November nitrate levels at surface and depth varied between 9 and 10 µg at. N/l. This date saw the initiation of the winter increase at the surface while at 5 m depth the rise did not begin till a fortnight later. The upward trend continued till 27 December when values of 12.1 and 13.3 µg at. N/l. were recorded at surface and depth. Following a short-lived depression on 10 January nitrate increased rapidly culminating in a peak of 20.9 µg at. N/l. at the surface on 21 February and 21.1 µg at. N/l. at 5 m depth on 8 March. An abrupt drop in nitrate concentrations from 8 to 26 March resulted in values of 10.1 µg at. N/l. at surface and 17.5 at depth. This decrease coincided with the reduction in phosphate and silicate levels. Concentrations of nitrate fluctuated at the surface with a slight depression to 9.5 µg at. N/l. being apparent on 17 May when the spring minimum of phosphate occurred. At 5 m depth the decline continued steadily from 26 March to reach 12.5 µg at. N/l. on 3 May, followed by a nutrient plateau till 17 May.

The decline in nitrate towards a summer minimum started at 5 m depth on 1 June decreasing, with minor fluctuations, to 7.5 on 26 July. At the surface, following a stable period, nitrate fell from 10.5 µg at. N/l. on 14 June to a minimum of 4.1 on 26 July. During August and September an increase was apparent reaching 10.1 µg at. N/l. at the surface and 12.5 at depth on 20 September.

The two main inflows to Loch Ard, the Ledard Burn and Water of Chon (Table 8(a)) were investigated and it is clear that the Water of Chon possesses generally higher levels of nitrate than the Ledard Burn. Both inflows exhibited marked seasonal variation in nitrate content being high in winter and low in summer.

The Ledard Burn had a maximum recorded nitrate level of 10.9 μg at. N/l. during March and a minimum, trace level in August. From low levels during October (1.2 μg at. N/l.) concentrations increased to 8.4 μg at. N/l. on 15 November and remained above 7 till 20 April. During this period nitrate fluctuated erratically, although a constant level of 10.8 to 10.9 μg at. N/l. persisted throughout March. On 3 May values fell to 4.1 μg at. N/l. and then remained below 5 for the rest of the sampling period, with the exception of two small peaks of 6.5 and 5.8 μg at. N/l. on 28 June and 26 July. From 23 August to 20 September the nitrate content of the water was almost undetectable.

The Water of Chon had an annual maximum nitrate concentration of 15.65 o on 27 December and a minimum of 3.45 μg at. N/l. on 18 October. Nitrate increased from low levels in October, 1972 (3.45) to 8.6 μg at. N/l. on 15 of November. A further increase raised levels to 10.6 μg at. N/l. on 29 November; from this date till 28 March nitrate never fell below 10.0. On 3 May nitrate fell to 7.5 μg at. N/l. and subsequently fluctuated between 7 and 10.0 till 11 July. 26 July saw a decline to 4.88 followed by a further decrease to 4.35 μg at. N/l. on 23 August. A slight increase was evident on 20 September when 5.3 μg at. N/l. was recorded.

4. Nitrite - nitrogen

(a) Loch Lomond

The levels of nitrite in Loch Lomond (Table 12) were generally very low varying from 0.12 μg at. N/l to almost undetectable levels (0.01). The six stations can be divided into two groups according to the pattern of nitrite variation and the seasonal range of this nutrient. The first group comprises the three stations of the lower loch, South Balmaha, South and Middle Stations, the second includes North INversnaid, North Falloch and North.

A prominent feature of the stations in the lower loch was their higher maximum levels of nitrite, ranging from 0.088 at the Middle Station to

0.12 µg at. N/l at the South Balmaha station. Moreover, levels of nitrite in the lower region of the loch did not descend below 0.023 while North Inversnaid and North Falloch fell to almost undetectable levels.

Nitrite concentrations at the North Falloch station showed a clear decline at the surface from 0.052 µg at. N/l in August 1972 to 0.03 in October. Low levels persisted till December followed by a rise in concentration to 0.05 in February 1973. No pattern was apparent during this period at 3 m depth. The subsequent decline in nitrite which occurred at surface and depth reduced levels to a trace in July. The maximum annual values of nitrite were reached at the surface (0.058) and depth (0.068) during August, when concentration of nitrite at this station was at its lowest level. The annual range of nitrite values was 0.058 µg at. N/l.

At the North Inversnaid station the amount of nitrite in the water declined from 0.062 µg at. N/l at both depth in August to 0.04 and 0.058 at surface and depth respectively in November. Levels increased slightly at surface and depth in December and January. From April a steady decline occurred reaching a surface minimum of 0.02 µg at. N/l in June and 0.027 at 3 m depth in July. A rise in nitrite at both surface and depth during August resulted in concentrations of 0.056 and 0.041 µg at N/l respectively. This pattern of variation closely paralleled that at the North Falloch station though the annual range of nitrite (0.043) was less. Like North Falloch station nitrite concentration at depth generally exceeded those at the surface.

The level of nitrite at the North Station was generally lower than at any other region of the loch. The initial low concentration of nitrite (0.03) during August and September 1972 diminished to an annual minimum value of 0.02 µg at. N/l in October. From November till the end of winter, values fluctuated between 0.025 and 0.03 µg at. N/l. The subsequent increase first appeared at 3 m depth in April, spreading to the surface during May when respective concentrations of 0.04 and 0.048 µg at. N/l were recorded. From June to August 1973 levels of nitrite remained around 0.05 at depth while at the surface a maximum of 0.068 µg at. N/l was recorded in August.

Table 12. Nitrite - Nitrogen (μg. at./l.) in Loch Lomond and the inflowing rivers and streams

	1972					1973							
Stations	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.
North Falloch - surface	0.052	0.043	0.03	0.032	0.03	0.042	0.052	0.04	0.031	0.033	0.01	0.01	0.058
" " - 3 m	0.058	0.063	0.058	0.063	0.05	0.052	0.056	0.048	0.058	0.023	0.033	0.02	0.068
North Inversnaid - surface	0.062	0.058	0.053	0.043	0.052	0.051	0.036	0.05	0.050	0.046	0.02	0.023	0.056
" " - 3 m	0.063	0.063	0.063	0.058	0.06	0.062	0.058	0.062	0.041	0.032	0.031	0.023	0.041
Loch Lomond (north) - surface	0.032	0.033	0.02	0.03	0.025	0.03	0.028	0.023	0.030	0.048	0.033	0.058	0.068
" " " - 3 m	0.03	0.03	0.02	0.026	0.03	0.028	0.032	0.032	0.038	0.04	0.05	0.05	0.052
" " (middle) - surface	0.063	0.033	0.034	0.032	0.032	0.042	0.033	0.052	0.058	0.052	0.05	0.071	0.088
" " " - 3 m	0.078	0.034	0.028	0.023	0.032	0.023	0.041	0.052	0.051	0.058	0.063	0.076	0.082
" " (south) - surface	0.082	0.033	0.028	0.026	0.026	0.032	-	0.062	0.082	0.07	0.05	0.076	0.08
" " " - 3 m	0.078	0.04	0.032	0.04	0.03	0.028	0.028	0.04	0.082	0.088	0.08	0.085	0.09
South Balmaha - surface	0.082	0.062	0.08	0.035	0.041	0.042	0.032	0.048	0.073	0.058	0.11	0.12	0.063
" " - 3 m	0.080	0.07	-	-	0.036	0.043	0.04	0.052	0.068	0.08	0.08	0.09	0.066
Endrick	0.63	0.77	0.78	0.78	0.53	0.44	0.26	0.33	0.434	0.29	0.45	0.33	0.33
Fruin	0.23	0.15	0.093	0.083	0.07	0.06	0.094	0.115	0.150	0.09	0.041	0.08	0.02
Luss	0.03	0.02	0.032	0.04	0.03	0.04	0.03	0.03	0.066	0.03	0.03	0.06	0.08
Finlass	0.12	0.05	0.04	0.05	0.03	0.03	0.03	0.03	0.050	0.034	0.036	0.059	0.1
Douglas	0.042	0.05	0.03	0.023	0.028	0.021	0.024	0.025	0.041	0.034	0.02	0.042	0.04
Falloch	0.063	0.052	0.032	0.026	0.023	0.024	0.023	0.026	0.058	0.034	0.03	0.06	0.06
Inveruglas	0.05	0.03	0.03	0.03	0.02	-	0.021	0.021	0.050	0.028	0.034	0.047	0.05
Inversnaid	0.09	0.06	0.02	0.023	0.02	0.01	0.02	0.02	0.030	0.033	0.05	0.06	0.07
Cailness	0.015	0.02	0.01	0.023	0.02	0.02	0.03	0.02	0.020	0.029	0.016	0.02	0.02
Coille Mhor Burn	0.02	0.03	0.02	0.023	0.023	0.02	0.02	0.021	0.033	0.03	0.02	0.02	0.02
Cashell	0.12	0.06	0.04	0.03	0.02	0.02	0.01	0.04	0.066	0.047	0.09	0.12	0.13
Rubha Ban	0.02	0.03	0.02	0.02	0.02	0.02	0.03	0.01	0.03	0.033	0.02	0.04	0.05
Blair Burn	0.09	0.08	0.03	0.03	0.01	0.013	0.02	0.03	0.066	0.034	0.01	0.08	0.74
Stuckindroin	0.03	0.02	0.03	0.03	0.12	0.03	0.08	0.025	0.116	0.027	0.019	0.031	0.06
Ardess	0.03	0.06	0.03	0.02	0.03	0.01	0.03	0.028	0.033	0.033	0.02	0.03	0.03
Coille Mhor L.	0.03	0.03	0.02	0.013	0.02	0.013	0.02	0.04	0.06	0.041	0.02	0.02	0.02
AlltArdvorlich	0.73	0.08	0.03	0.02	0.03	0.03	0.02	0.025	0.033	0.041	0.01	0.03	0.061

The annual range of nitrite values at this station was 0.048 µg at. N/l, similar to the North Inversnaid station.

The seasonal pattern of nitrite variation at the Middle and South stations showed very close similarities. Both stations exhibited initially (October 1972) high nitrite values, around 0.07 µg at. N/l at the Middle and 0.08 at the South station. Concentrations were reduced by half in September to around 0.03 at both stations, followed by a further decline to a joint minimum during November. The lowest value recorded at the South station was 0.026 (at the surface) while Middle station fell to 0.023 µg at. N/l (at 3 m depth). Values then fluctuated between 0.023 and 0.04 µg at.N/l till February. An increase started during March culminating in a peak of 0.058 µg at.N/l at the Middle and 0.082 at the South during April, May and June saw a slight decline in levels to 0.05 at the surface at both stations. A subsequent increase gave concentration of nitrite exceeding 0.07 µg at. N/l in July rising still further to attain maximum recorded levels during the following month. The Middle station had a nitrite content of 0.088 µg at.N/l at surface and 0.082 at depth, while South station recorded concentrations of 0.08 at surface and 0.09 µg at.N/l at depth in August 1973. The extreme range of nitrite values at the Middle and South stations were the same (0.064 µg at. N/l).

At the South Balmaha station the initial high nitrite values (0.08) found in August 1972 persisted till October and then diminished by half to 0.035 µg at. N/l in November. The slight rise in levels at the surface in December and January was interrupted by a drop during February to the annual minimum of 0.032 µg at. N/l. An upward trend in nitrite values continued at surface and depth from March onwards, rising to 0.058 at the surface and 0.08 µg at. N/l at depth in May. A subsequent large increase at the surface culminated in the annual maximum of 0.12 µg at. N/l during June and July, although the depth maximum (0.09 µg at. N/l) was not reached till a month later. In August a decline in nitrite was evident at both depths. The annual range at this station was 0.08 µg at. N/l.

(b) Rivers and Burns

The levels of nitrite in all rivers and burns inflowing to Loch Lomond with the exception of the Endrick and Fruin were extremely low (less than 0.03) for most of the year. The general pattern of seasonal variation of this nutrient was similar for most large inflows and several of the small ones. Periods of high nitrite content occurred during August 1972 and 1973 while a secondary peak during April was evident in most rivers and burns. Except for the Endrick and Fruin, all inflowing streams showed very low quantities of nitrite from October to March and during May and June.

The River Endrick showed concentrations of nitrite lying between 0.78 in October and November to 0.26 μg at. N/l in February. Generally levels remained in excess of 0.6 μg at. N/l during the Autumn and thereafter gradually declined to the February minimum. During the rest of the sampling period levels fluctuated erratically between 0.3 and 0.45 μg at. N/l. An August increase was absent in the Endrick with the nitrite content remaining steady at 0.33.

The Fruin showed a similar pattern, beginning with an annual maximum of 0.23 μg at. N/l in August 1972 falling rapidly to 0.15 in September followed by a gradual decline to reach a minimum of 0.06 μg at. N/l during January. A sustained increase culminated in a peak during April of 0.15 μg at. N/l. Nitrite levels then showed a gradual decline to reach the lowest recorded value for the Fruin of 0.02 μg at. N/l in August 1973. Most other rivers and burns follow a similar general pattern of nitrite variation. Typically nitrite commenced on August at its annual maximum, Fruin 0.23, Finlas 0.12, Douglas 0.05, Falloch 0.06, Inveruglas 0.05, Blair burn 0.09, Inversnaid 0.09, Cashell 0.12 and AlltArdvorlich 0.73 μg at. N/l. A steep depression then occurred in all except for Douglas, Falloch and Blair Burn greatly diminishing the concentration of nitrite. The decrease in the three latter inflows occurred in October. From this month onwards till March the winter levels were less than 0.03 μg at. N/l in all inflows. April saw an increase in all these inflows to secondary maximum lying between 0.45 and 0.07 µg at. N/l. Nitrite levels then declined again remaining low throughout May and June. A further increase ensued retaining levels to those of the previous August.

The other rivers and burns exhibited extremely low nitrite levels throughout the year, typically less than 0.03 µg at. N/l. No pattern of variation was evident in Coille Mhor, Ardess, Rubha Ban, and Cailness while Luss Water showed small maximum in April (0.066 µg at. N/l) and August (0.08). Stuckindroin showed a nitrite content of less than 0.03 µg at. N/l during every month except for a striking peak of 0.116 µg at. N/l in April.

In general the picture of seasonal variation was clear in most stations. The range of recorded nitrite values was less than 0.1 for all inflows except for the Endrick (0.52), Fruin (0.21), Cashell (0.13) and AlltArdvorlich (0.72). The nitrite minimum during the winter coincided with the period of maximum nitrate, whereas the nitrite maximum occurred simultaneously with the rise in nitrate, not with its minimum (i.e. after the nitrate minimum).

(c) The four Lochs

The pattern of nitrite variation in Loch Ard, Loch Achray, Loch Rusky and Lake of Menteith (Table 13) shows one very conspicuous feature, a prominent winter maximum. This occurred in all four Lochs between 24 January and 7 February, 1973 and distinguished these bodies of water from Loch Lomond where the minimum levels of nitrite occurred during the winter period. The recorded range of nitrite concentration in Loch Rusky and Lake of Menteith was typically greater than any region of Loch Lomond. Loch Rusky showed the largest range of nitrite values, 0.28 µg at. N/l, while Lake of Menteith was 0.16 and Loch Ard 0.11. The smallest range of values was found in Loch Achray where the extreme range was 0.07 µg at. N/l.

(i) Lake of Menteith

Lake of Menteith shows variable nitrite at surface and 3 m depth, the annual minimum, 0.03 µg at. N/l, being recorded on 15 November. A sustained upward movement of nitrite followed, culminating in the highest recorded value of 0.18 at surface and 0.19 µg at. N/l at 3 m depth on 7 February. A rapid decline, to a minimum of 0.032 on 26 March, was followed by a further

Table 13. Nitrite (μg. atom/1.)

	Lake of Menteith		Loch Rusky		Loch Achray		Loch Ard	
Date	Surface	3 m	Surface	3 m	Surface	3 m	Surface	3 m
18.10.72	0.034	0.0718	0.051	0.068	0.034	0.034	0.034	0.025
1.11.72	0.06	0.12	0.04	-	0.02	-	0.04	-
15.11.72	0.03	0.03	0.12	-	0.03	-	0.03	-
29.11.72	0.08	0.04	0.09	-	0.03	-	0.05	-
13.12.72	0.1008	0.068	0.0778	0.1154	0.034	0.036	0.071	0.057
27.12.72	0.12	0.12	0.13	-	0.07	-	0.08	-
10. 1.73	0.14	0.13	0.16	-	0.08	-	0.08	-
24. 1.73	0.16	0.18	0.19	-	0.09	-	0.13	-
7. 2.73	0.18	0.19	0.32	-	0.07	-	0.14	-
21. 2.73	0.16	0.12	0.295	-	0.05	-	0.125	-
8. 3.73	0.0513	0.0513	0.0513	-	0.042	-	0.025	-
26. 3.73	0.0317	0.033	0.05	0.06	0.036	0.033	0.03	0.03
8. 4.73	-	-	-	-	-	-	-	-
20. 4.73	0.068	0.079	0.034	0.034	0.025	0.034	0.034	0.034
3. 5.73	0.09	-	0.066	-	0.05	-	0.05	-
17. 5.73	0.0718	0.063	0.078	0.078	0.035	0.045	0.03	0.02
1. 6.73	0.037	0.05	0.066	0.116	0.033	-	0.033	-
14. 6.73	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034
28. 6.73	0.0478	0.047	0.085	0.085	0.063	-	0.044	-
11. 7.73	0.051	0.051	0.11	0.19	0.085	-	0.068	-
26. 7.73	0.068	0.068	0.119	0.119	0.085	0.094	0.068	0.068
8. 8.73	-	-	0.12	-	0.06	-	0.05	-
23. 8.73	0.035	-	0.05	-	0.03	-	0.03	-
20. 9.73	0.066	0.058	0.078	0.088	0.055	0.063	0.07	0.061

increase to give a peak of 0.09 µg at. N/l on 3 May. Subsidiary maxima also occurred on 26 July (0.068) and 20 September (0.066 µg at. N/l).

On 18 October and 1 November the concentration of nitrite at depth was double that at the surface. While on 15 November nitrite was constant with depth. From 29 November to 13 December the situation was reversed with surface nitrite being twice the depth value. Nevertheless for most of the year there was little to distinguish surface and depth concentrations.

The main inflow to Lake of Menteith, the Burn of Menteith (TAble 8A) exhibited a similar pattern of nitrite variation to the Lake. The maximum level (0.16 µg at. N/l) was reached on 24 January, two weeks prior to the winter maximum in Lake of Menteith. Subsidiary maxima in the burn occurred concurrently with secondary peaks in the lake, 0.12 µg at. N/l on 3 May, 0.088 on 26 July and 0.086 on 20 September. The minimum nitrite value, 0.017, was noted on 13 December. The range of nitrite values recorded was roughly the same for Lake of Menteith (0.16 µg at. N/l) and its main inflow 0.14.

(ii) Loch Rusky

Loch Rusky showed a similar pattern of nitrite changes to Lake of Menteith. Nitrite levels were low throughout October and November with a small peak of 0.12 µg at. N/l on 15 November. Following a decline, levels rapidly climbed to reach a peak of 0.32 µg at. N/l at the surface on 7 February. This was the highest nitrite value recorded for any of the Lochs studied.

An abrupt drop in nitrite took place between 21 February and 8 March when a level of 0.051 was observed. A further gradual decrease, reduced levels to a recorded minimum of 0.034 µg at. N/l on 20 April. A doubling in the nitrite content was observed on 3 May to give a concentration of around 0.07. This had persisted till 1 June when, following a transient decline, nitrite increased again rising to a summer maximum of 0.12 µg at. N/l on 26 July. No decrease was apparent till 23 August when levels fell to 0.05, thereafter rising slightly to a value of 0.078 µg at N/l at the surface and 0.088 at depth on 20 September.

The major inflow to Loch Rusky, the Letter Burn (Table 8A) had a similar range of variation (0.30 µg at. N/1) to the Loch. The peaks in nitrite content of the burn were roughly coincident with, or preceded the maxima found in Loch Rusky. A nitrite level of 0.15 µg at. N/1 was recorded on 15 November, rising to 0.32 on 29 November. A further peak showing the same level of this nutrient occurred on 10 January. Levels then declined to reach 0.2 µg at. N/1 on 21 February followed by a steep drop to 0.051 on 8 March. Values remained around 0.05 till 3 May, subsequently declining to 0.017 on 14 June. An increase ensued raising levels to summer maxima of 0.11 µg at. N/1 on 26 July. The nitrite concentrations then decline to 0.065 on 8 August and still further on 20 September.

(iii) Loch Achray

The nitrite concentration in Loch Achray was generally low, although conspicuous peaks were evident on 24 January and during July. From 18 October to 13 December nitrite show little variations and did not exceed 0.035 µg at. N/1. On 27 December concentrations of this nutrient doubled followed by a more gradual rise to attain a maximum of 0.09 µg at. N/1 at the surface on 24 January. The decline in levels which followed was slight, a minimum value of 0.025 µg at. N/1 being recorded on 20 April. A minor peak occurred on 3 May followed by a period during which the nitrite fluctuated around 0.035 µg at. N/1. A subsequent increase which was first evident on 28 June gave rise to a surface maximum of 0.085 in July. A steady decrease followed reducing nitrite levels to 0.055 µg at. N/1 at the surface on 20 September.

The most prominent tributary to Loch Achray, the Achray Water (TAble 8A) showed no distinct pattern of variation although levels were generally higher during the winter than in summer. From the initiation of sampling on 18 October to 29 November levels remained at an extremely low level (less than 0.035). From 13 December to 21 February nitrite values did not descend below 0.065 or rise above 0.083 µg at. N/1. During March and April the nitrite content of the water was extremely low (less than 0.035 µg at. N/1). An abrupt surge in nitrite levels gave the highest value recorded for this Burn of 0.35 µg at. N/1 on 17 May, levels then dropped to the usual low values (less than 0.06). A small peak was evident on 26 July of 0.068 µg at. N/1. The nitrite values recorded for this Burn approximated to the levels found in Loch Achray, with the exception of the single large peak in May.

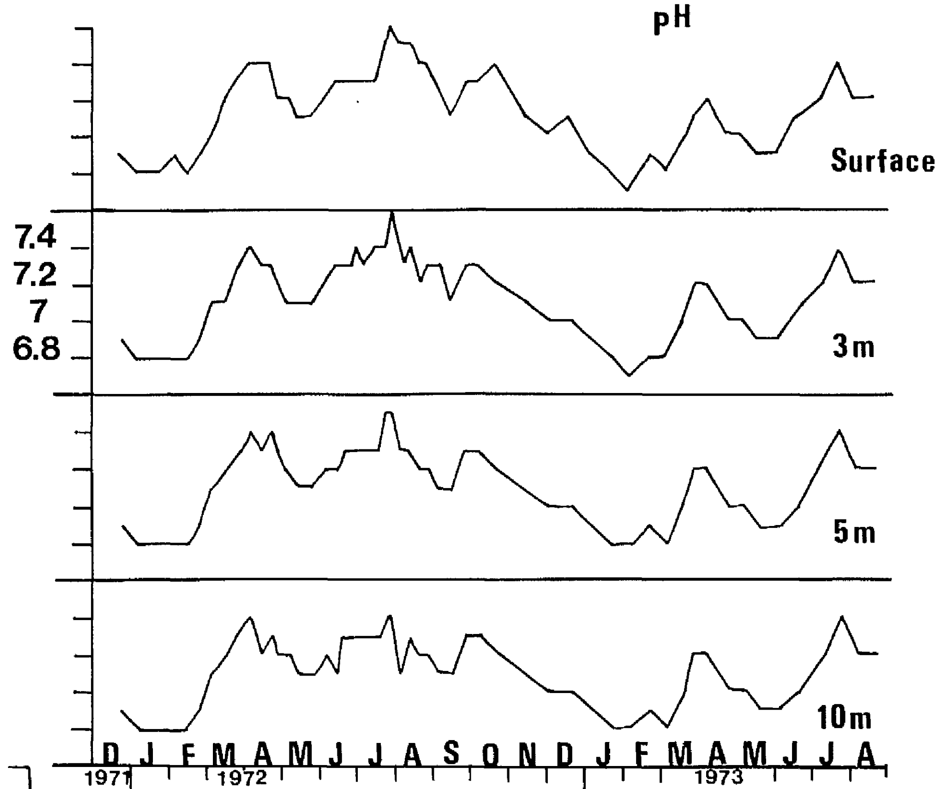
(iv) Loch Ard

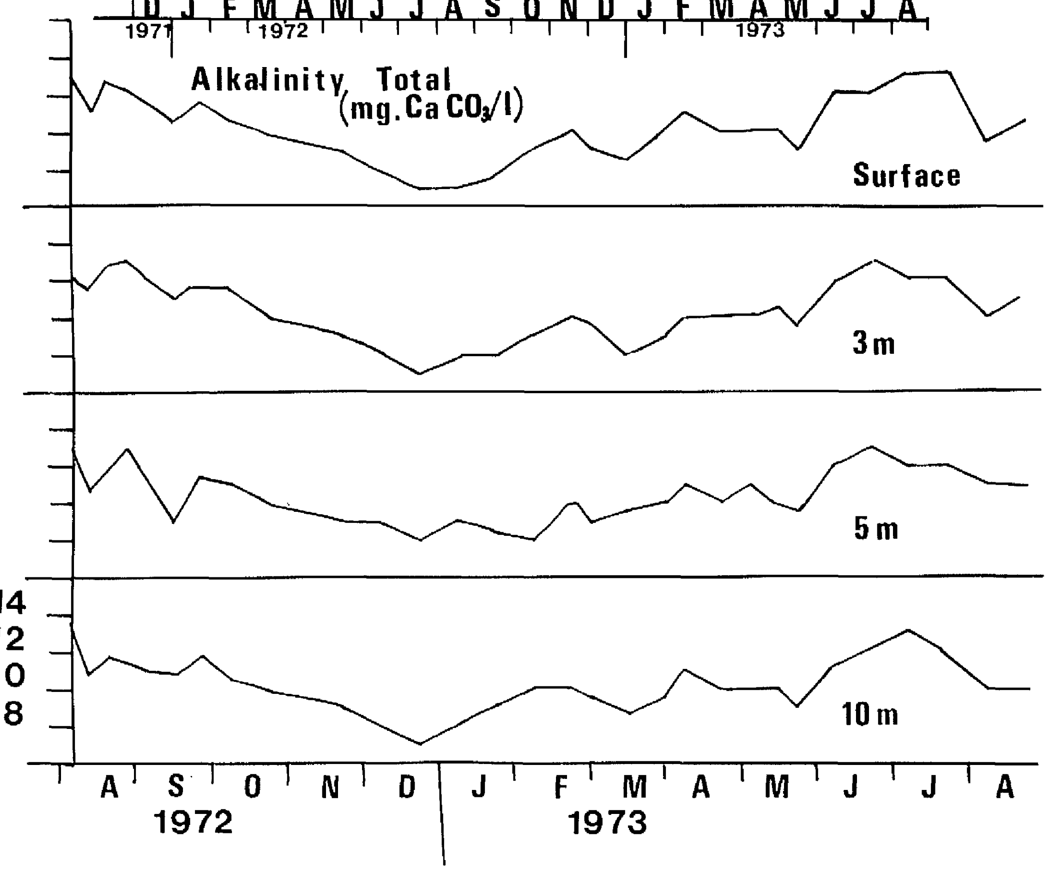
Loch Ard exhibits a range of nitrite values (0.11) intermediate between Loch Achray and Lake of Menteith. As in Loch Achray the maximum levels only occur for a few weeks during the winter, the rest of the year being characterized by low nitrite values. The initial period from October till the end of November was typically low in nitrite (less than 0.05 µg at. N/1). The increase which followed culminated in a peak of 0.14 µg at. N/1 on 7 February. A rapid decline followed reducing the concentration of nitrite to low values (around 0.03). These levels persisted till 14 June when a marked increase occurred, giving rise to a peak of 0.068 µg at. N/1 on 11 July. No decline occurred till August when levels were reduced to 0.03 µg at. N/1. The minimum value of nitrite (0.02) was observed on 17 May.

The two main inflows to Loch Ard, Ledard Burn and Water of Chon (Table 8A) were characterized by very low levels of nitrite. The Ledard Burn showed almost no detectable seasonal changes, with nitrite levels rarely rising above 0.05. The only distinctive feature was the slight summer rise in nitrite which was initiated on 14 June and gave rise to a small peak of 0.082 µg at. N/1 during August. During the rest of the year levels fluctuated between 0.03 and 0.05 except for a period during May and June when levels were barely detectable.

The Water of Chon displayed very low levels from October to November not exceeding 0.03 µg at. N/1. An increase, first evident on 13 December gave rise to a peak at 0.23 µg at. N/1 on 24 January. Levels then fell by half and remained around 0.11 till 21 February. A subsequent decline reduced nitrite to less than 0.03 on 8 March. Low values remained till September with the exception of a small peak of 0.05 at the end of April.

LOCH LOMOND SOUTH STATION Fig 16





5. pH

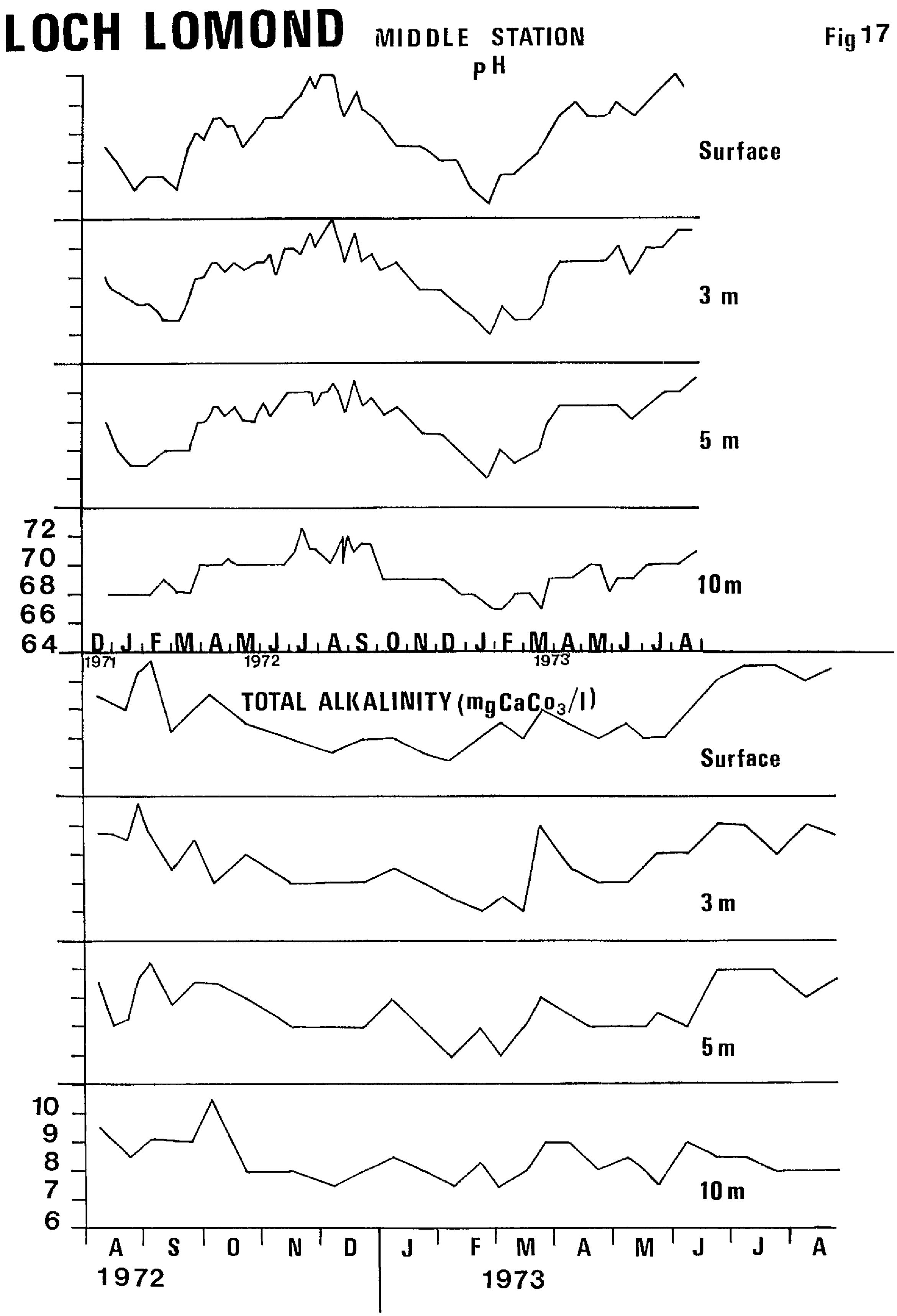
(a) Loch Lomond

pH measurement in the three original stations in Loch Lomond, North, Middle and South, were made from January 1972 to August 1973, while pH in North Falloch, North Inversnaid and South Balmaha stations were made from August 1972 to August 1973. Each station has its own specific range of pH and the pattern of variation seems to be constant from year to year. The features of the seasonal picture of pH changes which are general to all stations are the annual summer maximum and winter minimum.

The maximum pH values for each station decreased from South to the North; South Balmaha 7.7, South 7.6, Middle 7.4, North, 7.2, North Inversnaid 7.1, North Falloch 7.0. The minimum pH values were found at the most northerly station, North Falloch, where a value of 6.3 was recorded. South Balmaha was the only station which never fell below pH 7.0 during the investigation. The annual range of pH values has a tendency to become reduced with depth. The details of the seasonal pattern are clearly shown at the South Station (Fig. 16, Appendix Table 13), the surface and depth variation being distinctly similar. Features which are common to 1972 and 1973 are the winter minimum in January, the summer maximum in July and the subsidiary spring peak in April. The surface pH range of this station was 0.8 in 1972 and 0.9 in 1973 with values generally remaining above 7.

The pattern of pH variation at the Middle Station (Fig. 17, Appendix Table 14) was broadly similar to the picture described for the South Station. Minimum values were recorded in January of both years while the summer maximum occurred between July and August. A spring peak occurred towards the end of April in 1972 and 1973. The surface range of pH was 6.6 to 7.4 (0.8) in 1972 and 6.5 to 7.4 (0.9) in 1973.

The seasonal change in pH at the North Station (Fig. 18, Appendix Table 15) still follows the same general outline. Minimum pH values were 6.5 in both years occurring later than the corresponding depression in the Middle and South stations. The spring peak was transitory and occurred later than at the other two stations while the summer maximum came at the



LOCH LOMOND
MIDDLE STATION
Fig 17
pH
Surface
3 m
5 m
10m
72
70
68
66
64
D J F M A M J J A S O N D J F M A M J J A
1971
1972
1973
TOTAL ALKALINITY (mgCaCo3/l)
Surface
3 m
5 m
10 m
10
9
8
7
6
A S O N D J F M A M J J A
1972
1973

Table 14. pH of the rivers and streams inflowing to Loch Lomond

Date	Endrick	Fruin	Luss	Finlas	Douglas	Falloch	Inveruglus	Inversnaid	Cailness	Coille Mhor Burn	Cashell	Rubha Ban
1972												
8.8	7.7	7.0	6.5	6.4	5.9	–	–	–	–	5.7	–	–
15.8	–	–	–	–	–	6.7	6.4	6.8	5.8	–	–	7.2
6.9	9.1	7.3	7.8	7.3	7.2	–	–	–	–	–	6.9	–
12.9	–	–	–	–	–	6.9	7.6	6.8	6.6	5.3	–	7.5
11.10	7.1	6.9	7.1	7.6	7.4	6.4	7.1	6.5	5.3	5.6	5.3	7.8
25.10	7.2	7.3	7.8.	7.2	7.1	–	–	–	–	6.6	6.7	–
23.11	7.3	6.9	7.1	7.1	7.1	6.4	7.0	6.4	5.3	5.6	5.6	7.8
7.12	–	–	–	–	6.9	6.5	7.0	6.3	5.3	–	–	7.9
21.12	7.3	6.8	6.8	6.3	–	–	–	–	–	6.0	4.9	–
1973												
4.1	7.3	6.8	6.7	6.4	6.9	6.4	7.0	5.9	5.6	6.0	5.1	7.8
1.2	–	–	–	–	–	6.4	6.9	5.5	4.7	–	–	7.6
15.2	7.2	6.7	6.6	6.3	6.8	–	–	–	–	5.3	5.0	–
1.3	–	–	–	–	–	5.6	6.1	5.3	4.9	–	6.4	7.3
15.3	7.3	7.1	7.2	6.9	7.4	6.4	7.5	6.2	5.4	5.8	6.2	7.6
26.3	7.4	7.1	7.3	6.8	7.4	–	–	–	5.1	–	–	–
12.4	7.5	7.1	7.3	7.5	7.4	–	–	–	5.1	–	6.3	–
26.4	7.7	7.2	7.4	8.6	7.4	6.8	7.4	5.8	4.9	6.3	6.7	7.7
10.5	7.6	7.1	7.0	7.2	7.1	6.3	6.9	–	5.0	5.4	5.8	–
24.5	7.4	7.0	6.6	7.0	7.0	6.5	6.8	6.1	5.0	5.3	5.6	7.4
7.6	–	–	–	–	–	6.6	6.9	6.8	5.8	–	–	7.6
24.6	7.1	6.9	6.9	6.7	7.0	6.1	6.9	6.1	4.8	5.2	5.4	7.3
6.7	8.6	7.1	7.2	6.8	6.6	6.7	6.5	5.9	5.2	5.3	5.7	7.4
2.8	9.1	7.6	7.5	6.5	7.6	6.9	7.6	6.0	5.8	5.3	6.5	7.6

end of July. The maximum at 10 m depth generally occurred 1 or 2 weeks later. The surface pH range was 6.5 to 7.2 (0.7) in 1972 and 6.5 to 7.0 (0.5) in 1973.

Both North Falloch and North Inversnaid stations (Table 11) showed a pattern of pH variation similar to the north station. The maximum pH values recorded at North Inversnaid in 1972 was 7.1 at the surface in September while at North Falloch the maximum was 6.9 at the surface and 7.0 at depth in August. Minimum values of 6.3 and 6.6 were recorded at North Falloch and North Inversnaid respectively on 1 March, 1973 about 2 weeks later than the North Station. A small spring peak was detected at both stations towards the end of April, following which pH increased to an annual maximum during August 1973. There is a tendency for the annual pH maximum to occur later in these two stations. Generally North Falloch and North Inversnaid have a low pH value only rising to neutrality on one occasion in the year. South Balmaha (Table 11) showed close similarity with the South Station, with three clear peaks. An autumn maximum (7.5) occurred in September followed by a decline to a winter minimum of 7.1 in January. A spring peak followed in April and a summer maximum of 7.7 at the surface in July. The pH at this station was generally higher than elsewhere in the Loch.

(b) Rivers and burns inflowing to Loch Lomond

The pH values of the rivers and burns inflowing to Loch Lomond (Tables 6, 7 and 14) cover the range 4.8 to 9.1. The main inflows to the lower loch were generally neutral or slightly alkaline while the inflows to the upper loch were on the acid side of neutrality. However, individual variations from this were observed. The Endrick showed a marked difference from all other inflows to the loch and never fell below 7.0; its extreme range was 7.1 to 9.1. The maximum pH was found in summer and early autumn with a minimum in winter. A similar general pattern was observed in the Fruin (7.6 to 6.8) and in the Luss, Douglas and Finlas Waters which fluctuated around neutrality.

The Falloch, Inveruglas, Inversnaid, Cailness to the north and Coil Mhor, Cashell, Blair Burn and Ardess to the south exhibited pH values which

LOCH LOMOND

NORTH STATION

Fig 18

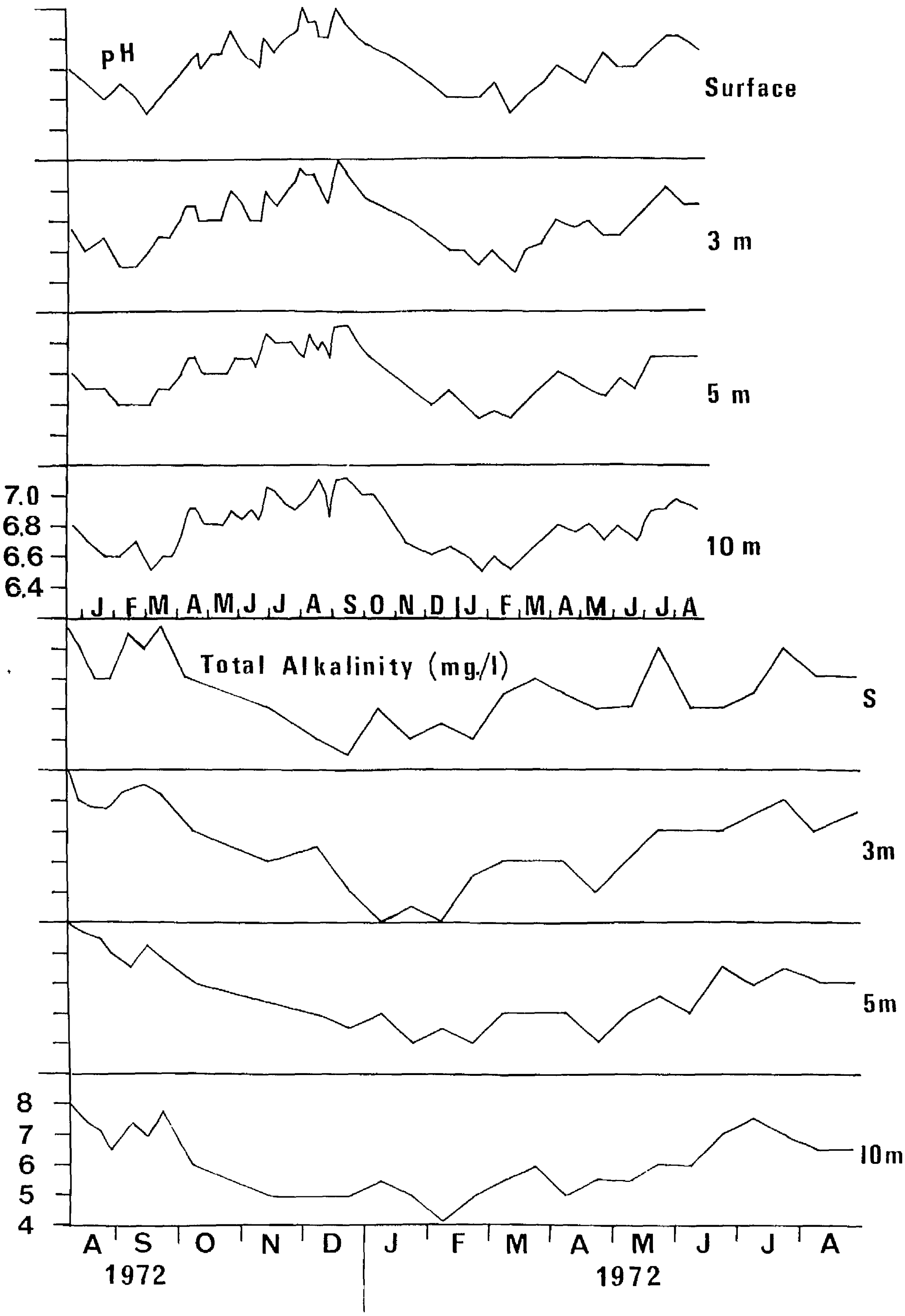


Table 15. pH

Date	Lake of Menteith		Loch Rusky		Loch Achray		Loch Ard	
	Surface	3 m	Surface	5 m	Surface	5 m	Surface	5 m
18.10.72	7.15	7.1	6.95	6.9	6.4	6.4	6.6	6.6
1.11.72	7.2	7.1	7.15	7.1	6.4	6.4	6.6	6.55
15.11.72	7.3	7.2	7.0	7.0	6.4	6.3	6.6	6.6
29.11.72	7.2	7.2	6.9	6.8	6.4	6.4	6.7	6.7
13.12.72	7.0	7.0	6.80	6.8	6.2	6.3	6.5	6.6
27.12.72	7.0	7.0	-	6.7	6.1	6.2	6.4	6.5
10. 1.73	7.2	7.1	6.6	6.6	6.1	6.2	6.35	6.4
24. 1.73	7.1	7.0	6.7	6.6	6.2	6.3	6.3	6.4
7. 2.73	7.0	7.0	6.65	6.7	6.2	6.2	6.4	6.3
21. 2.73	7.2	7.1	6.6	6.6	6.2	6.2	6.4	6.4
8. 3.73	7.4	7.2	6.65	6.7	6.3	6.2	6.45	6.5
26. 3.73	7.6	7.5	7.0	6.9	6.4	6.3	6.5	6.5
8. 4.73	-	-	-	-	-	-	-	-
20. 4.73	7.7	7.6	7.2	7.1	6.5	6.4	6.6	6.6
3. 5.73	7.9	7.8	-	7.0	6.6	6.5	6.6	6.6
17. 5.73	7.6	7.7	6.9	6.9	6.6	6.4	6.5	6.6
1. 6.73	7.3	7.4	-	6.9	6.4	6.4	6.5	6.5
14. 6.73	7.3	7.3	6.8	6.8	6.4	6.5	6.5	6.5
28. 6.73	7.3	7.3	6.9	6.9	6.4	6.4	6.6	6.6
11. 7.73	7.3	7.2	-	6.9	6.5	6.5	6.6	6.6
26. 7.73	7.4	7.3	7.2	7.1	6.7	6.5	6.8	6.8
8. 8.73	7.6	7.5	7.3	7.2	6.7	6.6	6.8	6.8
23. 8.73	7.7	7.7	7.4	7.4	6.6	6.5	6.7	6.7
20. 9.73	7.4	7.4	7.3	7.3	6.4	6.4	6.6	6.6

were nearly always below 7. The four northern inflows were generally acidic with Falloch ranging from 5.6 to 6.4. Burns to the upper loch which were alkaline include Stuckindroin (5.6 - 7.9), Rubha Ban (7.3 - 7.9) and AlltArdvorlich (5.4 - 7.6). The pH of the inflows to the upper lochs was less than that of the loch itself while in the lower loch it was often greater. There was a distinct seasonal pattern of pH, most inflows reaching their maximum value during late summer and autumn and their minimum during the spring.

(c) The four Lochs

Loch Achray, Loch Ard, Loch Rusky and Lake of Menteith all show a broadly similar pattern of variation with seasons. The conspicuous features of this variation were the spring and summer maximum and the winter minimum of pH. The only body of water which was constantly alkaline was Lake of Menteith while Loch Achray and Loch Ard were slightly acidic; Loch Rusky was intermediate in this respect.

Lake of Menteith (Table 15, Figure 19) had its lowest value of pH (7.0) during December rising to a summer maximum of 7.7 in August. The main inflow, the Burn of Menteith (Table 8C) exhibited pH values only slightly exceeding those of the lake itself with low values only during the winter.

The pH readings in Loch Rusky fluctuated between 6.6 to 7.4 (Table 15, Fig. 20) with the lowest value during January and February and the annual maximum during August. The pH of the main inflow, the Letter Burn (Table 8C) extends over a wider range (5.4 - 7.5) than does the loch itself, and changes generally coincide with or precede those in the loch itself.

Loch Achray, unlike Loch Rusky, or Lake of Menteith, remains on the acid side of neutrality for the entire year (Table 15, Fig. 11). The annual maximum of 6.7 was recorded during the summer; the lowest pH (6.1) was found in December. The main inflowing stream, the Achray Water, exhibited a larger pH range, falling to 5.1 in January and fluctuating irregularly for the rest of the year, with a peak of 7.0 in April.

Loch Ard showed the smallest annual range of pH (Table 15, Fig. 10) varying from 6.3 to 6.8. The season of low pH occurred during the winter months and the maximum between July and August.. In both Loch Ard and Loch Achray there was never a variation of more than 0.1 pH units with depth. The two main tributaries to Loch Ard (Table 8C), the Ledard Burn and Water of Chon, had a manifestly wider range of pH than the loch itself. The Ledard Burn ~~had~~ ranged from 7.5 in August to 6.2 in April with little consistent pattern. The Water of Chon showed a peculiar feature of having a winter pH maximum (7.1), with pH being low throughout the rest of the year with a minimum of 5.3 in February and March.

6. Alkalinity

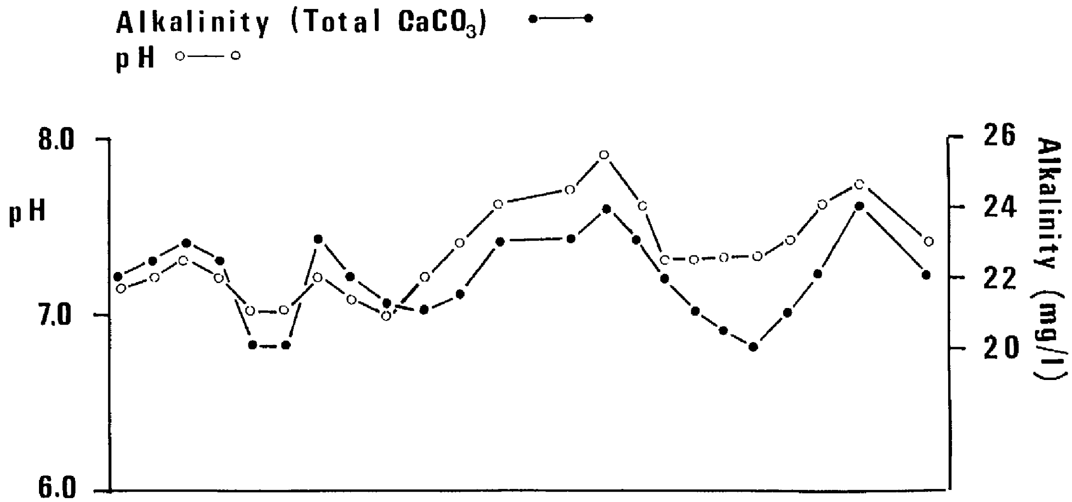
(a) Loch Lomond

In general the seasonal picture of alkalinity changes closely parallels the variation of pH at the same station. The same characteristic pattern is evident with a maximum in summer and a minimum in winter. The highest level of alkalinity recorded in Loch Lomond was 18.75 mg $CaCO_3$/l at South Balmaha while the lowest was 4.0 found at the North and North Inversnaid stations. The maximum recorded alkalinity values decreased, passing northwards. The greatest value of alkalinity observed at the South Station was 13.5, at the Middle Station 10.75 was recorded and at the North Station alkalinity only reached 9.0 mg $CaCO_3$/l. The lowest alkalinity value was identical in the South and Middle Stations (7.0) while at the North Station a value of 4.0 was found. Surface variations are generally reflected at each depth measured, although the annual range decreased with increasing depth.

The curve of alkalinity variation at the South Station (Table 16 and Fig. 16) clearly shows an almost identical pattern with the pH curve already described. The peak values occurred either at the same time or slightly earlier than the pH maxima. The highest recorded level in 1972 (12.5) occurred on 8 - 22 August, while in 1973 a value of 13 was found from 6 - 24 July; a lesser maximum was evident on 12 April (11.0). All these peaks occurred coincidentally with pH maxima; however, an increase in alkalinity on 12 September, 1972 took place over a month before the pH maximum. The lowest value of alkalinity (7.0 mg $CaCO_3$/l) was found to occur a month prior to the annual depression of pH (21 December, 1972 to 4 January, 1973).

LAKE OF MENTEITH

SURFACE Fig 19



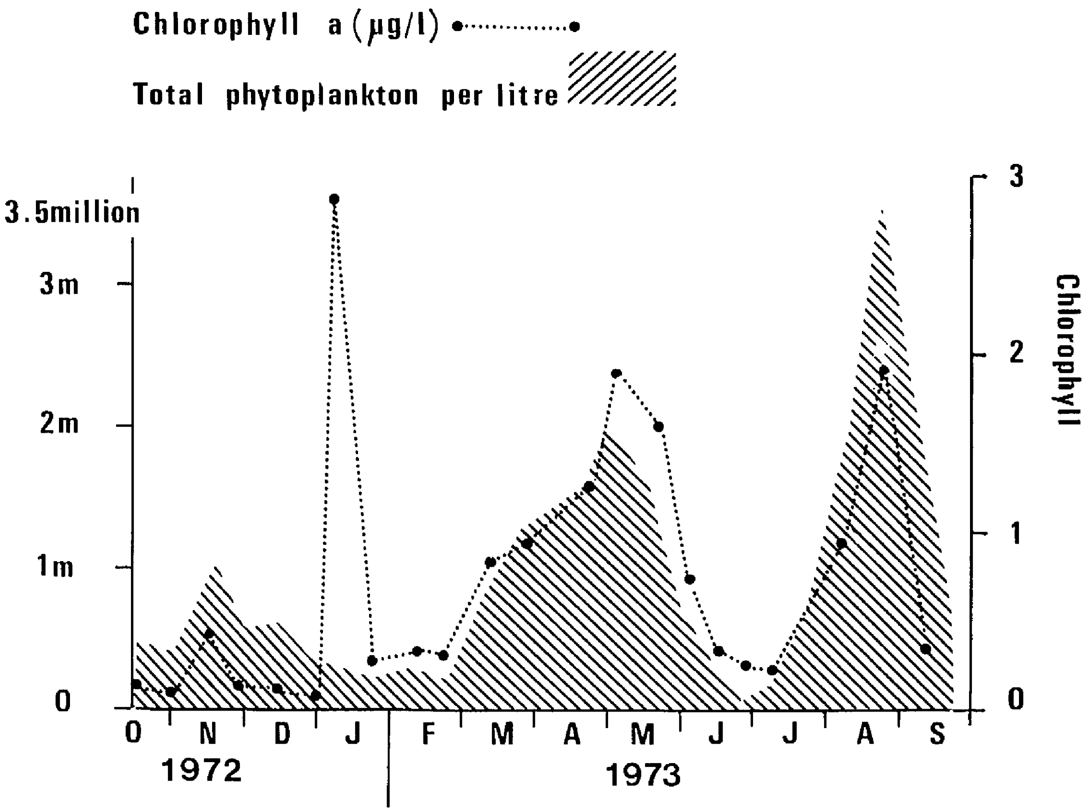


Table 16 Loch Lomond

Total Alkalinity as mg. $CaCO_3$/l.

	South basin				Middle basin				North basin			
	Surface	3 m	5 m	10 m	Surface	3 m	5 m	10 m	Surface	3 m	5 m	10 m
8. 8.72	12.5	12.0	13	13.5	9.5	9.75	9.5	9.5	8.7	9.0	9.0	8.0
15. 8.72	11.0	11.5	10.75	10.85	9.25	9.75	8.0	9.0	8.0	8.0	8.6	7.5
22.8.72	12.5	12.75	11.5	11.5	9	9.5	8.25	8.5	7.0	7.75	8.5	7.25
29. 8.72	12.25	13.0	13.0	11.25	10.25	10.75	9.75	8.75	7.0	7.75	8.0	6.5
6. 9.72	11.75	12.0	11.75	11.1	10.75	9.75	10.25	9.1	8.5	8.25	7.5	7.5
12. 9.72	10.5	11.0	9.0	10.75	8.25	8.5	8.75	9.0	8.0	8.5	8.25	7.00
27. 9.72	11.5	11.5	11.5	11.75	9.0	9.5	9.5	9.0	8.75	8.25	7.75	7.75
11.10.72	10.5	11.5	11.0	10.5	9.5	8.0	9.5	10.5	7.0	7.0	7.0	6.0
25.10.72	10.0	10.0	10.0	10.0	8.5	9.0	9.0	8.0	-	-	-	-
23.11.72	9.0	9.0	9.0	9.0	8.0	8.0	8.0	8.0	6.0	6.0	6.5	5.0
7.12.72	8.0	8.0	9.0	8.0	7.5	8.0	8.0	7.5	5.0	6.5	6.0	5.0
21.12.72	7.0	7.0	8.0	7.0	8.0	8.0	8.0	8.0	4.5	5.0	5.5	5.0
4. 1.73	7.0	8.0	9.0	8.0	8.0	8.5	9.0	8.5	6.0	4.0	6.0	5.5
17. 1.73	7.5	8.0	8.25	9.0	7.5	8.0	8.0	8.0	5.0	4.5	5.0	5.0
1. 2.73	9.0	9.0	8.0	10.0	7.25	7.5	7.0	7.5	5.5	4.0	5.5	4.0
15. 2.73	10.0	10.0	10.0	10.0	8.0	7.0	8.0	8.25	5.0	5.5	5.0	5.0
1. 3.73	9.0.	9.5	9.0	9.5	8.5	7.5	7.0	7.5	6.5	6.0	6.0	5.5
15. 3.73	8.5	8.0	9.5	8.5	8.0	7.0	8.0	8.0	7.0	6.0	6.0	6.0
28. 3.73	9.5	9.0	10.0	9.5	9.0	10.0	9.0	9.0	-	-	-	-
12. 4.73	11.0	10.0	11.0	11.0	8.5	8.5	8.0	9.0	6.5	6.0	6.0	6.5
26. 4.73	10.0	10.0	10.0	10.0	8.0	8.0	8.0	8.0	6.0	5.0	5.0	5.5
2. 5.73	10.0	10.0	11.0	10.0	8.5	8.0	8.0	8.5	-	-	-	-
10. 5.73	10.0	10.5	10.0	10.0	8.0	8.5	8.0	8.0	6.0	6.0	6.0	5.5
24. 5.73	9.0	9.5	9.5	9.0	8.0	9.0	8.5	7.5	8.0	7.0	6.5	6.0
7. 6.73	12.0	12.0	12.0	11.0	9.0	9.0	8.0	9.0	6.5	7.0	6.0	6.0
24. 6.73	12.0	13.0	13.0	12.0	10.0	10.0	10.0	8.5	6.0	7.0	7.5	7.0
6. 7.73	13.0	12.0	12.0	13.0	10.5	10.0	10.0	8.5	6.5	7.5	7.0	7.5
24. 7.73	13.0	12.0	12.0	12.0	10.5	9.0	10.0	8.0	8.0	8.0	7.5	7.0
2. 8.73	9.5	10.0	11.0	10.0	10.0	10.0	9.0	8.0	7.0	7.0	7.0	6.5
17. 8.73	10.5	11.0	11.0	11.0	9.5	9.5	9.5	8.0	7.0	7.5	7.0	6.5

The curve of alkalinity at the Middle Station (Fig. 17 and Table 16) shows larger week to week fluctuations than the South Station though the same seasonal pattern is still clear. Maximum surface value (1.75) occurred on 6 September concurrently with high pH and in July 1973 (10.5) slightly before the peak of pH. A subsidiary maximum was evident on 28 March with 9.0 mg $CaCO_3$/l being recorded at the surface and 10.0 at 3 m depth. The annual minimum of alkalinity (7.5) was observed on 7 December and 17 January. The seasonal variation at 5 m and 10 m depth was largely obscured by the magnitude of the week to week fluctuation.

The only consistent pattern which can be detected at surface and depth at the North Station (Table 16, Fig. 18) is a period of low alkalinity in the winter rising to a maximum in late summer and early autumn. Alkalinity reached a peak of 8.75 mg $CaCO_3$/l on 27 September and subsequently decreased to a surface minimum of 4.5 mg $CaCO_3$/l in December. Low levels persisted till February when a sustained increase was initiated rising to a spring and summer maximum of 8.0 mg $CaCO_3$/l.

At the North Inversnaid station the highest value of alkalinity (8.0 mg $CaCO_3$/l) occurred during the summer and autumn. A minimum value of 5.5 mg $CaCO_3$/l was observed on 1 February. Although the highest level of alkalinity recorded at North Falloch (9.25 mg $CaCO_3$/l) was higher than at North Inversnaid, the average alkalinity was less. In fact for more than half the year values remained at 5.0 mg $CaCO_3$/l while at North Inversnaid values exceeded 6 mg $CaCO_3$/l for most of the year. The alkalinity at South Balmaha ranged from 18.75 mg $CaCO_3$/l on 6 September to a minimum of 9.5 mg $CaCO_3$/l recorded on 15 March.

(b) Rivers and burns inflowing to Loch Lomond (Tables 17, 6 and 7)

The alkalinity of the main inflows to the lower loch were typically high throughout the year, with values rarely falling below 10 mg $CaCO_3$/l. The maximum recorded value of alkalinity was 96.5 mg $CaCO_3$/l in the River Endrick, which maintained an exceptionally high alkalinity content throughout the year. The only other large inflow which had persistently high levels of alkalinity was the Fruin which reached a peak of 50.0 mg $CaCO_3$/l.

LOCH RUSKY

Fig 20

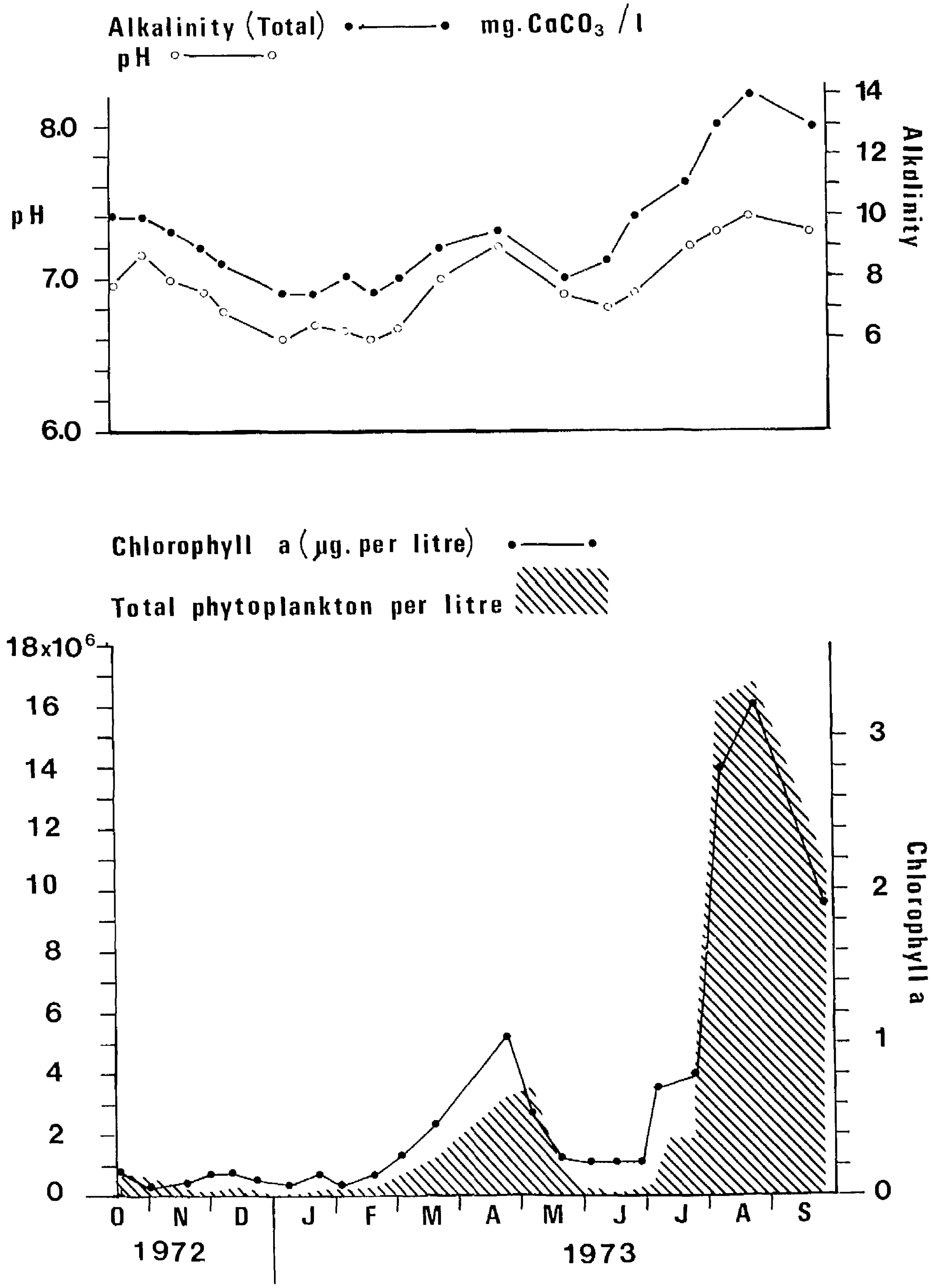


Table 17. Total Alkalinity ($CaCO_3$ - mg./l) of the rivers and streams inflowing to Loch Lomond

Date	Endrick	Fruin	Luss	Finlas	Douglas	Falloch	Inveruglas	Inversnaid	Cailness	Coille Mhor Burn	Cashell	Rubha Ban
8. 8.72	48.75	16.00	7.25	9.75	6.25	-	-	-	-	2.5	4.5	-
15. 8.72	-	-	-	-	-	10.75	4.5	6.8	3.8	-	-	25.25
6. 9.72	96.5	50.0	25.75	18.75	29.25	-	-	-	-	2.0	8.75	-
12. 9.72	-	-	-	-	-	3.75	20.00	6.00	10.5	-	-	30.5
11.10.72	96.5	49.75	27.5	26.75	13.25	6.5	10.5	2.75	1.00	1.5	4.25	39.25
25.10.72	81.5	50.0	21.0	18.2	14.0	6.5	10.0	2.0	0.5	1.00	4.00	42.0
23.11.72	58.0	29.0	18.0	16.0	13.0	5.0	8.0	2.5	1.5	2.0	2.0	44.0
7.12.72	-	-	-	-	-	6.0	8.5	2.0	2.0	2.5	2.0	41.0
21.12.72	48.0	22.0	18.0	16.0	13.0	-	-	-	-	-	-	-
4. 1.73	43.0	18.0	11.0	10.0	12.0	6.0	10.0	2.0	2.0	2.5	3.0	35.0
1. 2.73	-	-	-	-	-	3.0	7.5	1.5	0.5	-	-	33.0
15. 2.73	41.1	17.75	10.5	8.5	12.0	-	-	-	-	3.0	2.5	-
1. 3.73	-	-	-	-	-	2.5	3.0	1.00	5.00	-	-	22.0
15. 3.73	57.0	28.0	13.0	11.0	17.0	7.0	12.0	4.00	2.00	3.0	4.0	34.0
26. 3.73	-	-	-	-	-	-	-	3.5	3.0	2.0	4.0	42.0
12. 4.73	62.2	31.0	17.0	10.0	-	6,0	9.0	-	-	-	-	-
26. 4.73	70.0	39.0	19.0	-	20.0	-	-	3.5	2.0	2.5	3.5	44.0
10. 5.73	45.0	23.0	11.0	10.0	15.0	5.0	9.0	-	-	2.0	3.0	-
24. 5.73	45.0	21.0	10.0	11.0	15.0	7.0	8.5	2.5	1.0	0.8	1.5	43.0
7. 6.73	-	-	-	-	-	10.0	9.5	12.0	5.0	1.5	2.5	40.0
24. 6.73	44.0	18.0	12.0	11.0	15.0	-	-	-	-	-	-	-
6. 7.73	76.5	25.0	18.0	10.0	18.0	8.5	21.0	4.5	2.5	1.0	4.5	5.0
2. 8.73	90.0	40.0	25.0	11.0	20.0	9.0	22.0	5.0	2.0	2.0	6.0	40.0

The remaining large inflows to this region, the Luss, Finlas and Douglas, displayed an almost identical range of alkalinity from 30 to 10 mg $CaCO_3$/l.

The remaining burns draining to Loch Lomond were generally low in alkalinity, except for Rubha Ban and Stuckindroin which show exceptionally high values. These inflows fall into two groups; those in which the alkalinity seldom exceeds 5 mg $CaCO_3$/l - Cashell, Inversnaid, Cailness, Blair and AlltArdvorlich and those in which the alkalinity rarely exceeds 10 mg $CaCO_3$/l - Falloch and Inveruglas.

Unlike the loch itself there was poor correlation between pH and alkalinity, although it is evident that single high values of alkalinity were often reflected in high pH readings. Overall alkalinity in inflows was considerably lower during the winter than in summer, a broadly similar pattern to the seasonal variation of pH.

(c) The four Lochs

In Lake of Menteith, Loch Rusky, Loch Achray and Loch Ard, the peaks and depressions in the alkalinity curve follow those of the pH curve in each station. The short term fluctuation in alkalinity which tended to obscure the pattern in Loch Lomond was absent in these lochs. Lake of Menteith possessed the highest average alkalinity which was over twice that of Loch Rusky. Low levels of alkalinity were recorded in Loch Achray and Loch Ard. In general the surface and depth readings rarely differed by more than 1 mg $CaCO_3$/l.

(i) Lake of Menteith

Tha alkalinity in Lake of Menteith (Fig. 19, Table 18) fell to a minimum of 20 mg $CaCO_3$/l in December and rose to a maximum of 24 mg $CaCO_3$/l in May and August. The main inflow, the Burn of Menteith (Table 8C), displayed a much wider range of alkalinity with a maximum of 80.5 mg $CaCO_3$/l in October 1972, falling to a minimum of 10.0 mg $CaCO_3$/l in January. In 1973 a peak of 74 mg $CaCO_3$/l occurred in July.

(ii) Loch Rusky (Table 18, Fig. 20)

The minimum alkalinity measured in Loch Rusky was 7.5 mg $CaCO_3$/l at surface and 7.0 mg $CaCO_3$/l at depth in January. A spring maximum of

Table 18. Total Alkalinity as mg. $CaCO_3$/l.

	Lake of Menteith		Loch Rusky		Loch Achray		Loch Ard	
Date	Surface	3 m	Surface	5 m	Surface	5 m	Surface	5 m
18.10.72	22.0	21.0	10.0	10.0	5.5	5.0	5.5	5.5
1.11.72	22.5	22.0	10.0	9.5	5.0	5.0	5.0	6.0
15.11.72	23.0	22.0	9.5	9.5	5.0	4.0	5.0	5.5
29.11.72	25.5	21.0	9.0	9.0	5.0	4.0	5.0	5.0
13.12.72	20.0	20.0	8.5	8.5	4.0	3.5	4.0	5.0
27. 2.72	20.0	21.0	-	8.0	4.0	3.0	4.0	5.0
10. 1.73	23.0	23.0	7.5	7.0	4.0	3.0	3.0	4.5
24. 1.73	22.0	22.0	7.5	7.0	3.5	2.5	2.5	3.5
7. 2.73	21.0	20.0	8.0	7.5	3.5	3.0	3.0	3.0
21. 2.73	21.0	20.0	7.5	7.0	3.2	2.5	3.0	3.0
8. 3.73	21.5	22.0	8.0	8.0	3.5	2.5	4.0	4.0
26. 3.73	23.0	22.0	9.0	9.0	4.0	3.0	5.0	4.5
8. 4.73	-	-	-	-	-	-	-	-
20. 4.73	23.0	23.0	9.5	9.0	6.0	4.0	6.0	5.5
3. 5.73	24.0	24.0	-	10.0	5.5	5.0	6.0	6.0
17. 5.73	23.0	24.0	8.0	9.0	6.0	5.0	6.0	6.5
1. 6.73	22.0	21.0	-	9.0	5.0	5.0	5.0	6.0
14. 6.73	21.0	20.0	8.5	9.0	4.0	4.0	5.0	5.5
28. 6.73	20.5	20.0	10.0	10.0	4.0	3.0	6.0	6.0
11. 7.73	20.0	19.0	-	9.0	4.0	4.0	6.0	6.0
26. 7.73	21.0	20.0	11.0	11.0	5.5	5.0	7.0	7.0
8. 8.73	22.0	23.0	13.0	12.0	5.0	5.0	6.0	6.5
23. 8.73	24.0	25.0	14.0	13.0	4.5	4.0	6.0	6.0
20. 9.73	22.0	24.0	13.0	13.0	4.0	3.5	5.5	5.0

9.5 mg $CaCO_3$/l occurred in April and a summer maximum of 14 mg $CaCO_3$/l in August. This coincided with the maximum alkalinity in Lake of Menteith and with maximum pH in both Lochs. The main inflowing stream to Loch Rusky, the Letter Burn (Table 8C), exhibited values of alkalinity ranging from 47 to 20 mg $CaCO_3$/l with a maximum in October 1972 and a minimum in December. In 1973 alkalinity reached 38.5 mg $CaCO_3$/l on 26 July.

(iii) Loch Achray

Loch Achray displayed very low levels of alkalinity (Table 18, Fig. 11) ranging from 2.5 to 6 mg $CaCO_3$/l. Nevertheless a clear seasonal pattern was evident with a prominent winter minimum and summer maximum. The Achray Water (Table 8C) had only a slightly wider range of alkalinity (1.5 to 8.5 mg $CaCO_3$/l) than Loch Achray with lowest value in November.

(iv) Loch Ard

Loch Ard (Table 18, Fig. 10) exhibited a similar range of alkalinity to Loch Achray with a minimum of 2.5 mg $CaCO_3$/l in winter and a maximum of 7.0 mg $CaCO_3$/l in summer. In contrast to the loch, the alkalinity of Ledard Burn and Water of Chon (Table 8C) occasionally rose to high values. The Ledard Burn had an annual range of 3 - 32.5 mg $CaCO_3$/l while the Water of Chon ranged from 1.0 to 15.0 mg $CaCO_3$/l, but generally remained low for most of the year.

7. Oxygen and Temperature

(a) Loch Lomond

Oxygen and temperature profiles were recorded on a regular basis at the three main stations (North, Middle and South) in Loch Lomond from October 1971 to August 1973 and on occasions from the other three stations, South Balmaha, North Inversnaid and North Falloch, from August 1972 to August 1973.

Dissolved oxygen was generally high throughout the loch, with levels generally being higher during the winter than in the summer. Even during the period of stagnation oxygen was not reduced to low levels and never fell below 72% during the sampling periods.

At all stations in Loch Lomond thermal stratification of the water column occurred at some period during the year, the only exception being the South Balmaha station. The duration of stratified conditions was found to be short (one or two months) at South and North Falloch stations, 6 - 7 months at the Middle Station, while at the North and North Inversnaid Stations the water was stratified for most of the year. At no station was a reverse thermal gradient ever recorded.

(i) South Station

The maximum surface temperature recorded at the South station (Fig. 22 and Appendix Table 16A and 16B) in 1972 was 17.5°C on 26 July, whereas in 1973 a maximum of 18.5°C was recorded on 2 August. In both years the maximum recorded temperature at the bottom occurred slightly later than the surface maximum. In the former year 14.1°C was noted on 6 September while a bottom maximum of 13.5°C occurred on 21 August in the latter year. The annual minimum recorded surface temperature in 1972 was 4.1°C on 2 March while the lowest recorded temperature was 3.8°C at the bottom on 17 February. In 1973the surface and bottom minimum temperature was the same, 4.5°C recorded on 20 January and 1 February. Thus the annual range of temperature recorded in 1972 was 13.4 at the surface and 10.3 at the bottom while the temperature ranges in 1973 were 14.0°C and 9.0°C respectively.

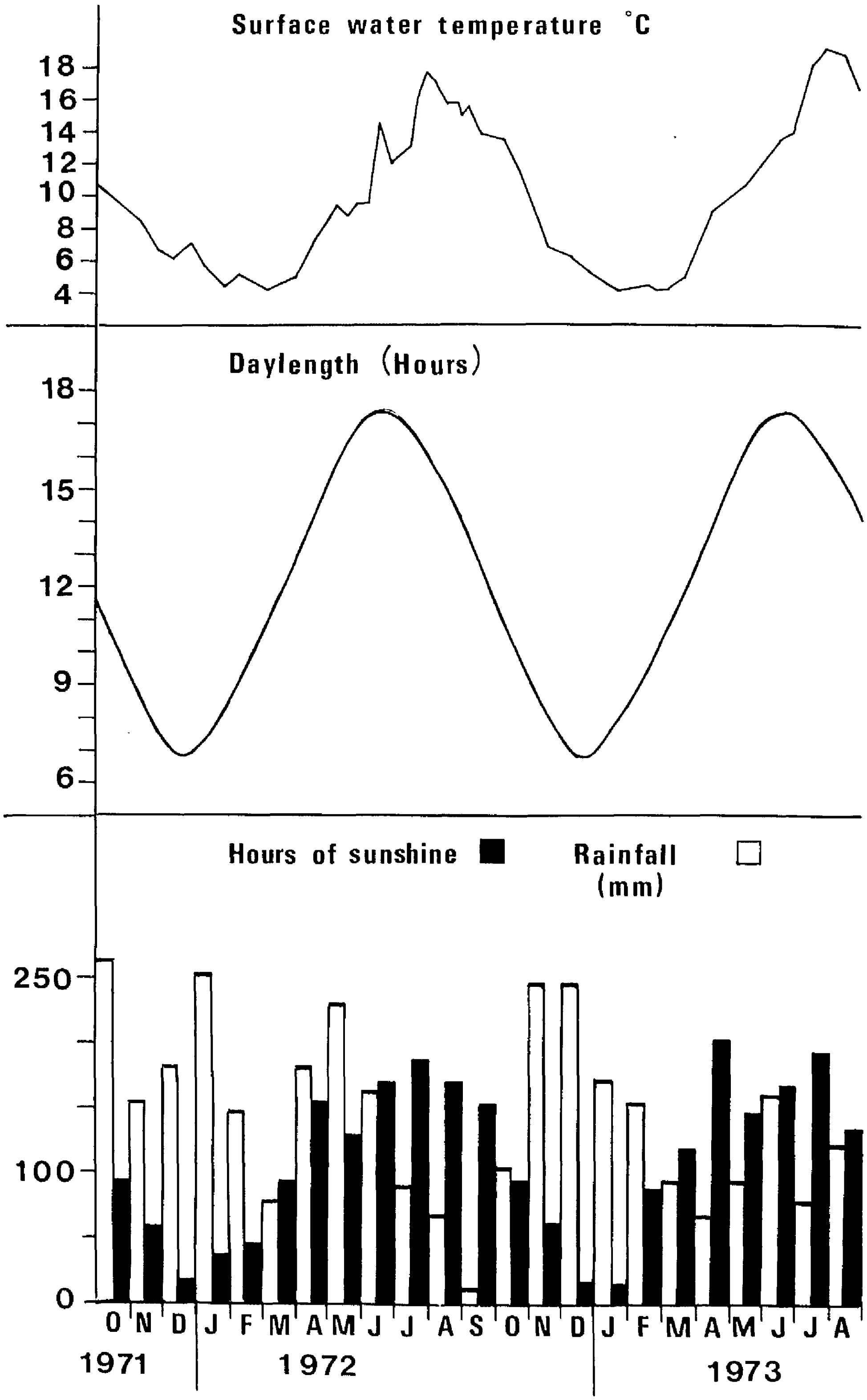
The highest percentage oxygen saturation recorded in 1972 was 110% at the surface on 17 February; in 1973 a similar surface maximum occurred. At its minimum level oxygen fell to 78% at the bottom on 17 July, 1972 and 82% at the bottom on 21 August, 1973.

On commencement of sampling at the South Station on 27 October, 1971 the water was nearly isothermal, with a temperature of 10.4 to 10.5°C in the top 5 m and 10.3°C below that ~~of~~ to the bottom (20 m). The oxygen saturation was greatest between 7 m and 15 m where 98 - 99% was recorded.

On 10 November the temperature had fallen sharply, decreasing by 2°C at the surface and 1.5°C below 10 m resulting in a slightly higher reading at the bottom (8.7) than at the surface (8.5°). The oxygen saturation increased from 94% at the surface to 99% at 9 m depth, remained at this value to 17 m depth and then fell sharply at 19 m to 94%. On 23 December completely isothermal conditions were observed, with a temperature of 5.8°C,

LOCH LOMOND SOUTH BASIN

Fig 21



the oxygen levels showed a considerable increase reaching 108 at the surface and 105 at 1 m. From 3 m depth to the bottom 100% saturation was recorded.

On 7 January, 1972 no significant changes were apparent, but by 20 January the temperature had decreased by 1.3°C at all depths to 4.5°C. Oxygen values showed an overall decrease, falling to 96% at surface and 1 m. A saturation of 102% was recorded at 3 m declining to 84% at and below 17 m. Two weeks later on 3 February, temperatures above 10 m had increased while those below 10 m had decreased. This resulted in a marginal gradient from 5.1°C at the surface to 4.0 at the bottom while the oxygen reading of 97% was almost constant at all depths. 17 February saw a decline in temperature at all depths. The actual range was from 4.2°C at the surface declining to 3.8°C at and below 7 m; this was the lowest temperature recorded at the South Station in 1972. Oxygen showed a large increase in the top 5 m reaching a saturation of 110% at the surface and 105% at 5 m depth.

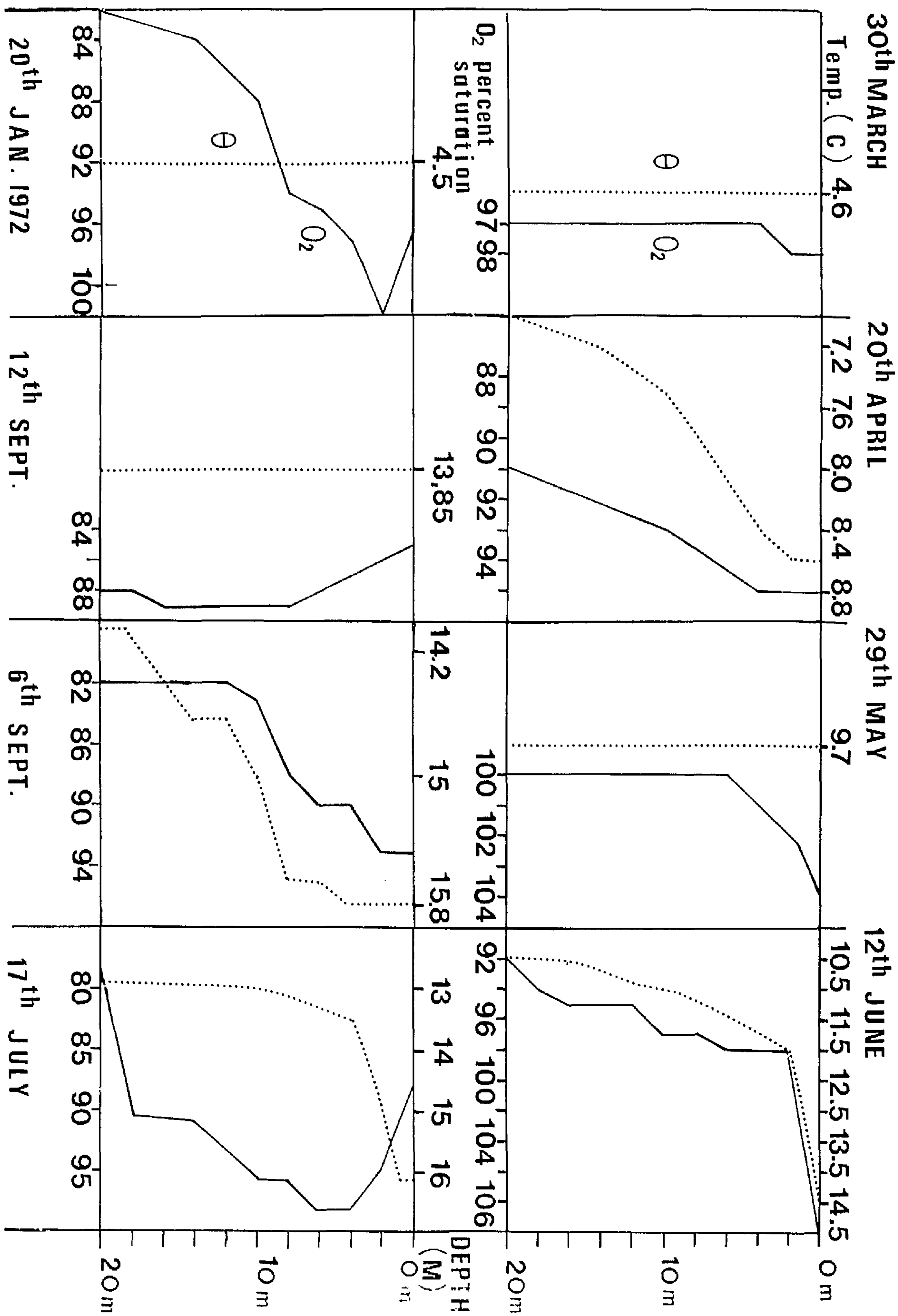
On 2 March the temperature had marginally increased to around 4.0°C at depth, while the oxygen had shown a decrease. This fall was greatest at the surface where a value of 99% saturation was recorded. From 1 m to 9 m values lay between 101 - 103% while at 11 m and below 92% was recorded. Temperature showed little change on 16 March with the surface temperature at 4.3°C and a bottom value of 3.9°C. Oxygen showed its lowest value at the surface, 96% saturation rising to 99% below 7 m depth. On 30 March the water was still isothermal although the temperature had increased to 4.6°C, while oxygen remained between 97 - 98% at all depths.

The establishment of a distinct thermal gradient occurred on 20 April when the range of temperature from surface to bottom was 1.5°C. In the upper 2 m the temperature was constant at 8.6°C, while from 3 to 5 m 8.4 was recorded. The underlying 5 m saw a steeper decline to 7.5°C which ultimately declined to 7.1°C at the bottom. Oxygen levels generally followed this pattern, remaining at 95% from surface to 4 m depth and then declining to 91% at the bottom. On 27 April little change was apparent whereas a

LOCH LOMOND

Fig 22

SOUTH BASIN OXYGEN and TEMPERATURE



slight increase in oxygen and temperature occurred on 4 May. On this date temperature gradually declined from 9.3 at the surface to 7.3 at the bottom. Oxygen declined from 97% at the surface to 96% at 13 m, while at the bottom the oxygen saturation was 92%. May 16th saw an overall increase in temperature and a rise in oxygen at all depths. Temperature was constant (8.8 - 8.9°C) over the top 11 metres and fell to 8.1 at the bottom. Oxygen displayed its highest value at 1 m (104%) decreased to 101% at 3 m depth and fell again to 94% below 15 m. The surface oxygen concentration was 100%. By 29 May the water had returned to an isothermal condition and temperature had increased to 9.7°C at all depths. The oxygen saturation was 104% at the surface, declining to 100% at 6 m depth and them remaining constant till the bottom. Little change~~s~~ was were apparent on 5 June.

On 12 June a strong temperature gradient was apparent from 14.9°C at the surface to 12.0 at 2 m depth. This was accompanied by a decrease in oxygen saturation from 110% to 98%. Below 2 m the temperature gradually declined to 10.5 at the bottom while oxygen fell to 92% over the same distance. 19 June saw a return to almost isothermal conditions with a recorded temperature ranging from 12.2 at the surface to 11.8 at the bottom. Oxygen, likewise, showed only a slight gradient from 101 at the surface to 98 at 20 m depth with a marginal increase to 102% between 5 and 9 m. By 26 June temperatures had risen by about 1.5°C but little gradient was evident with depth (13.6 - 13.7) apart from a bottom reading of 13.1°C. Oxygen had shown little change from the preceding date. By 10 July an unequal rise in temperature at all depths produced a gradient from 14.3°C at the surface to 13.4°C at 20 m depth. The oxygen concentration had shown an overall decrease, resulting in a 96% saturation at the surface declining to 93% at and below 11 m depth.

On 17 July the water column showed a distinct stratification, with a shallow epilimnion. Below this a steep temperature gradient was apparent from 16.1°C at 1 m to 13.5 at 4 m, followed by a less steep gradient to the bottom of thermocline. The hypolimnion lay between 10 m depth and the bottom and had a uniform temperature of 13.0°. The minimum oxygen saturation occurred at the bottom where 78% was recorded. However, above 18 m depth the dissolved oxygen value generally exceeded 90% and had a maximum of 98% at 4 and 6 m depth while 88% was recorded in the upper 3 m. By 26 July the surface temperature had increased to its annual recorded maximum of 17.5°C and the thermocline had widened to lie between 1 and 13 m. From the bottom of the thermal discontinuity to 20 m depth the temperature fell from 13.2 to 13.0°C. Oxygen values fluctuated between 86 and 89% over the upper 13 m but remained constant at 84% throughout the hypolimnion.

On 1 August the epilimnion had deepened, with the thermocline commencing at 5 m depth and continuing to 13 m. The temperature of the epilimnion was 17.0 while the hypolimnion was constant at 13.5°C. The highest saturation of oxygen occurred at the surface where 96% was recorded, while a value of 80% was noted at the bottom. By 8 August little change had taken place although temperature showed a marginal decline and oxygen had increased considerably below 10 m depth (to 90%).

By 22 August the stratification had been replaced by a continuous temperature gradient which ranged from 15.5°C at the surface to 13.4°C at the bottom. The oxygen profile was irregular, fluctuating between 91 to 94% in the upper 3 m and 82 to 88% below that. On 29 August a thermocline was apparent between 9 and 11 m. The epilimnion had a constant temperature of 15.0°C while the hypolimnion showed a slight gradient from 14.1 at the top 11 m to 13.0 at the bottom. In the upper 13 m of the water column oxygen was uniform at 93% falling irregularly to 87% towards the bottom of the hypolimnion. On 6 September, 1972 the thermocline was again initiated at a depth of 7 m and extended over the underlying 10 m. The epilimnion temperature was constant at 15.8°C while the zone of temperature discontinuity showed an irregular thermal gradient falling to 14.1°C at the top of the hypolimnion (19 m) where the temperature remained uniform. Oxygen values showed a gradient from 93% at the surface to 82% at 13 m depth (this reading remained constant to the bottom). 12 September, 1972 saw the return of isothermal conditions with a temperature of 13.85 being recorded at all depths. Oxygen increased from 85% at the surface to

89% at 11 m and remained constant to the bottom. On 27 September both temperature and oxygen were constant with depth at 13.4°C and 88% saturation. A slight fall in temperature was evident on 11 October, 1972 when 13.2°C was recorded at all depths. Oxygen decreased from 91% at the surface to 88% at 15 m followed by a drop to 80% at 20 m d epth.

Between 25 October, 1972 and 21 December, 1972 the water column at South Station remained isothermal with a decline in temperature from 11.5 to 5.85°C and a continuous increase in oxygen saturation from 83% to 110%.

The lowest recorded temperature in 1973, 4.5°C, was recorded at all depths on 20 January, while oxygen showed a wide range of values, from 102% to 82%. On 1 February, 1973, the temperature remained the same (4.5°C) while oxygen generally increased to 99% throughout the water column. A rise in temperature in 1973, first apparent on 15 February, reached 5.0°C on 15 March whereas oxygen levels during this period varied between 93 and 96%. Temperature rose to around 9.0°C in April, 1973 and the first distinct temperature gradient occurred in May 1973 when a range of 1.5°C was recorded from surface to bottom. A gradient from 13.1 to 10.0°C was recorded over the entire water column on 7 June, 1973 while later in the same month the first clear stratification occurred. The presence of a thermocline was clear throughout July and August, 1973, and was still present on completion of sampling on 21 August. In general variation in oxygen followed the same pattern as in 1972.

In summary the water mass at this station was found to be generally isothermal from September till the beginning of April although transient thermal gradient were occasionally set up during February and March. A clear stratification of the water column (with a well-defined epilimnion, thermocline and hypolimnion) commenced in June to July and remained till September although the thermal structure of the water column was still unstable. In fact the usually well defined layers occasionally merged to form a single gradient from surface to bottom. The value of oxygen saturation usually lay between 80 to 100% with oxygen level being generally higher in the winter than in the summer.

(ii) Middle Station (Fig. 23 and Appendix Tables 17a, b and c

The maximum surface temperature recorded in 1972 was 17.6°C on 26 July (same day as South Station) whereas in 1973 maximum. 18.5°C, occurred on 21 August. The maximum recorded temperature at the bottom (10.2°C) occurred on 11 October, 1972; this was about one month later than the bottom maximum at the South Station. The annual minimum surface temperature in 1972 (4.0°C) occurred on 2 March while the lowest recorded temperature (3.7°C) was recorded at the bottom on 17 February, 1972. In 1973 the surface and bottom minimum temperature were the same at 5.0°C on 15 February. Thus the annual recorded temperature range in 1972 was 13.6 at the surface and 6.5°C at the bottom while in 1973 the recorded ranges were 13.5°C and 5.0°C at surface and bottom respectively.

The highest percentage oxygen in 1972 was 105% recorded at the surface on 12 June whereas in 1973 a maximum of 103% was recorded at 3 m depth on 10 May. At its minimum oxygen fell to 80%on 11 October, 1972 and 78% on 21 August, 1973, both readings were taken at the bottom.

On 27 October, 1971 at the commencement of sampling the temperature was fairly uniform throughout the top 19 m of the water column, generally lying between 10.5 and 10.6°C. From 20 m downwards the temperature fell gradually reaching 10.2°C at the top layer of the thermocline (at 25 m), thereafter the temperature declined more steeply to 8.8°C at 30 m depth. The temperature gradually decreased till 40 m where 7.8°C was recorded; this marked the top of the hypolimnion which was 10 m in depth.

In the upper 5 m oxygen saturation fluctuated between 94 to 97% and thereafter remained constant at about 98% to the top of the thermocline. In the upper 5 m of thermocline the oxygen values fell steeply from 96 to 86%, while 86 - 85% was recorded throughout the rest of the thermocline and hypolimnion. By 10 November the surface and bottom temperature had fallen slightly and the thermocline had deepened. The hypolimnion had almost disappeared, being replaced by a continuous gradient from 25 m to the bottom. In the upper 22 m, the temperature was constant at 9.1°C declining to 8.2°C at 45 m below which the reading fell to 7.4°C. Oxygen values varied between 94 - 98% in the top 30 m, below which levels fell to 88% at 40 m and below. On 23 December, 1971 the temperature gradient between surface and bottom diminished to 0.2°C ranging from 6.2°C over the top 8 m to 6.0°C below that. Oxygen levels showed an increase at the bottom compared with previous week, with a uniform saturation of 91% being recorded.

During January 1972 completely isothermal conditions were observed, with a temperature (on 20th) of 5.3°C. The oxygen saturation fluctuated between 96 to 100% in the upper 4 m and then fell gradually towards the bottom where 81% was observed. February 1972 saw a further decrease in temperature. From the surface to 20 m a gradient occurred (from 5.1 to 4.1°C) below which the water was uniform in temperature. The distribution of oxygen was constant with depth, a saturation of 96% being recorded.

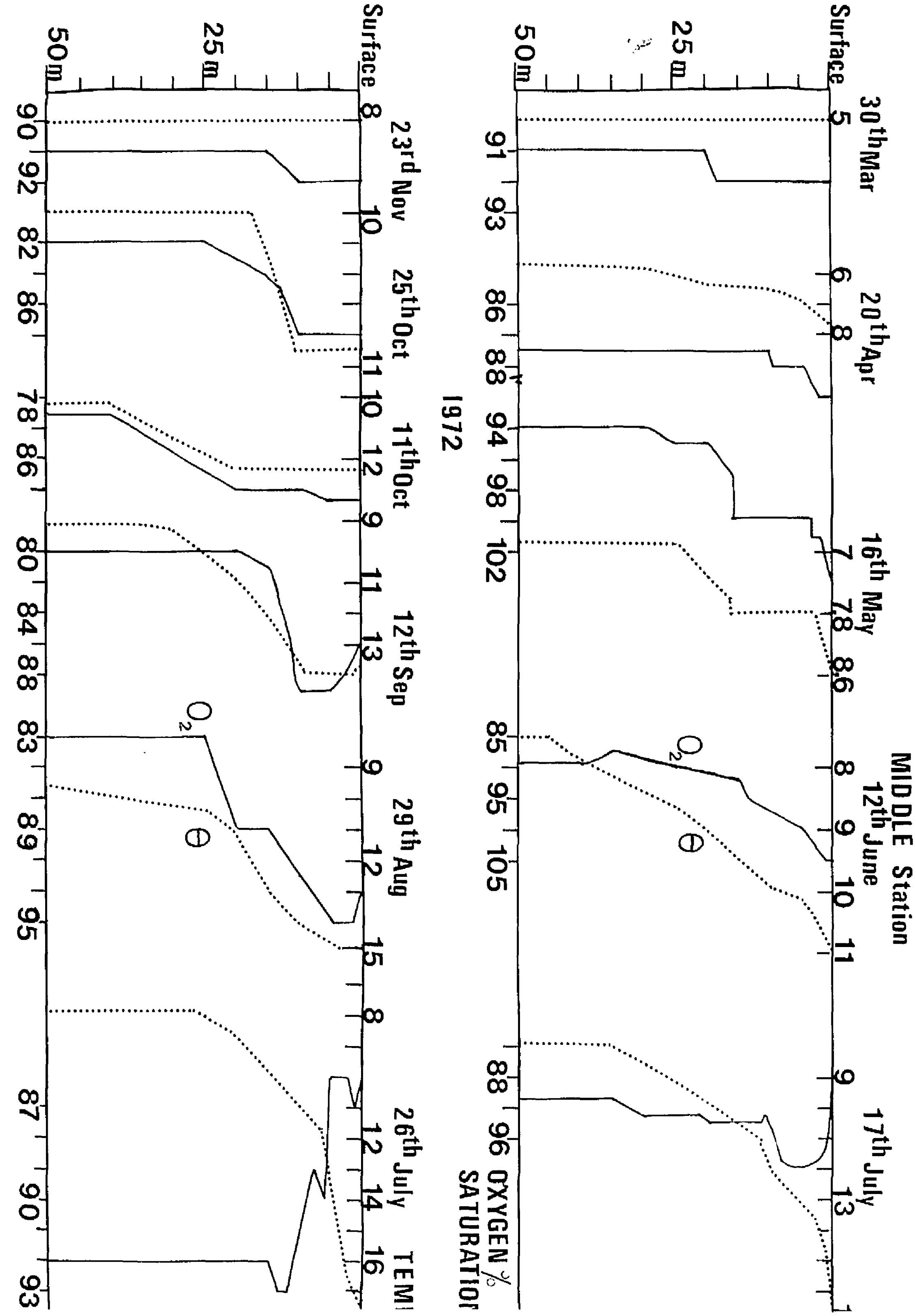
On 2 March the lowest annual temperature (4.0°C) was recorded at the surface below which the water column had a uniform temperature of 4.1°C. On 16 March, 1972 the temperature below 10 m fell to 4.0°C while a continuous gradient occurred from the surface (4.8°C) to 10 m. Completely isothermal conditions were re-established on 30 March when a uniform temperature (5.0°C) was recorded throughout the water column. During March 1972 oxygen never fell below 91% at any depth. Oxygen content of the bottom water was 100% on 2 March falling to 91% on 16 and 30 March.

In April 1972 the increase in temperature continued with 5.7°C being recorded below 3 m on 20 April 1972 and 7.9°C at the surface. On 27 April a thermal gradient was also apparent from 7.8°C at the surface to 6.2°C at 18 m below which a uniform temperature was recorded. Thus, during April 1972 there was no differentiation of a well defined epilimnion and thermocline, although a layer of uniform temperature did occur at the bottom. Oxygen values remained high during the first two weeks of April (90 - 100%) while it fell on 20 April when a saturation of 87% was recorded at the bottom. This period of relatively low oxygen content ended on 27 April when oxygen increased to 97% at the bottom and 100% in the top 5 m.

During May 1972 the surface temperature rose above 8.0°C and the first

LOCH LOMOND

Fig 23



appearance of a thermocline was observed (16 May). On this date the epilimnion covered the top 15 m of the water column and had a constant temperature of 7.8°C except for the top 3 m where 8.6°C was recorded. The beginning of a weak thermocline was detected at 15 m, extending to 25 m depth where the temperature was 6.9°C. This temperature was constant throughout the hypolimnion. Oxygen variations corresponded with the thermal structure of the water. Within the epilimnion an oxygen saturation of 100% or more was recorded, while within the layer of temperature discontinuity it varied from 95 - 100%. 94% was recorded in the hypolimnion.

On 12 June no distinction could be made between an epilimnion and thermocline, instead a continuous gradient occurred over the top 45 m with the temperature falling from 11.0°C to 7.5°C. Below this, a region of uniform temperature (7.5°C) was clear. Distinct stratification of the water reappeared on 26 June with an epilimnion extending to a depth of 15 m. The temperature remained at 11.0°C throughout the epilimnion and then fell steeply over the next 3 m where 10, 9.2, and 8.3°C were recorded at successive metres. The thermal gradient then became more shallow till 25 m where 7.7°C was recorded. Below this the temperature remained constant to the bottom (hypolimnion). The highest oxygen saturation was on 12 June when 105% was recorded at the surface, falling gradually to 89% at the bottom. On 26 June oxygen was around 100% saturation within the epilimnion and hypolimnion whereas at the top of thermocline the minimum oxygen saturation was recorded, 91% and 92% at 16 m and 17 m respectively.

In July the layer of water of uniform temperature at the bottom was clear while no clear distinction could be made between the epilimnion and thermocline. A continuous thermal gradient continued to 35 m on 17 July and to 30 m on 26 July. However the temperature gradient at the latter date was less steep in the top 3 m (17.6 - 16.7°C) than in the underlying 5 m where a fall from 16.7 to 11.1 was recorded. Below this a shallow gradient occurred till 30 m. Oxygen showed its greatest percentage of saturation on 17 July between 2 - 5 , where around 100% was recorded. A steep fall was observed in the underlying 5 m reaching 92% and thereafter remaining constant to the bottom. On 26 July the minimum oxygen saturation was detected in the top 5 m of the water column (86%) increasing gradually to 92 - 93% at the remaining depths.

Throughout the month of August distinct stratification of the water was clear. The epilimnion extended to about 8 - 10 m depth, the hypolimnion occupied the bottom 5 - 10 m while the thermocline occupied the region in between. Within this region, the steepest temperature gradient occurred from 10 - 25 m, above and below which a small gradient was apparent. Between the 1st and 29th August the surface temperature gradually decreased from 17.4^{O}C to 14.7^{O}C whereas the hypolimnion temperature rose from 8.0^{O}C to 9.6^{O}C. The minimum value of oxygen was detected at the beginning of the thermocline on 1 August and at the bottom of thermocline on 8, 15 and 22 August. This oxygen minimum continued to the bottom of the hypolimnion. On 22 August (90%) and 29 August, 1972 (83%).

On 6 September the temperature over the entire 10 m depth of epilimnion varied from 13.6 to 13.9 below which a steep temperature gradient was apparent to 10^{O}C at 25 m. A subsequent gradual fall reached 9.1^{O}C at 35 m, below which the temperature remained uniform. By 27 September, 1972 the epilimnion had deepened to 15 m and the temperature had fallen to 13.3^{O}C at all depths (except for 13.0^{O}C at the surface). Within the thermocline the temperature fell to 9.9^{O}C at 22 m and thereafter more gradually to 8.8^{O}C at 35 m, below which the temperature remained constant. On 12 September maximum levels of oxygen were found in the top 10 m where values fluctuated between 86 - 90%, declining to 82% at 15 m and then falling further to the minimum annual value of 80% below 20 m. The region of rapid reduction in oxygen coincided with the top layer of the thermocline. On 27 September a similar situation was clear with a minimum value of 80% being recorded at the top of the thermocline. At the surface 90% was recorded while at the bottom of thermocline and throughout the hypolimnion 83% saturation was recorded. The deepening of epilimnion and thermocline on this date was reflected in the deepening of oxygen minimum layer.

On 11 October, 1972 the epilimnion with a uniform temperature of

12.4°C covered the top 22 m of the water column. Below this a thermal gradient extended to 40 m depth where a temperature of 10.2°C was observed. This remained constant throughout the hypolimnion. 88% oxygen saturation was recorded in the epilimnion falling gradually to 82% at and below 25 m depth. On 25 October, 1972 a region of uniform temperature (10.9°C) extended from the surface to 10 m below which a decline took place to 13 m. The temperature at this depth (10.0°C) remained constant to the bottom. Oxygen remained around 90% throughout the epilimnion layer and then fell gradually to 80% at the bottom of thermocline. Completely isothermal conditions were re-established during November 1972. A temperature of 8.0°C was recorded on 23 November while the oxygen varied from 92 - 93%.

The water column remained isothermal throughout the winter, with the temperature falling from 6.65°C in December 1972 to an annual minimum of 5.0°C recorded on 15 February, 1973. Oxygen increased during this period from around 90% on 7 December, 1972 to 100% on 21 December and then declined to 98% on 1 February, to 95% on 15 February, 1973. During March 1973 and the first half of April the water column was still well mixed. Temperature increased to around 5.3°C on 15 March and to 6.0 on 30th while oxygen varied between 90 to 94% saturation.

On 24 April, 1973 a weak stratification first appeared and the oxygen level showed a slight decline to 98 - 88%. During May and June the water mass showed no distinct thermocline. Instead a continuous thermal gradient appeared from the surface to about 20 m, below which a zone of constant temperature was apparent. By the end of June 1973 surface temperatures had risen to about 14.0°C and the thermal gradient was about 4.0°C with a tendency for thermocline formation. Throughout this period oxygen values were high, generally between 95 to 100% with a maximum of 103% being recorded on 3 May, 1973. July saw the establishment of a permanent stratification of the water column. In August 1973 the maximum surface temperature (17.6°C) was recorded on 21st in the epilimnion. Oxygen declined during this period to low values (around 80%) throughout the water column, with a recorded minimum of 78% on 21 August.

In general the pattern of the two years (1972 and 1973) was similar, with the first appearance of stratification occurring at the end of April. This was followed by two months in which a layer of water of constant temperature was present in the lower part of the water column, with a continuous gradient from the surface to the top of this layer. A permanent thermocline was established during July in both years and remained till November when complete mixing occurred (in 1971 and 1972). Oxygen saturation was higher during the winter than the summer with values generally lying between 80 to 100%.

(iii) North Station (Fig. 24, 25 and Appendix Table 18a, b and c)

The maximum surface temperature in 1972 (16.1°C) coincided with that at the South and Middle Stations (26 July) while in 1973 a maximum of 16.6°C was recorded on 2 August. The temperature at the bottom rose to a maximum value of 5.9°C on 22 August, 1972 while in 1973 a similar value (5.8°C) was noted on 2 August. Minimum surface temperatures were 4.5°C on 30 March, 1972 and 4.9°C on 15 February, 1973. Whereas at the bottom the lowest recorded temperature was 4.1°C on 3 February, 1972 and 4.0°C on 15 February, 1973. Thus, this station showed the lowest annual range of surface temperature, 11.6 in 1972 and 11.7°C in 1973. The annual range of bottom temperature was extremely low, 1.8°C in both 1972 and 1973.

The lowest value of oxygen saturation was 72% recorded at the bottom on 11 October, 1972; this was the lowest level of oxygen recorded anywhere in the loch. The maximum oxygen content of the water in both 1971 and 1972 occurred in December when a similar surface saturation of 110% was noted.

On 27 October, 1971 when sampling commenced there was a clear stratification at the North Station of Loch Lomond. The epilimnion extended to a depth of 20 m with a slight gradient from 9.2 at the surface to 10.2°C. A steep thermal gradient continued to 50 m where a temperature of 5.9°C was recorded. Below this the gradient became less steep to 100 m which marked the top of the hypolimnion. Throughout this layer to the bottom (150 m) the temperature was 5.1°C. The lowest value of oxygen saturation on this date occurred in the region of the thermocline, where 84% was recorded (from 25 - 35 m). Below this, oxygen increased to 92% in the hypolimnion while in the epilimnion oxygen values fell from 96% at the surface to 89%.

On 10 November, 1972 the epilimnion extended to the same depth as the previous sampling (20 m) while the hypolimnion had deepened to start at 120 m. The thermocline was weaker and slightly wider. Temperature had fallen at all depths giving values of 7.8°C at the surface to 8.1°C at the bottom of epilimnion, the hypolimnion temperature was 4.9°C. Oxygen was again at its lowest in the zone of temperature discontinuity where 91% was recorded at 35 m. Below this, oxygen was constant at 93% while in the upper part of the water column levels fluctuated between 92 and 96%.

By 23rd December, 1971 the depth of the epilimnion was 19 m, throughout which the temperature was uniform at 6.5°C (except for 6.2°C at the surface). A continuous thermal gradient was detected over the next 80 m at the bottom of which a temperature of 5.1°C was recorded. The hypolimnion commenced at a depth of 120 m and had a constant temperature of 4.8°C. Oxygen showed its highest value at the surface, 110%; this fell to 92% at 5 m below which it was uniform to the bottom (150 m). The fall in temperature at all depths continued on 20 January, 1972 when isothermal conditions were established. The surface water (5.7°C) was 1.0°C warmer than the water at the bottom, while oxygen varied from 95% at 1 m depth to 80% at 60 m depth, thereafter remaining constant to the bottom. On 3 February the temperature varied from the surface value of 5.2°C to 4.1°C at 30 m depth, and was then uniform till the bottom. Oxygen showed a continuous decline from surface value of 97% to 92% at 30 m below which no change was detected.

Completely isothermal conditions were observed on 2 March with a temperature of 4.9°C at all depths (except for 4.8°C at the surface); this represents a decrease in temperature in the upper 5 m and an increase throughout the rest of the water column. Below 12 m depth oxygen was uniform at 97% while a maximum value of 100% saturation was observed at 2 m depth. On 16 March the surface temperature fell slightly to 4.8 and the bottom temperature fell to 4.1; the gradient was continuous from surface to 100 m.

The maximum value of oxygen saturation, 100%, was found between 20 - 35 m, falling to 90% at 100 m depth. From surface to 20 m depth the oxygen saturation increased from 96 to 100%. On 30 March the temperature over the top 50 m was 4.4 - 4.5°C, falling to 4.1°C at 100 m depth. As on the previous sampling date oxygen showed its maximum value between 25 - 35 m at 100% decreasing to 92% at the bottom and 96% at the surface.

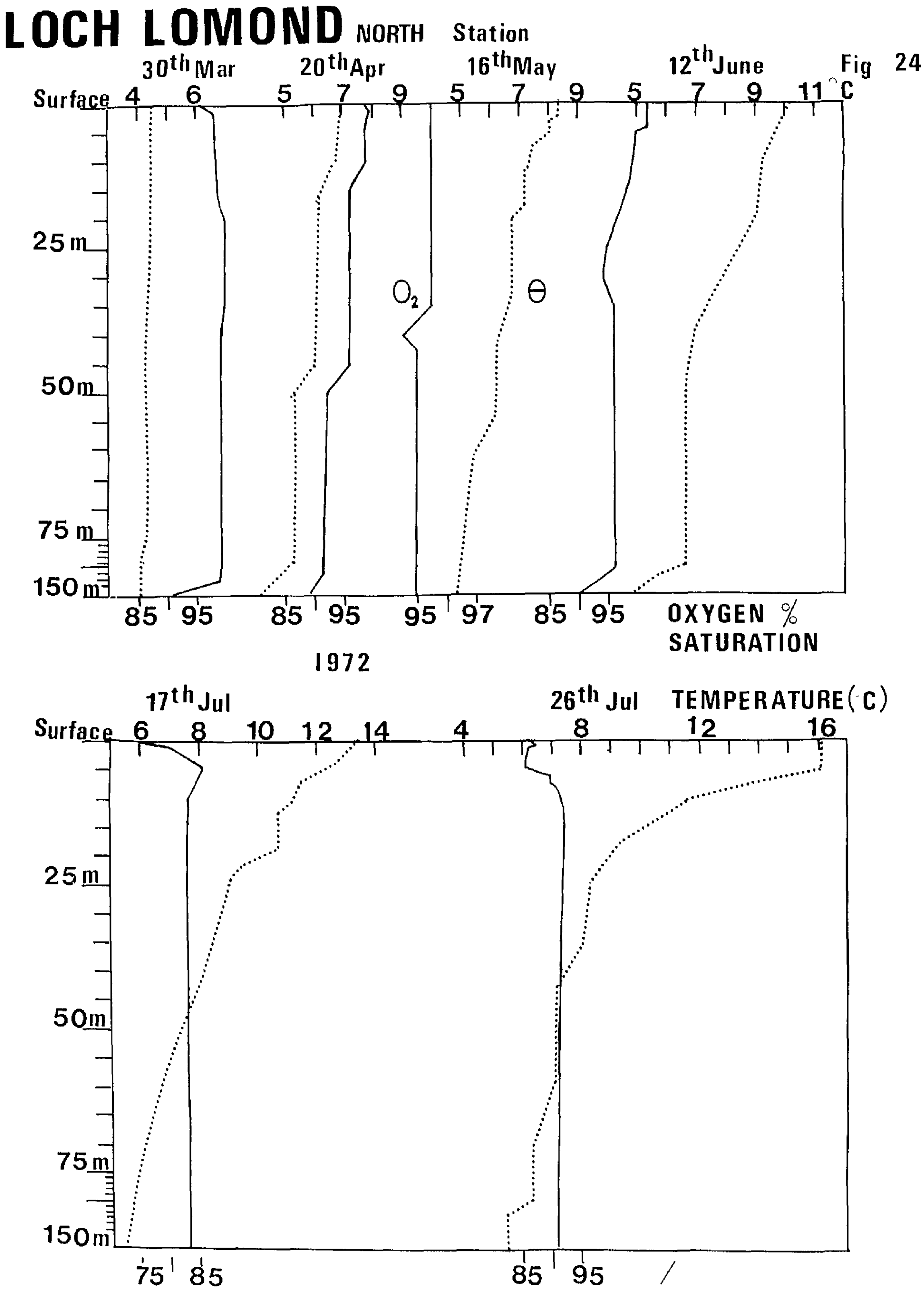
On 20 April, 1972 a slight thermal gradient occurred from 45 to 50 m with a fall in temperature of 0.7°C and a decline in oxygen of 4%. The temperature fell from 6.9°C at the surface to 6.0°C at the top of thermal gradient, whereas below this zone the temperature fell from 5.3°C to 4.5°C at 150 m. Oxygen had a maximum value of 99% saturation near the surface, falling to a minimum of 88% at the bottom. On 27 April, 1972 a weak thermocline was established between 10 and 12 m where the temperature fell from 6.8 to 6.3°C. Below this region a small gradient occurred reaching 4.5°C at the bottom, while above the thermocline the temperature reached 7.2°C at the surface. The maximum level of oxygen saturation occurred in the top 8 m where 98 - 99% was recorded. Below this oxygen declined irregularly to the bottom value of 92%.

No stratification of the water was apparent on 4 May, 1972 when a continuous gradient occurred from the surface (6.8°C) to the bottom (4.5°C). Oxygen declined f rom 101% at the surface to 95% at 80 m thereafter remaining at 91% saturation to the bottom. Two weeks later, on 16 May, 1972, the surface temperature had increased by 1.5°C and the bottom temperature by 0.4°C. A weak thermocline could be detected from 6 to 9 m where the temperature declined from 8.0°C to 7.4°C. Below this the temperature followed a continuous gradient to reach a constant 4.9°C below 80 metres. Oxygen showed complete constancy over the upper 35 m of the water column (at 96%) and then fell to a value of 93% at 50 m.

On 12 June a f airly steep thermal gradient occurred from the surface to a depth of 40 m. In the upper 20 m temperature declined from 10.3°C to 9.0°C, followed by a gradient to 6.9°C at 40 m. Below this the temperature fell gradually to 5.0°C at 150 m. Oxygen reached its highest values at the surface (102%) and then fell irregularly to reach a reading of 90% saturation at the bottom. By 26 June well defined stratification of the water column had taken place. The epilimnion had a constant temperature of 13.0°C and extended to a depth of 5 m below which a steep thermal gradient continued to 20 m where a temperature of 9.4°C was observed. The gradient then became less steep reaching a temperature of 5.6°C at 100 m. The hypolimnion began at 120 m with a temperature of 5.5°C. Oxygen saturation remained constant at 90% to a d epth of 20 m, increased to 91% at 25 m and then remained steady at 88% throughout the remainder of the water column.

On 17 July the region of most rapid thermal change occurred between 19 and 23 m, where temperature reading fell from 11.5 to 9.2°C. In the 6 m of water above this zone temperature was constant although surface temperature was higher (13.3°C). Below 23 m the gradient was less steep, reaching 5.6°C at 100 m depth below which the temperature was uniform. By this date the overall oxygen content of the water had decreased, being 83% at all depths below 10 m. The lowest value, 75%, was recorded at the surface and the maximum, 86%, at 5 m d epth. 26 July saw the maximum development of the thermocline and the maximum surface temperature (16.1°C). A well-defined epilimnion with a uniform temperature (16.1°C) extended to a depth of 5 m, below which a temperature discontinuity occurred reaching 8.2°C at 25 m, and 5.8 at 100 m where the hypolimnion commenced. The lowest oxygen values were found at the surface where 86% was recorded, This increased to 92% at 11 m and thereafter remained uniform to the bottom.

On 8 August the epilimnion temperature had fallen to 15.7°C and the layer had deepened. The thermocline was initiated at 10 m with a steep thermal gradient to 20 m where 10.8°C was recorded. Below this a gradual decline in temperature was evident to 5.6°C at 120 m where the hypolimnion began. Oxygen values in the region of the thermocline fell to 89% while levels were higher at the surface (91 - 93%) and at the bottom, 92%. The zone of temperature discontinuity was again initiated at 10 m depth on 22 August. A rapid fall in temperature occurred from 10 m (14.1°C) to


LOCH LOMOND NORTH Station
30th Mar
20th Apr
16th May
12th June
Fig 24
Surface
4 6 5 7 9 5 7 9 5 7 9 11 °C
25 m
50m
75 m
150 m
O_2
Θ
85 95 85 95 95 97 85 95
OXYGEN %
SATURATION
1972
17th Jul
26th Jul
TEMPERATURE (°C)
Surface
6 8 10 12 14 4 8 12 16
25 m
50m
75 m
150m
75 85 85 95

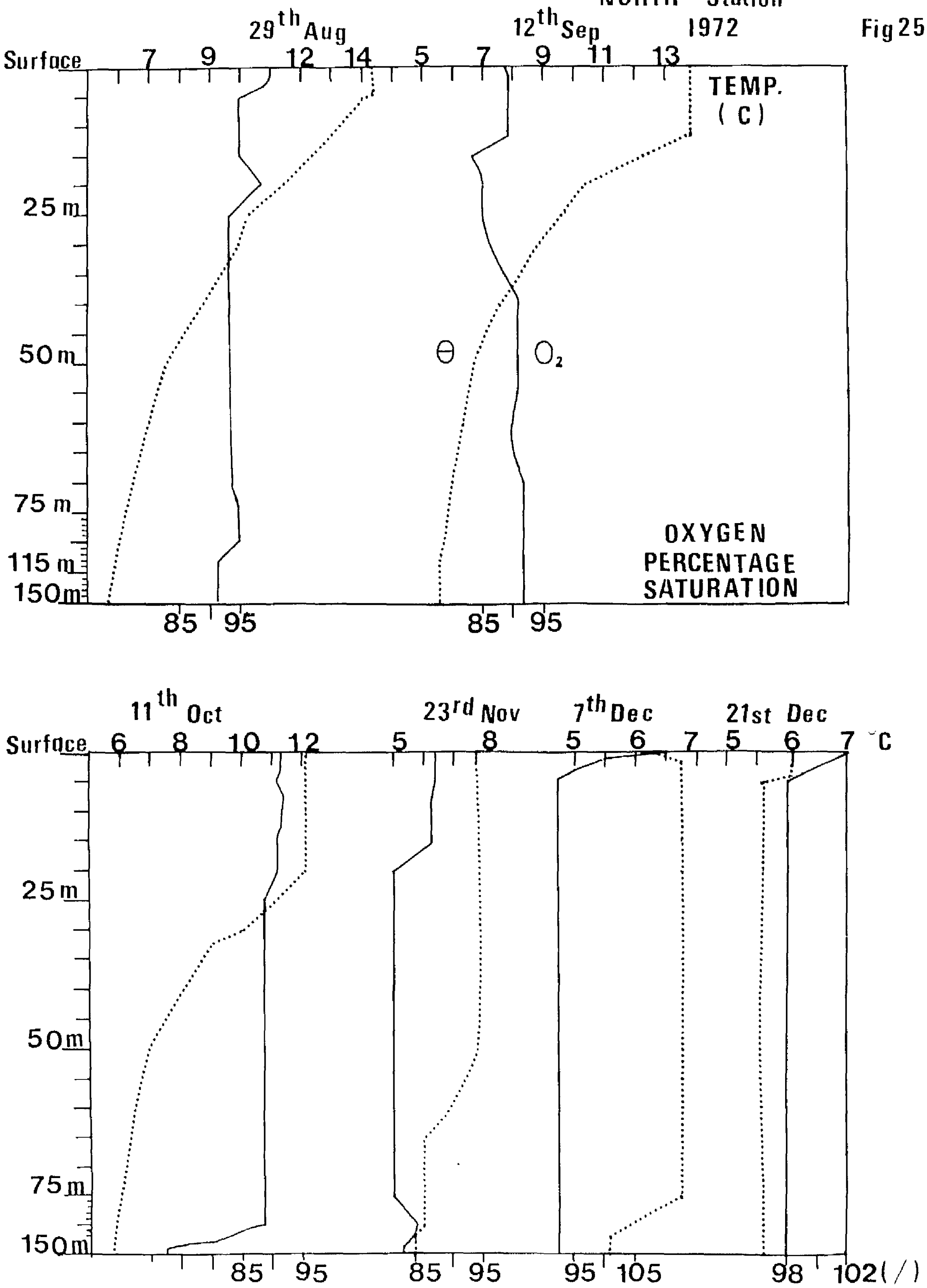
15 m (12.2) below which the gradient lessened reaching 5.9°C at 100 m depth. Oxygen showed its lowest percentage saturation, 84% at 12 m depth, increased to 88% at the surface while below 17 m depth the oxygen content of the water was 92%. On 29 August the epilimnion had fallen in temperature to 14.4°C and was less deep. The thermocline was initiated at 5 m depth below which a steep gradient occurred to 25 m where a reading of 10.3°C was taken. The thermal gradient then became less steep, ending at 100 m where a temperature of 5.9°C was recorded this value remained uniform throughout the hypolimnion. Oxygen reached its maximum value, 100%, at the surface followed by an irregular decline to 92%, recorded throughout the hypolimnion. An oxygen maximum (99%) was recorded towards the bottom of the temperature discontinuity (20 m). The epilimnion deepened to 12 m on 12 September and had a temperature of 13.8°C. A steep gradient continued to 20 m where 10.2°C was observed, the subsequent decrease was less steep, reaching 5.6°C at 100 m depth and remaining constant thereafter. The minimum value of oxygen saturation, 83%, was observed at 15 m, this increased to 89% in the epilimnion, while 92% was recorded throughout the lower 80 metres. On 27 September, 1972, the epilimnion had deepened further to 19 m and the temperature had fallen to 12.7°C. The thermocline was very short, extending over 1 m and giving a temperature gradient of 2.5°C. The hypolimnion occurred at the same depth as before (100 m) and had a temperature of 5.6 to 5.8°C. From the surface to 19 m oxygen values declined from 95 to 91% and then dropped by 6% in the next metre. Below 30 m depth, levels were constant at 90%.

The epilimnion attained a depth of 20 m on 11 October when the temperature was 12.1°C. Over the next 15 m a steep gradient occurred reaching 8.6°C, a lesser decline continued to 80 m where 5.9°C was recorded. This temperature was constant throughout the hypolimnion. Oxygen persisted around 92% in the upper 20 m of the water column falling to 88% in the thermocline. Below 80 m the oxygen value fell from 85 to 72% the lowest recorded value for the North Station. On 25 October, 1972 the epilimnion covered the upper 25 metres and the hypolimnion extended over the lower

LOCH LOMOND

NORTH Station 1972

Fig 25



70 metres. The epilimnion temperature was 10.3°C except for a reduction towards the surface where 9.6°C was recorded and the hypolimnion temperature was 5.4°C. The zone of temperature discontinuity occurred from 25-35 m where a temperature fall of 3.6°C was recorded. Oxygen declined from 97% at the surface to 83% at 30 metres (within the thermocline) and thereafter increased to 90% at and below 50 m.

On 23 November, 1972 and 7 December the epilimnion deepened to 50 m and 75 m respectively and fell in temperature from 7.9°C to 6.7°C. The hypolimnion commenced at a depth of 65 m on 23 November and at 120 m on 7 December, with respective temperatures of 6.0 and 5.6°C. On 23 November oxygen was highest at the surface and fell to around 80 - 84% at and below 20 m while on 7 December the surface value was 110% falling to a constant value of 92% below 4 m depth.

Isothermal conditions were re-established on 21 December with a uniform temperature of 5.6°C below 5 m depth and an oxygen concentration of 98%. Both temperature and oxygen were slightly higher at the surface (6.1°C and 102% respectively). A decline in temperature throughout January 1973 was accompanied by a slight fall in the oxygen content of the water. On 1 February, 1973 a uniform temperature of 5.5°C was recorded below 40 m while the overlying water varied from 5.85 to 5.6°C. Oxygen saturation was 92% below 25 m and was variable over the rest of water column. The annual minimum temperature at this station was recorded on 15 February when the water column was uniform at 4.9°C. Oxygen showed an overall increase in saturation to 95%.

During March, 1973 the water mass remained isothermal with a temperature of around 5.5°C. Dissolved oxygen during March was generally low varying from 88 ~~to~~ to 94% saturation. April saw the first indication of thermal stratification (on 24th) with a small gradient occurring between 20 to 60 m. Oxygen values had generally shown a slight rise (to 96 - 93%) while temperatures ranged from 7.6°C at the surface to 5.5°C at the bottom. On 10 May the situation was similar with the epilimnion extending to 20 m and the thermocline to 50 m. However, the oxygen content of the water registered a marginal decline.

During the rest of May and June 1973 the epilimnion was typically shallow, not extending to more than 5 m in depth except for the 7 June when the epilimnion and thermocline were replaced by a continuous thermal gradient. The thermocline layer gradually widened, reaching 130 m depth on 21 June, 1973. As the temperature increased in June the oxygen values fell in the lower part of the water column (to 88% on 21 June, 1973) while high concentrations (generally exceeding 100%) were recorded in the upper 10 m. In July and August 1973 the temperature gradually increased reaching a maximum on 21 August when the highest epilimnion temperature (16.6°C) was observed. Oxygen values continued to decline falling to a minimum of 80% on 21 August, 1973.

In general thermal stratification of the water column occurred at some period of the year throughout Loch Lomond with the exception of South Balmaha station. The duration of stratified conditions was found to be short (1 or 2 months) at South and North Falloch stations, 6 - 7 months at the Middle station, while at the North and North Inversnaid stations the water was stratified for most of the year. At no station was a reverse thermal gradient ever recorded for any length of time.

At the South, Middle and North Falloch stations the period of stratification was interrupted by periods in which a continuous thermal gradient occurred from surface to bottom. At North and North Inversnaid stations a permanent stratification existed from the time of formation to the end of the year. During this period there was a tendency for a secondary thermocline to form. At the South Balmaha Station no stratification occurred although a continuous thermal gradient was evident during the summer.

The South Balmaha and South stations showed the highest maximum surface temperature of 18.8°C and 18.5°C respectively. This decreased to 16.6°C at the North and 17.0°C at the North Falloch stations. The annual range of surface and bottom temperatures were also greatest at the South Station where 14.0 and 10.3°C was found at the surface and the bottom respectively. At the Middle Station the range was 13.6°C at the surface and 6.5°C at the bottom while the North Station exhibited an annual range of surface temperature of 11.7°C and only 1.8°C at the bottom. Any changes in water temperature always became evident first at the South Station becoming progressively later moving northwards.

From the results of the survey it is clear that the epilimnion, thermocline, and hypolimnion at each station differ from one another in temperature, in the strength of the thermal gradient and in the position of each layer on the same date. The earliest appearance of isothermal conditions was clearly at the South Station where a uniform temperature was recorded in September. At the Middle Station isothermal conditions occurred two months later while at the North Station a completely uniform water column was not apparent till January. All three stations showed isothermal conditions during the months January and February. The reappearance of uniform temperature conditions at any station usually coincided with an increase in nutrient throughout the Loch. This was particularly evident in May and September.

Oxygen saturation was generally high in Loch Lomond, never falling below 72% at the North Station and 78% at the MIddle and South Stations. During periods of thermocline formation the oxygen values were lowest at the top of the temperature discontinuity. The maximum oxygen value recorded at the South and North Stations was 110% while the highest value found at the Middle Station was 105%. The oxygen content of the water below 10 m depth was usually higher in winter than in summer, while the oxygen content was variable over the top 10 m throughout the year at all stations.

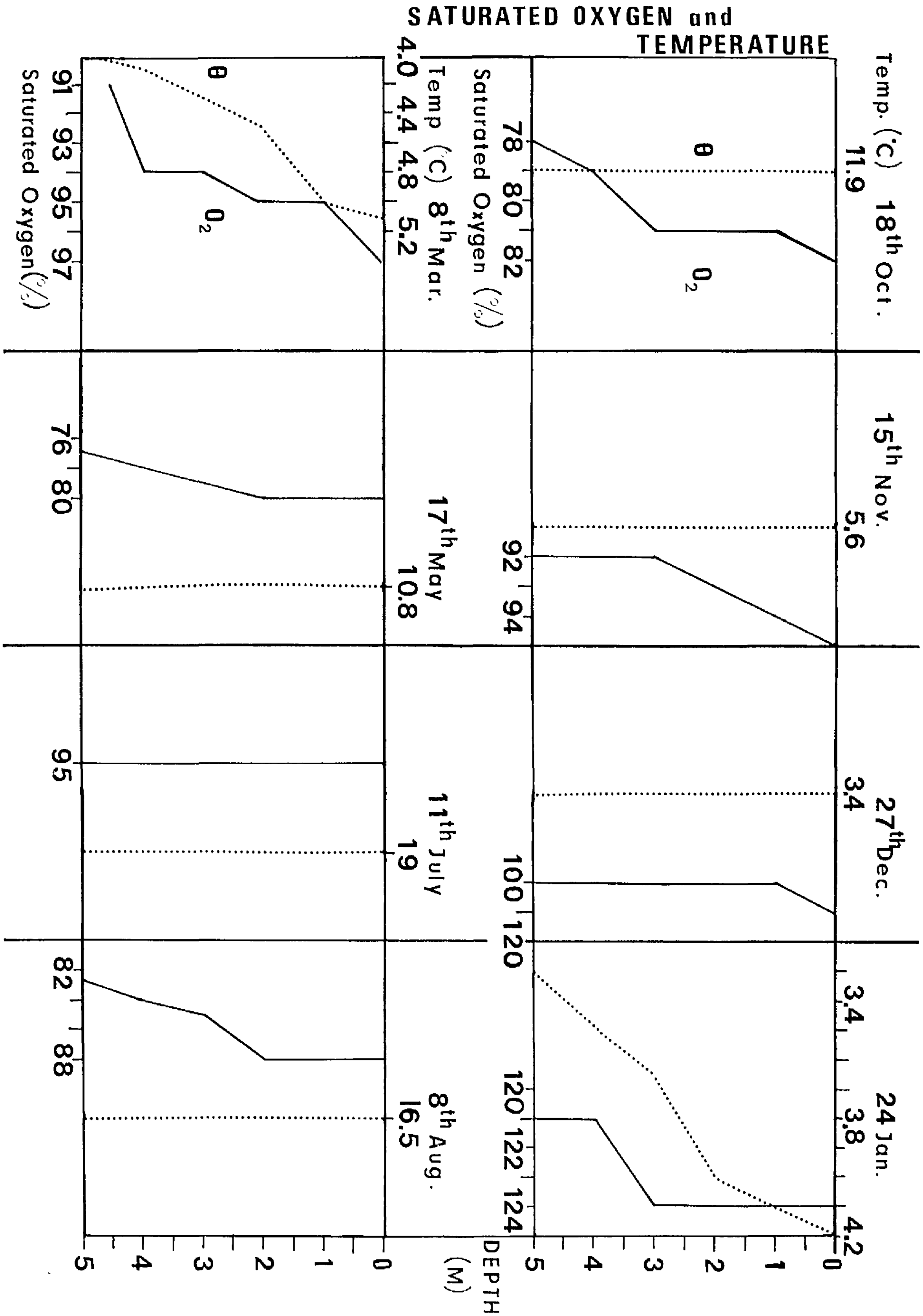
(b) The four Lochs

(i) Lake of Menteith

In Lake of Menteith (Fig. 26 and Appendix Table 19a, b and c) samples were not taken from the deepest part of the lake, for reasons described earlier. Consequently, no stratification was ever detected at this station, although a distinct temperature gradient was apparent during the cold weather (January, February and March). However, the weather was never cold enough for the lake to freeze though it may do so during severe winter.

LAKE OF MENTEITH

Fig 26



Isothermal conditions persisted throughout the rest of the year and, while it is possible for temperature gradient to occur during the summer, none was detected on the sampling days.

The maximum temperature recorded was 20.0°C on 26 July, 1973 while the minimum was 3.2°C at the bottom (7 m) on 24 January. Thus the annual range of temperature in this lake was 16.8°C. A high oxygen saturation was observed during winter while the lowest level of oxygen recorded was 77% on 18 October, 1972 and 17 May, 1973 at the bottom. Generally oxygen values were similar over the entire water column, or higher at the surface.

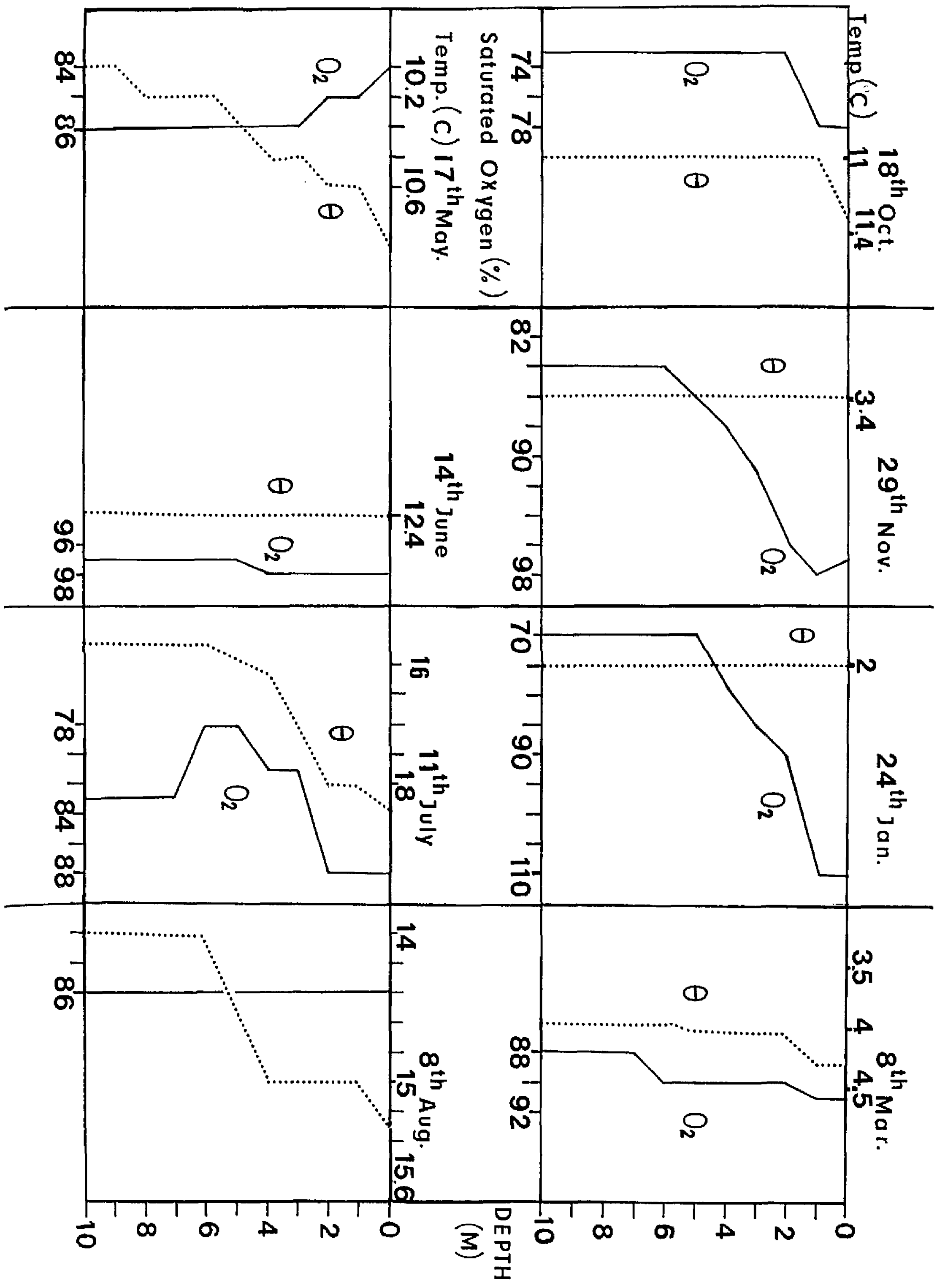
At the commencement of sampling in Lake of Menteith on 18 October, 1972 the water column had a uniform temperature of 11.9°C. Conditions remained isothermal till 10 January by which date the temperature had fallen to around 4.0°C. Oxygen values at the surface rose considerably over this period increasing from 82% to 115% while the saturation of oxygen at the bottom rose irregularly from 77% to 103%. The oxygen gradient from surface to bottom was generally small though on 29 November, 1972 the surface value of 103% fell to 80% at the bottom, giving a large gradient of 23%. This gradient declined to 10% saturation (110 - 100%) on 27 December and was 12% on 10 January (115 - 103%). On the latter date a small thermal gradient occurred in the upper part of the water column from 4.3°C at the surface to 4.0°C at 3 m.

On 24 January, 1973 a distinct thermal gradient was evident, from 4.2°C at the surface to 3.2°C at the bottom. While temperature had declined to its minimum, oxygen reached its annual maximum value of 124% at the surface and 120% at the bottom. By 7 February, 1973 the temperature had increased below 3 m depth to 3.4°C while oxygen had fallen to 95% at all depths. The water column was completely uniform on 21 February with respect both to oxygen (100%) and temperature (4.5°C). On 8 March, 1973 the bottom temperature had decreased to 4.0°C and the surface temperature risen to 5.1°C. Oxygen was on the decline ranging from 97% at the surface to 91% at the bottom.

On 26 March, 1973 oxygen showed no variation with depth (95%) while the temperature fell from 7.2°C at the surface to 7.0°C at the bottom.

LOCH RUSKY SATURATED OXYGEN and TEMPERATURE

Fig 27



From this date onwards the water remained isothermal. By 20 April the temperature continued to rise (to 9.0°C) and oxygen fell at the bottom to 85%. During May 1973 the temperature marginally increased from 9.6 to 9.7°C on 3 May and to 10.8°C on 17th. The oxygen saturation on 3 May ranged from 96% at the surface to 90% at the bottom while on 17 May a marked fall had taken place at all depths. The surface and bottom minima were recorded on this date being 80% and 77% respectively.

On 14 June, 1973 the temperature showed an increase of 3.0°C followed by a further rise to 19.2°C at the surface on 28 June and 18.0°C at the bottom. This was the only temperature gradient observed during the summer at this station in Lake of Menteith. 102% saturation was recorded at all depths on 14 July when the temperature increased to a recorded maximum of 20.0°C at all depths.

By 8 August, 1973 the temperature had fallen to 16.5°C and oxygen showed a gradient from 88% at the surface to a fairly low value of 83% at the bottom. During September 1973 a decline in temperature was evident reaching 14.0°C at all depths on 20th. Oxygen showed an increase at the surface to 95% with a gradient to 80% at the bottom.

(ii) Loch Rusky

The formation of a distinct thermocline in Loch Rusky (Fig. 27 and Appendix Table 19a, b and c) was apparent from the end of June till September 1973. The thermocline was generally shallow, not penetrating deeper than 6 m, except for 8 August, 1973 when the hypolimnion began at 9 m depth. Throughout the rest of the year isothermal conditions prevailed, although small thermal gradients were occasionally apparent during this period.

Oxygen was generally variable with the lowest value of 70% being recorded at the bottom on 24 January and the highest at the surface, 115% on 3 May. A very large gradient was apparent from surface to bottom on 24 January when a range of 40% (110 - 70%) was recorded. The lowest temperature noted in this Loch was 2.0°C throughout the entire water column (14 m) on 24 January. The maximum temperature, 19.0°c, was observed at the surface on 26 July, 1973. Thus both maximum and minimum temperatures occurred simultaneously with those of Lake of Menteith but were lower in each case.

At the commencement of sampling on 18 October, 1972, the temperature was uniform throughout the water column at 11.0°C except for a surface value of 11.4°C. Oxygen was generally low, ranging from 78% at the surface to 73% from 2 m at the bottom (14 m depth). By 1 November, 1972 oxygen had increased by more than 10% at all depths while a considerable fall in temperature was evident. There was a tendency for a reverse thermal gradient to form with the temperature being cooler at the surface, 8.3°C, than at 6 m depth, 8.6°C. 15 November saw a very small thermal gradient (0.1°C) and a fall in temperature to around 5.0°C. Oxygen was constant with depth at 86% with the exception of slightly higher value between 4 and 6 m. At the end of November the water column was cooler at 3.4°C and oxygen had increased to 97% saturation at the surface and fallen to 84% from 6 m depth to the bottom. A further marginal fall in temperature occurred on 27 December, accompanied by a fairly large increase in oxygen saturation to 100% at all depths below 3 m and 108% at the surface. These conditions persisted till 10 January, 1973, although the surface oxygen level rose by another 4% and temperature decreased by 0.9°C.

On 24 January, 1973 high levels of oxygen were evident in the upper 2 m (110%). Below this a steep gradient occurred, reaching the minimum annual value of 70% at 5 m depth and then remaining constant to the bottom. This oxygen minimum also coincided with the lowest recorded temperature, 2.0°C at all depths. On 7 February a thermal gradient was apparent from 3.95°C at the surface to 3.0°C at 5 m thereafter remaining constant to the bottom. Oxygen had greatly increased by 20% in the lower part of the water column and ranged from 96% at the surface to 90% below 6 m. The water column was again isothermal on 21 February at 4.5°C while the oxygen content of the water had fallen to low levels (75%) below 5 m depth. Little change in temperature was apparent on 8 March when reading fell from 4.3°C at the surface to 4.0°C in the upper 6 m. Oxygen lay between 91% to 88%.

From 26 March to 3 May, 1973 the water column was isothermal, and increased in temperature from 6.8°C to 8.0°C (on 20 April) and further to around 9.6°C on 3 May. The oxygen content of the water r emained similar from 26 March to 20 April, with a gradient on both occasions from 93% at the surface to 88 - 87% in the lower 9 m of the water column. On 3 May a large rise in percentage saturation of more than 15% was apparent at all depths. Surface values reached their annual maximum of 115% while 100% saturation was recorded below 9 m depth.

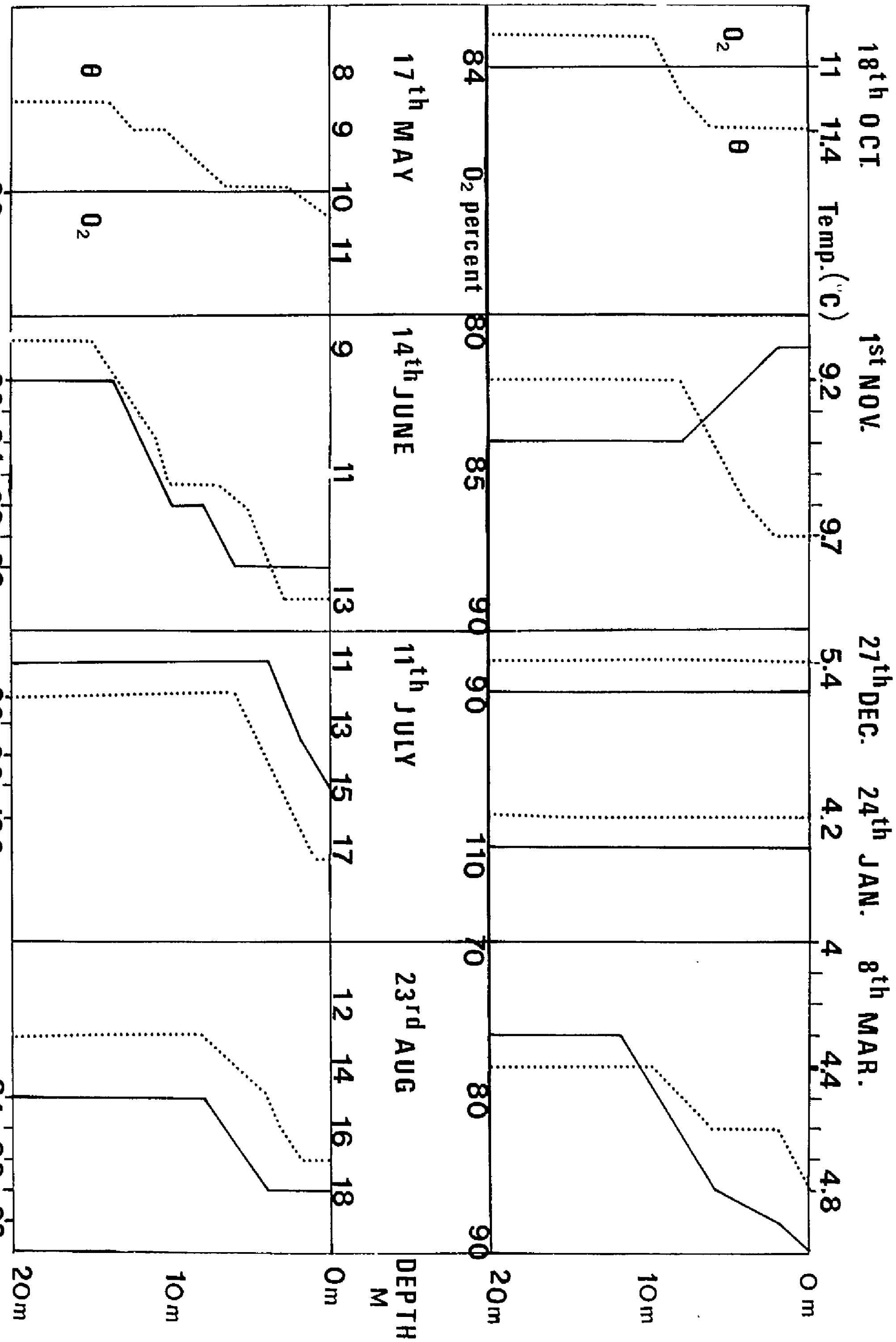
On 17 May, 1973 a continuous thermal gradient was established from 10.8°C at the surface to 10.2°C at 9 m depth. This was accompanied by a considerable fall in oxvgen values, ranging from 84 to 86%. Oxygen increased by about 10% on 14 June (97 - 98%) while the water column was again isothermal at 12.4°C.

Stratification of the water column was first established on 28 June, 1973 when the epilimnion covered the top 2 m and had a temperature of 19.0°C; the thermocline extended over the next 4 m with a strong gradient to 12.2°C at the top of hypolimnion. Oxygen fell from 96% at the surface to 82% in the middle of thermocline and then remained constant to the bottom. A similar situation obtained on 11 July, the epilimnion and thermocline occurred at the same depth while the temperature of the lower part of the water column had increased. Minimum levels of saturated oxygen 78% occurred at the bottom of the thermocline, while surface and bottom values were 88% and 83% respectively. The thermocline showed no signs of deepening on 26 July although the temperature throughout the water had increased by about 1.0°C or less. The maximum annual temperature, 19.0°C, was recorded at the surface on this date. Very low levels of oxygen (73%) were recorded at the bottom of thermocline while surface and bottom oxygen values were the same as for previous sampling. A deepening of the epilimnion and thermocline layers was evident on 8 August as the temperature started to decrease. The epilimnion extended to a depth of 4 m and fell to 15.5°C while the thermocline continued to 9 m at which a temperature of 12.5°C was recorded; oxygen levels were constant at 88% throughout the water column. Temperature

LOCH ACHRAY

Fig 28

SATURATED OXYGEN and TEMPERATURE



declined to 13.8°C at the epilimnion on 20 September and a continuous gradient was evident till 10 m where 9.8°C were recorded. Oxygen showed an overall increase to 92% at the surface while 90% was recorded from 9 m downward.

(iii) <u>Loch Achray</u>

In Loch Achray (Fig. 28, Appendix Table 20a, b, and c) isothermal conditions occurred from the middle of November, 1972 till the beginning of May 1973, despite the appearance of transient thermal gradients during February and March. Distinct thermal stratification of the water mass appeared on 17 May, 1973 when the thermocline was initiated at a depth of 6 m and extended to 12 m. During June there was a corresponding decrease in the width of epilimnion and an increase in the width of thermocline layer. July, August and September, 1973 and October 1972 saw an increase in the width of hypolimnion with a consequent shortening of the thermocline.

The lowest temperature in Loch Achray occurred on 27 December and 10 January when 4.0°C was recorded at all depths. The surface water rose to a maximum value of 18.7°C on 28 June while the bottom maximum occurred later on 8 August (15.0°C). Thus the range of surface temperature in Loch Achray (14.7°C) is less than Loch Rusky (17.0°C) or Lake of Menteith (16.8°C). The lowest level of saturated oxygen, 76%, occurred at the bottom (20 m) on 8 March while the maximum value recorded was 112% found at the surface on 10 January, 1973. The highest value of oxygen saturation observed at the bottom was 110% found on 24 January. In general the range of oxygen reading from surface to bottom was small and never exceeded 16%.

The commencement of sampling on 18 October, 1972 occurred towards the end of the period of stratification, although a temperature discontinuity was discernable. The thermocline lay between 6 and 10 m depth, with a temperature gradient from 11.4°C (in the epilimnion) to 10.8°C (in the hypolimnion). Oxygen showed no variation with depth and gave a reading of 84% throughout the water column (20 m). By 1 November the epilimnion had decreased in depth and The hypolimnion had increased; the thermocline covered the region between 3 - 8 m depth. Oxygen showed a slight fall at the surface where 81% was recorded.

Isothermal conditions appeared on 15 November, 1972 when temperature had fallen to 6.7°C and oxygen to 81% at all depths. The temperature continued to fall till 21 December when 4.0°C was recorded, while oxygen continuously increased reaching 90% on 29 November and 100 - 103% on 27 December, 1972. On 10 January, 1973 temperature remained as before while oxygen rose to 105% below 3 m and to 112% at the surface. A further rise in saturated oxygen throughout the water column (except for the surface) reached 110% on 24 January, 1973.

On 7 February, 1973 oxygen had decreased to 95% and was uniform with depth while temperature showed a small gradient from 4.5°C at the surface to 4.1°C at 6 m. Apart from a marginal rise in temperature (0.3 or less) the situation on 21 February was identical. On 8 March temperature showed a gradient from 4.8°C at the surface to 4.4°C at 10 m, and then remained constant to the bottom. Oxygen showed a decrease in saturation at all depths and a f airly steep gradient was apparent from the surface (90%) to 12 m (76%). A considerable rise in temperature had occurred by 26 March 1973 reaching 6.0°C at the surface and 5.6°C below 3 m. An increase in oxygen content had also begun with values lying between 93% at the surface and 90% below 3 m. On 20 April and 3 May, 1973 conditions were again isothermal and oxygen showed no variations with depth. Temperature rose from 8.0°C while oxygen showed a slight fall in saturation from 94% to 92%.

Stratified conditions were first apparent on 17 May when the thermocline was initiated at a depth of 7 m and continued to the top of the hypolimnion at 12 m depth. The thermal gradient was 1.2°C, from 10.0°C in the epilimnion to 8.8°C in the hypolimnion. Dissolved oxygen on the other hand, showed no variation with depth having a 96% saturation throughout the water column. On 14 June the thermocline widened greatly, extending from 3 m to 15 m. The temperatures in the epilimnion and hypolimnion were 13.0°C and 8.7°C respectively, while the percentage saturation of oxygen fell regularly from 98% at the surface to 92% at the bottom. On 28 June, 1973 the epilimnion shortened to 1 m where a temperature of 18.7°C was recorded. This large rise in surface temperature was not reflected at the bottom where a reading of 9.0°C was taken. Oxygen saturation decreased regularly from the surface (100%) to 84% at 11 m depth.

During July 1973 the thermocline shortened and the hypolimnion became much wider. On 26 the thermal gradient was initiated at a depth of 2 m and continued to 7 m below which a uniform temperature of 13.3°C was recorded. The epilimnion on this date had a temperature of 18.6°C. The lowest value of saturated oxygen, 84%, was detected at the bottom of the thermocline while values of 88% and 92% occurred at bottom and surface respectively.

By 8 August the surface temperature fell while the bottom temperature continued to rise. The thermal discontinuity layer shortened still further. The actual extent of the laver was from 3 to 4 m and the temperature gradient was from 15.5 to 15.0°C. Oxygen showed a small gradient from the surface 92% to 88% at 11 m and then remained constant at 86%. The epilimnion showed a slight rise in temperature (17.0°C) on 23 August while the hypolimnion temperature declined to 13°C. This resulted in a larger thermal gradient (4.0°C) and an increase of thermocline width (2 - 8 m). Levels of saturated oxygen generally followed the thermocline, being higher in the epilimnion, 88%, than in the hypolimnion, 84%. On 20 September, 1973, the temperature showed an overall decline falling to 13°C in the epilimnion and to 11.0°C in the hypolimnion. The thermocline was initiated at 5 m depth and extended to 7 m. Oxygen values had risen at the surface and fallen at the bottom with a clear gradient from 90% to 80%.

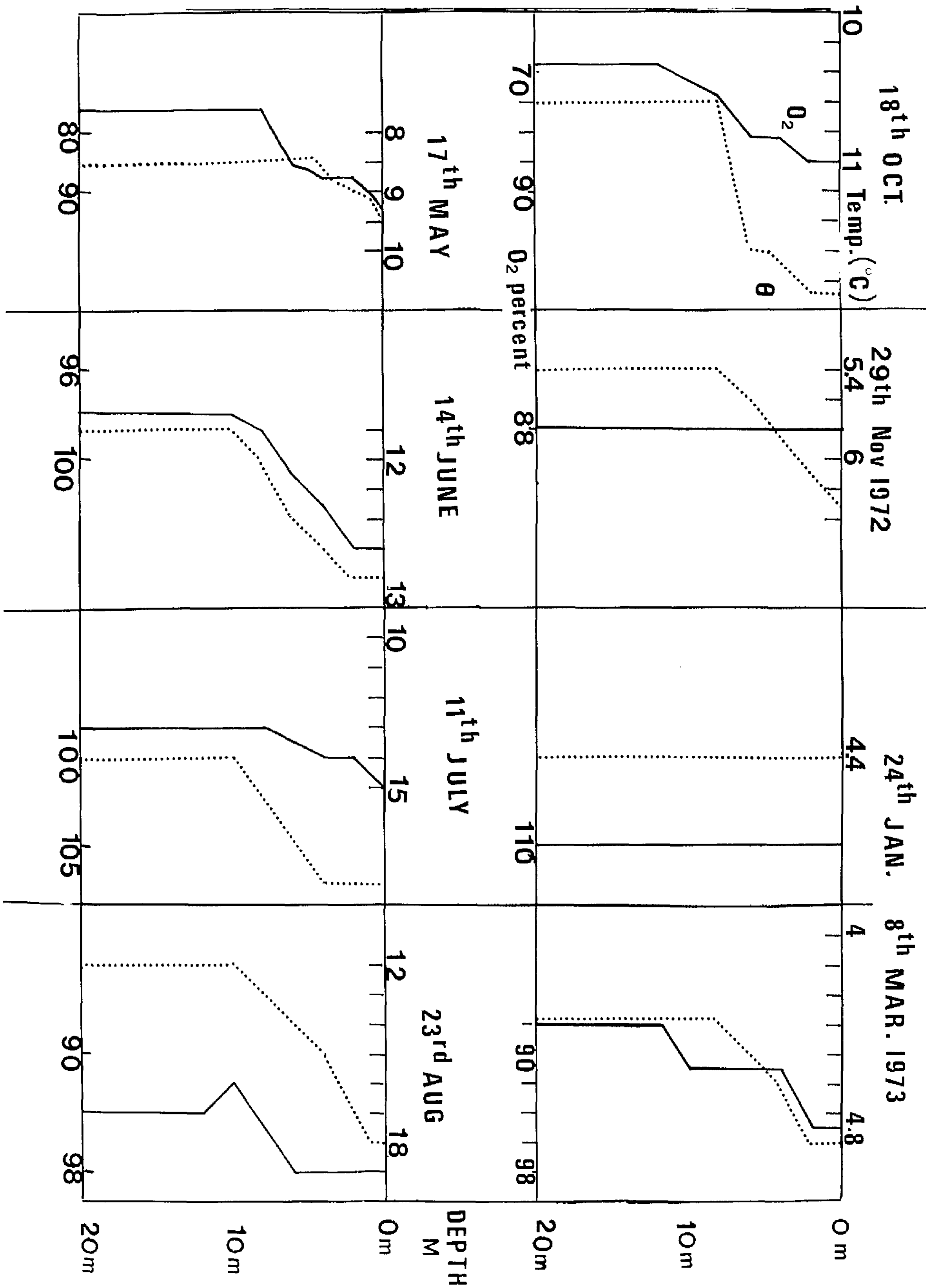
(iv) Loch Ard

In Loch Ard (Fig. 29 and Appendix Table 20a, b and c) isothermal conditions persisted from the middle of November 1972 till the end of April, 1973, although temporary thermal gradients occurred during this period. Stratification first appeared during May when a very short thermocline was present. As temperatures increased the width of the gradient also increased, reaching its maximum development on 28 June when it extended from 1 m to 11 m. As the bottom temperatures rose and the surface temperatures fell the thermocline became shorter and the hypolimnion widened. On the latest

LOCH ARD

Fig 29

SATURATED OXYGEN and TEMPERATURE



date on which a thermocline could be detected, 1 November, 1972, the hypolimnion began at a depth of 3 m.

The maximum surface temperature, 18.6°C, was measured on 28 June while the minimum, 4.4°C, was found at all depths on 24 January. The maximum temperature at the bottom (15.5°C) occurred considerably later than the surface maximum; thus the recorded annual range at surface and bottom temperature (14.2°C and 11.1°C) were similar to that found in Loch Achray and in the South of Loch Lomond. The maximum value of oxygen saturation recorded at this station, 112%, was found on 28 June at the surface. The minimum level, 68%, was the lowest recorded in any of the five Lochs investigated. This reading was taken at the bottom (20 m) on 18 October, 1972.

On commencement of sampling in October 1972 stratification was clear with the thermocline extending from 2 to 8 m. The epilimnion and hypolimnion temperatures were 11.9°C and 10.6°C respectively. Oxygen was generally low falling from 85% at the surface to 68% at 12 m depth and then remaining constant to the bottom. On 1 November, 1972 the thermocline was just detectable between 1 and 3 m depth. The thermal gradient was from 10.7 to 10.3°C below which the temperature was constant to the bottom. Oxygen was again low, fluctuating between 80 and 83% over the upper 4 m then declining to 76% at 6 m depth.

On 15 November, 1972 the water column became isothermal at a temperature of 8.0°C and oxygen was evenly distributed. Oxygen saturation increased regularly during the next two months rising from 84% on 15 November to 88% on 29 November, and reaching 100% saturation on 27 December, 1972. Temperature had decreased by 29 November although a small gradient was evident over the top 8 m of the water column, with readings of 6.3°C at the surface to 5.4°C at depth. The temperature of the water reached 5.0 to 5.1°C on 27 December, 1972. Little overall change was evident on 10 January although oxygen saturation had increased by 3%.

24 January saw a fall in temperature to 4.4°C and a rise in oxygen to the maximum recorded winter value of 110% at all depths. On 7 February,

1973 the temperature showed little change (4.5°C) while oxygen fell to around 94%. A short lived stratification appeared on 8 March with temperatures ranging from 4.8°C in the top 2 m to 4.4°C at 8 m. Oxygen reading also showed a gradient from 95% to 88% at 12 m depth. Temperatures increased from 6.0°C at all depths on 26 March to 7.0°C on 20 April while oxygen rose from 92% to 94% over the same period.

The beginning of the period of continuous stratification occurred on 3 May, 1973 when a thermal discontinuity layer was found between 5 and 6 m. The epilimnion and hypolimnion temperatures were 8.5°C and 8.0°C respectively while the oxygen saturation showed no change from previous sampling (94%). By 17 May the surface water had warmed while the hypolimnion had shown no change in temperature. The thermocline was still very narrow, being situated between 3 and 4 m where the temperature range was 0.9°C. The oxygen content of the water had fallen considerably and a gradient was evident from 93% at the surface to 76% at 8 m depth, below which oxygen was uniform.

The thermocline layer had widened and deepened on 14 June, 1973 with a gradient from 12.8°C at the bottom of the epilimnion (2 m) to 11.8°C at the top of the hypolimnion (10 m). Oxygen values had shown a large increase at all depths reaching 106% at the surface and 97% throughout the hypolimnion. A large rise in surface temperature by 28 June, 1973 gave a reading of 18.6°C in the 1 m depth of the epilimnion. Below the thermocline attained its maximum width of 10 m with a temperature gradient falling to 11.2°C at the top of the hypolimnion. The oxygen content of the water reached its annual maximum of 112% at the surface, falling regularly to 92% at 15 m.

On 11 July, 1973 the epilimnion remained at the same temperature and deepened while the hypolimnion increased in temperature by about 3.0°C. The thermocline shortened to between 4 m and 10 m with a thermal gradient from 18.6°C to 14.0°C. Oxygen readings were slightly higher at the surface (102%) than in the hypolimnion (98%). On 26 July, 1973 the thermocline became very narrow as the hypolimnion widened to be within 5 m of the surface. Gradient was from 18.6°C at 1 m to 15.2°C at 5 m depth. A considerable fall in oxygen saturation was evident with values ranging from 88% in the epilimnion to 80% throughout the hypolimnion.

On 8 August, 1973 a continuous thermal gradient was evident from the surface (16.1°C) to 6 m (15.5°C) below this a uniform temperature was recorded to the bottom. Oxygen values were highest between 2 and 5 m at 96% saturation, falling by about 2% over the rest of the water column. A distinct epilimnion was again apparent on 23 August, having a temperature of 18.0°C. The temperature discontinuity layer extended from 1 m to 10 m where a temperature of 12.0°C was recorded. The lowest oxygen value, 92%, was observed at the top of hypolimnion; this increased to 98% at the surface. On 20 September the temperature showed an ovwrall decline reaching 13.8°C in the epilimnion. Oxygen values were highest at the surface, 98%, falling gradually to 90% at the bottom.

8. Meteorological data

All data for this section was kindly supplied by the Clyde River Purification Board and the Lower Clyde Water Board. The recording stations in the Loch Lomond area for which regular meterological data are available are as follows: Arrochymore Point (Grid. Ref. 26/415919) near the South Station, Rowardennan (Easter Sallochy) (Grid Ref. 26/387955) near the Middle Station, Glen Douglas (Inverbeg) (Grid Ref. 26/344981) at the west side of the loch at Lower end of Tarbet basin, Rowardennan (Ardess (Grid Ref. 26/360994) on the east side of the Loch at the lower end of Tarbet basin, and Inverarnan (Grid Ref. 27/317185) at the northern end of the upper loch. The only station for which data on wind speed and direction are available is Arrochymore Point, where readings were taken once daily at 09.00 hrs. The meterological station nearest Loch Achray is at Brig o' Turk (Grid ref. 529080) while the station nearest Loch Ard is at Loch Dhu (Grid Ref. 429037). There were no recording stations located near Lake of Menteith or Loch Rusky.

(a) Wind velocity and direction

Wind data from Arrochymore station have been considered from January 1972 to August 1973. During the first 18 days of January 1972 the winds were generally strong, north-easterly, ranging from 5 to 9 knots and reaching a maximum of 19 knots on 17th. The wind then came from the south-west quadrant for the next 8 days reaching a lesser maximum of 13 knots on 23rd. Winds lessened to the end of the month, again becoming north-easterly.

In February 1972 wind direction ranged from north-east to south-east, with the maximum strength of 19 knots being recorded on the first 2 days of the month. High winds (13 knots) were recorded around the middle of the month and also towards the end of the month (25 - 26th). Fairly strong north-east winds were recorded during the first 18 days of March 1972, reaching a maximum velocity of 13 knots on 12th to 13th.Fe Following a brief calm period, winds changed to westerly and south-westerly reaching a maximum of 13 knots at the end of the month.

Throughout April 1972 winds were variable, though most frequently the direction was west to south-westerly. Velocities were generally higher during the first half of the month (5 - 9 knots) attaining a maximum of 13 knots on the 8th. From 15th to 28th the weather was calm and winds did not exceed 2 knots; however, on 29th and 30th April speeds rose to 9 knots. In the first 23 days of May winds came from the north-east to easterly quadrant and were generally moderate in strength. A maximum wind ~~e~~ velocity of 13 knots was reached on 6th and 21st of the month. Direction became west to south-westerly towards the end of the month and wind strengthened with a maximum recorded speed of 13 knots on 24 and 26th May, 1972.

During June the prevailing wind was from the west or south-west, with maximum velocities (5-9 knots) occurring during the first 6 days of the month following a brief calm period, wind speeds rose on 17th to 9 knots and remained at this strength for a week with the exception of two less windy days. For the first half of July winds lay between the west and south-west quadrant and were generally light (around 2 knots). During the second half of the month the direction veered towards the south to south-east with a maximum speed of 13 knots recorded on 19th. The mean wind speed was 2.8 knots.

In August, 1972 winds were variable in strength and direction, being light south-westerly in the first week, then increasing during the second week to a maximum of 13 knots on the 8th. Wind speeds were generally 5 knots or less for the rest of the month except for a single high reading of 9 knots on 17 August. Direction was variable mov~~e~~ing towards the north generally.

Throughout September 1972 the weather was calm with little or no wind. On the last day of September and first 2 days of October the wind speed reached 5 knots; this was followed by 5 days of calm weather. Following a high wind of 9 knots on the 8th October, conditions remained calm till 23rd when winds again increased and became variable in direction. During the first 12 days of November 1972 winds were south-westerly and generally strong reaching a maximum of 13 knots on the 8th. A completely calm period followed till the 19th when winds again became strong south-westerly and remained so till the end of the month. Variable south to south-westerly winds prevailed during the first half of December 1972 reaching 13 knots on 1st and 13th. A calm period occurred from 15th to 22nd following which winds became variable, strong, reaching 9 knots and originating mainly from the south or easterly quadrants.

The first two weeks of January 1973 were generally calm, followed by 3 days of windy weather (5-6 knots) from 14th to 16th. Following a further calm period a monthly maximum of 13 knots was noted on 20th. For the rest of the month winds came from the south and south-west quarter and were generally around 2 knots except for 26th when 9 knots was recorded. For the first 3 weeks of February 1973 winds came from the south and west while during the rest of the month, north winds predominated. The monthly maximum wind speed, 13,0 knots, was recorded on 6th, following which conditions remained calm till 21st when 3 days of strong wind (9 knots) occurred.

At the beginning of March 1973 winds were southerly, variable, reaching a maximum of 9 knots on the 5th. A long calm period followed in which little or no wind was recorded except for a singly high wind speed of 5 knots on 17th. This was broken by 9 knots winds on 24 March and winds of a similar strength at the end of the month. During this period winds came from the south and west. During the first week of April winds were generally strong south-westerly reaching 9 knots on 1st, 4th, 5th and 6th. From 7th onwards the wind changed direction to become mainly northerly, decreased in strength slightly and then varied during the rest of the month between 5 and 9 knots.

The first three weeks in May showed periods of very high winds. During the first four days 13 knots was recorded. This was followed by a period of variable winds. Between 17th to 21st May, 1973 very strong north-easterly winds were recorded, at no time falling below a speed of 9 knots, and reaching a maximum of 19 knots on 20th. In the last week of May the weather became calmer but was still variable. During June the prevailing winds came from the west and were predominantly strong. A reading of 9 knots was recorded on 1st and 2nd of the month and on the 12th, 13th, 16th and 29th.

During July, 1973 the winds came predominantly from the south and west quadrants and had a velocity of 2 knots. Only at the beginning of the month and at the middle were higher wind speeds attained, the maximum being 13 knots observed on 15th July. During August 1973 the weather became calmer and the wind became variable. South-westerly winds predominated in the first half of August while in the second half winds lay between north and north-east. In September 1973 winds were variable and fairly slight. During the first week south-westerly winds prevailed with a strength from 2-5 knots, while in the following 10 days the wind speed increased to reach 9 knots on three occasions (10th, 15th and 16th). For the rest of the month the weather was calm and the wind direction showed wide variation.

No data on wind direction or velocity was available for any other of the four other Lochs investigated.

(b) Day length and hours of bright sunshine

Data on total hours of bright sunshine were only available for the Arrochymore station at the southern part of Loch Lomond, while the day length for this latitude (56^{o}N) was obtained from the Astronomical Ephemerics for the year 1971 (HMSO, London).

During January and February 1972 the daily mean numbers of bright sunshine increased from 1.10 to 1.44 while the day length rose from a minimum of 7 hours at the beginning of January to 10.5 hours at the end of February. A further increase occurred from 3.08 in March to 5.16 in April when the daylength was 15 hours. In May the daily average of bright sunshine fell to 4.14 even though the daylength (17 hours) was approaching its maximum. The daily average of bright sunshine reached 5.75 in June when the daylength was longest (17.5 hours) while the highest number of sunshine hours was recorded in July (6.01). In August the daily average declined slightly to 5.58 while the daylength fell to 14 hours at the end of the month. During September, October and November a regular decline was evident with the sunshine average falling from 5.12 to 2.13 and the daylength decreasing to 7.5 hours. The lowest daily average of bright sunshine occurred in December when 0.47 hours was recorded.

An even lower value, 0.42 hours, occurred in January 1973 increasing considerably to 2.97 hours in February 1973. This was more than twice the corresponding value for 1972. Further increases were evident during the next two months, reaching 3.87 in March and 6.78 in April; this was the highest daily mean for 1973 and was higher than at any time during 1972. A decline to 4.83 hours per day was apparent in May 1973 with the same value being reached in June. July saw an increase to a daily average of 6.27 hours of bright sunshine declining to 4.28 in August and 3.70 in September, 1973.

(c) Air temperature

The air temperature recorded at the Arrochymore station ranged from -8.0°C in January and -8.4°C in February 1972 to 27.4°C on 17 July, 1972. This maximum occurred 10 days before the highest recorded water temperature in the southern part of Loch Lomond. Only during the months of July, August and September was temperature in excess of 20°C recorded while temperatures below freezing were occasionally found in January, February, March, April and October, November, December.

The lowest temperature in 1972 occurred during January and February when the monthly average was 3.9°C in both cases. Temperature of air increased to reach 7.8°C in April, 9.9°C in May and 10.7°C in June while the maximum of 14.5°C was not recorded until July. A slight fall was evident in August to 13.4°C after which the decline became more rapid, dropping to 11.0°C in September and 9.7°C in October. A considerable fall from October to November resulted in a monthly average temperature of 5.1°C increasing to 5.3°C in December.

In 1973 the lowest temperature occurred in February when -8.4°C was recorded while the maximum 26.5°C was observed on 15 August. The lowest monthly mean temperature, 3.8°C, occurred in February, rising to 5.9°C in March and 6.5°C in April. A further rise of about 3.0°C per month occurred during May and June when a temperature of 12.9°C was recorded. The highest average monthly temperature, 14.8°C was observed in July, falling slightly to 14.3°C in August. An average temperature of 12.5°C was recorded for September.

No data on air temperature or hours of bright sunshine were available for any other region of Loch Lomond or any of the other four Lochs studied.

(d) Rainfall

The recording station in the Loch Lomond area for which rainfall data are available is as follows: Arrochymore near the South Station, Easter Sallochy near the Middle Station, Inverbeg on the west side of the Loch at the lower end of the Tarbet basin, Ardess opposite it on the east side of the Loch and Inverarnan at the northern end of the Upper Loch. In general all station exhibited a similar pattern of rainfall variation, although the actual monthly average greatly increased passing from south to north. In fact the most northerly station, Inverarnan usually received twice as much rain per month as the most southerly station, Arrochymore.

In January 1972 all stations except for Inverbeg showed their annual maximum rainfall, with the following monthly figures: Arrochymore 173.5 mm, Easter Sollochy 254.4 mm, Ardess 263.7 mm and Inverarnan 352.1 mm. Inverbeg had a slightly lower amount of precipitation (2)9.6 mm) than Ardess;

this feature continued till March. By March the monthly totals had fallen to less than 100 mm at all stations with the exception of Inverarnan where 119 mm was recorded. The lowest rainfall occurred at Arrochymore (70.5 mm) while Inverbeg and Ardess showed similar means (around 84 mm).

In April the monthly precipitation more than doubled at most stations reaching its highest value at Inverarnan where 280.9 mm was recorded, while at Arrochymore 120.2 mm was recorded. During this period the rainfall at the west side of the loch at Inverbeg (230 mm) was higher than that of the east, at Ardess (204.2 mm) this feature was evident throughout the rest of the year. The recorded amount of precipitation increased again during May, reaching levels approaching the winter maximum. Most of the rainfall occurred during the last 10 days of the month, with more than a quarter of the monthly total falling on the 25th. At the Inverbeg station the monthly total (261 mm) actually exceeded the winter maximum. The total monthly rainfalls were 165.5 mm at Arrochymore, 230.0 at East Sallochy, 239 mm at Ardess and the highest, 287.8 mm, at Inverarnan.

In June rainfall declined at all stations but still remained above the level of March 1972. Easter Sallochy, Inverbeg and Ardess stations all recorded a total rainfall in June which was twice that of March. In July 1972 precipitation decreased by almost half but still equalled or exceeded the figure for March 1972. 66.1 mm was measured at Arrochymore, 85.5 mm at Easter Sallochy, 95.9 mm at Inverbeg, 87.0 at Ardess and 13.7 mm at Inverarnan. The totals for August were similar to July with a slight decline in rainfall evident at all stations.

September was the driest month on record, during either 1972 or 1973, with the lowest amount of precipitation (12.1 mm) being measured at the most southerly station, Arrochymore, in 1972. 13.7 mm was recorded at the Easter Sallochy, 21.0 at Inverbeg, 14.5 mm at Ardess and 32.1 mm at Inverarnan. A five-fold rise in the amount of rainfall occurred in October at all stations with most of the precipitation falling in the last third of the month. This was followed by a larger increase in November when the highest rainfall, 336.4 mm occurred at Inverarnan, while Ardess (249.8 mm) and Inverbeg (230.8) received considerably less. The least rainfall was recorded at Arrochymore (138.9 mm).

The winter maximum occurred in December when the total monthly rainfall generally equalled that of January or exceeded it. The only station to exceed 300 mm was Inverarnan where 347.4 mm of rainfall was recorded, most of it during the first 10 days of the month. Easter Sallochy, Ardess, and Inverbeg all exceeded 200 mm at 248.6 mm, 257.0 mm and 272.6 mm respectively, while the most southerly station, Arrochymore, had a maximum of 165.3 mm.

The total rainfall in January 1973 was considerably less than that for the previous January at all stations except for Inverbeg where the total rainfall (190.6 mm) was only marginally less. Ardess exhibited a similar monthly total to Inverbeg, while Inverarnan still exceeded 200 mm at 254.8 mm. Easter Sallochy and Arrochymore recorded values of 174.2mm and 156.2 mm respectively. February saw a slight decline in rainfall at all stations except for Inverbeg where the total increased to 197.2 mm. This reading was higher than the corresponding station on the east side of the loch, Ardess (174.8 mm), a feature which continued till April 1973.

In March 1973 the amount of precipitation decreased considerably at most stations, although Inverarnan showed only a marginal decline (to 191.0 mm). Inverbeg and Ardess still exceeded 100 mm with totals of 126.8 mm and 104.6 mm respectively. The total rainfall was less than 100 mm at Easter Sallochy and Arrochymore where 94.7mm and 67.9 mm was received. Precipitation reached a spring minimum in April at all stations with the lowest total occurring at Arrochymore and Easter Sallochy both of which received about 70 mm of rain. Figures of 87.3 and 80.0 mm were measured at Inverbeg and Ardess while 93.8 mm of rain fell at Inverarnan.

Considerably wetter weather was apparent during May when all stations received between 100 mm and 140 mm of rain, most of which fell during the first 12 days of the month. The highest amount (138 mm) fell at Inverarnan while further south Ardess on the east side of the loch received more rain (128 mm) than Inverbeg (121.8 mm) on the west side of the loch. June saw a further increase in the amount of rain, equalling the total received in February - 117.8 mm at Arrochymore, 161.5 mm at Easter Sallochy, 132.8 mm at Inverbeg, 163.9 mm at Ardess and 192.7 mm at Inverarnan. At all stations m most of the precipitation was received during the middle of the month.

July was the driest month of the year (compared with September in 1972) with less than 100 mm of rain being received at all stations except for Inverarnan 127.2 mm fell. Inverbeg and Ardess received about 80 mm of rainfall while 76.2 mm was measured at East Sallochy and 61.3 mm at Arrochymore. The last 10 days of the month were completely dry. In August the amount of rainfall almost doubled at most stations with the majority of the precipitation falling during the first third of the month. All stations recorded in excess of 100 mm with 188.1 mm falling at the most northerly stations, around 145 mm at Inverbeg and Ardess, 125.2 mm at East Sallochy and 112.4 at Arrochymore. This is in direct contrast with the picture in 1972 when rainfall was still declining in August to reach a minimum in September.

In summary, the five stations considered for rainfall data in the Loch Lomond area maintained a constant relationship to one another in the relative amount of rainfall received. The maximum monthly rainfall was always to be found at the most northerly station (Inverarnan) which has twice the annual total rainfall of the most southerly station (Arrochymore). The actual figures for 1972 were 2559.1 mm and 1274.2 mm respectively The annual totals for Inverbeg and Ardess were similar although one or the other exhibited higher montly rainfalls at different periods of the year. In 1972 the annual totals were 1950.1 mm and 1937.0 mm respectively, while Ardess showed higher monthly values from January to end of March and lower values for the rest of the year. The total rainfall for the year 1972 at Easter Sallochy (1830.9 mm) was closer to the figures for Inverbeg and Ardess than for the Arrochymore station.

In 1972 the maximum rainfall was recorded in January, November and December. At the Inverarnan station, precipitation exceeded 300 mm, at the Ardess, Inverbeg and Easter Sallochy stations more than 200 mm fell, while at the Arrochymore station less than 200 mm was recorded. Following a decline in March high rainfall was recorded during April, May and June at all stations. The total precipitation during this period was actually higher than in preceding 3 months of January, February and March. Rainfall fell to half at all stations during July and remained constant in August and fell to a minimum in September. This was the driest month on record either in 1972 or 1973 and the driest three months (July, August and September) of 1972. An overall increase was apparent in October reaching levels similar to or slightly greater than the totals for August. Rainfall doubled at all stations in November and further increased to a maximum in December.

In 1973 as in the previous year, rainfall was high in January, February and declined in March. This decrease continued into April when less than 100 mm of rain was recorded at all stations. This is strongly contrasted with 1972 when rainfall started to increase in April, exceeding 100 mm at the two southerly stations and 200 mm at the other stations. During May and June, 1973 rainfall was generally much higher (between 100 mm and 200 mm at all stations) but was considerably less than the monthly precipitation recorded in those months in 1972. The lowest rainfall in 1973 occurred at all stations in July. During this period between 60 and 80 mm fell at all stations except for the Inverarnan station which exceeded 100 mm. This minimum was not as low as the minimum observed in September 1972. August saw a doubling in the amount of rainfall at all stations, except for the most northerly station where a smaller rise was apparent. A slight decline was evident in September, although rainfall was still in excess of 100 mm at all stations.

(e) Catchment area, inflows, outflows and water level

The total catchment of Loch Lomond covers an area of 768.91 square kilometres and has an average annual rainfall over the whole area of 2050 mm (average of 35 years). The catchment was divided into seven zones for each of which the long term average annual total rainfall was estimated. These are: Falloch, Sloy, Luss, Balloch, Endrick, Rowardennan and Arklet. The highest annual totals occurred in the Sloy and Falloch drainage zone which both exceeded 3000 mm per year, the lowest were found at the Balloch and the Endrick zones which receives 1397 mm and 1548 mm respectively. The Sloy and Arklet lie opposite each other at the northern part of Loch Lomond and both have high rainfall. Nevertheless the zone on the eastern side of the Loch (Arklet) has a lower annual total (2576 mm). A similar phenomenon was evident in the southern portion of the loch where the Rowardennan drainage zone on the east side showed a smaller annual amount of precipitation (2090 mm) than the Luss zone in the west (2288 mm).

From a calculation of annual runoff volumes it was found that the River Falloch contributes more water (253 mcum) to Loch Lomond than the River Endrick (227 mcum) despite having less than half the latter's catchment area (14.2% of total catchment of Loch Lomond compared with 32.6%). In fact the River Falloch contributes 22.18% of the annual input into Loch Lomond. The River Endrick, Douglas, Luss and Fruin each contribute slightly less. In general the region of the Loch to the north of Ross point, contains approximately one third of the total surface area of the Loch, but receives about two-thirds of the run off input.

The seasonal rainfall totals for each zone show a similar pattern with November, December and January having the highest rainfall total (677 mm for the entire catchment). The total precipitation is considerably reduced in February, March and April (420 mm) and reaches a minimum in May, June, and July (379 mm). An increase in rainfall occurres during August, September and October (574 mm). A calculation of average run-off volumes from 1963 to 1969 inclusive (7 years) showed that twice as much water flows into the loch during November, December and January (373 mcum) as in May, June and July (187 mcum).

The average annual volume of water passing to the River Leven is 1254 mcum (measured over a 7 year period). The average annual run-off input to Loch Lomond is 1142 mcum. The direct rainfall onto the surface of the Loch is 146 mcum, while the annual evaporation from the Loch is 28 mcum. Hence runoff + rainfall - evaporation is 1260 mcum. This figure corresponds very closely with the observed run off data. The recorded extreme levels of the water surface of the Loch are 6.91 metres to 9.78 metres above sea levels.

In general the velocities of water in the Loch appear to be low. It has been shown that the potential movement towards the River Leven is small, between 50 and 260 metres per day. There is no evidence of direct movement of water from the Endrick to the Leven, to the south of the Island chain.

(f) The four Lochs

The only meterological data which are available for the other Lochs are records of rainfall, which were kindly supplied by the Lower Clyde Water Board. The nearest recording station to Loch Achray is at Brig o' Turk (Grid Ref 529 080) while the closest station to Loch Ard is at Loch Dhu (Grid ref. 429 325). There were no stations in the vicinity of either Lake of Menteith or Loch Rusky.

(i) Loch Achray (Rainfall gauge at Brig o' Turk)

In 1972, September was the driest month on record with a total rainfall of 9.8 mm and generally calm, dull weather. October was considerably wetter with a monthly total of 95.4 mm most of which fell during the last third of the month. The prevailing wind during this period was from the south-west. November saw a doubling of the quantity of the precipitation to 191.4 mm, most of which fell during the last two-thirds of the month. The winds during this month were variable, westerly to south-westerly. The annual maximum monthly rainfall, 214.3 mm, was recorded in December. Only south-west winds were observed during this month.

The amount of rainfall lessened in January, 1973 to 151.5 mm. The majority of which fell in the middle of the month. For the first 10 days of the month the weather was calm although during the rest of the month south-westerly winds prevailed. The rainfall decreased further in February to give a monthly total of 132.9 mm. The wind during this month was variable becoming northerly later. A prolonged calm day period occurred during March from 8th to 21st; nevertheless the monthly rainfall total still exceeded 100 mm (at 102.3). Apart from the beginning of the month the rainfall in April was low giving a monthly total of 78.2 mm. Winds were generally from the north. May was considerably wetter than April or

March with variable winds and a monthly total rainfall of 121.6 mm. June was almost as wet as January and received a total rainfall of 145.5 mm. The prevailing winds in June came mainly from the west and south-west.

July was the driest month of the year, receiving 73.0 mm of precipitation, considerably more than the driest period in 1972. Frequent calm periods occurred during this month. In August the amount of rainfall almost doubled reaching 118.9 mm. Most of this precipitation fell at the beginning and the end of the month with a long calm period in the middle. A slight drop in the quantity of rainfall was evident in September when 109.7 mm was recorded, mostly at the beginning and the end of the month. The weather remained generally calm from 19th to 26th of the month, with south-westerly winds for the rest of the period.

The annual average total rainfall for a 35 year period in this station is 1646.4 mm.

(ii) Loch Ard (Rain gauge at Loch Dhu)

In 1972 the driest month was September when only 12.0 mm of rain fell in the area. October was considerably wetter (116.6 mm) with one third of the monthly total falling on the 8th and the rest falling during the last 10 days of the month. The quantity of the precipitation received during November 1972 (211.9 mm) was almost twice that recorded in October. The rainfall was continuous throughout the month except for a single dry period from 12th to 17th. The winter maximum was observed during December when some rain fell on almost every day of the month, giving a total of 267.8 mm.

The amount of rainfall received at this station in January 1973 was 100 mm lower than the total for December. In fact the first third of the month received very little precipitation while some rainfall occurred on almost every day for the rest of the month. February showed a slightly lower monthly total at 159.0 mm, whereas a more considerable decline was clear in March. During this month no rain fell at all from the 8th to the 21st while the total for the remaining weeks was 105.8 mm.

April was a fairly dry month when only 90.0 mm of rain was received, mostly at the beginning and the end of the month. May was wetter with a monthly total of 132.6 mm; nevertheless a completely dry period occurred from 14th to 19th of the month. High rainfall was recorded in June with a monthly total of 161.2 mm equalling the amount which fell in February. July was a generally dry month with prolonged periods without any rain; the monthly total of precipitation was 80.9 mm.

During August the first 10 days showed a high amount of rainfall while the next 15 days were dry. The total for this month, 132.6 mm, was markedly higher than the total for July. September saw a marginal increase in the monthly rainfall, to 135.8 mm, most of which fell in very short periods at the beginning of the month (3rd and 6th) and at the end (27th and 28th). The standard average monthly mean for this station from 1916 to 1950 is 2058.4 mm.

9. Phytoplankton

(a) General features

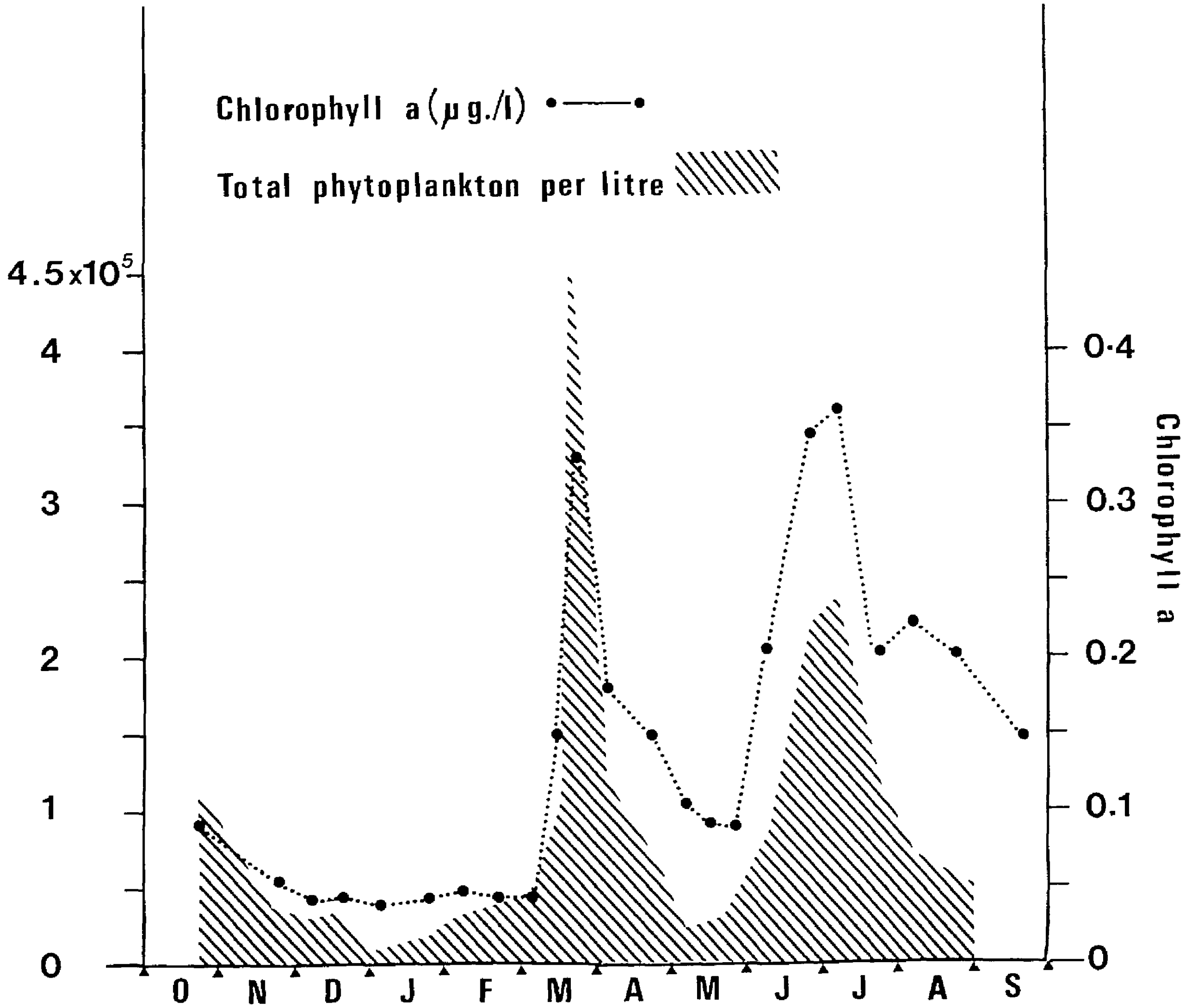
From the commencement of sampling in Loch Lomond in October 1971 net samples were taken from the three main stations (North, Middle and South) for the qualitative study of phytoplankton and in March 1972 this was augmented by a quantitative study.

From the examination of net samples it was found that desmids and diatoms accompanied by blue green algae were present throughout the year at all three stations. Desmids were characterized by species of *Staurastrum*, *Xanthidium*, *Arthrodesmus*, *Closterium*, *Cosmarium* and *Spondylosium* and occasionally by *Roya* *Microsterias*, *Eustrum* and *Cosmoclodium*. A marked periodicity in diatoms was evident from the study of net phytoplankton: *Melosira* was abundant during the winter and spring while *Asterionella*, *Tabellaria fenestrata*, *T. flocculosa* and *Fragilaria* were present on most occasions. Of the Chlorophycean algae *Dictyosphaerium* and *Botryococcus* were found throughout the year. Dinophyceae were represented by *Ceratium* and *Peridinium* during the summer, autumn and winter. Of the Chrysophycean algae found *Mallomonas* occurred throughout the year while *Dinobryon* was found in late summer and in the autumn. The only blue-green algal genus found throughout the year was Coelosphaerium; this was often accompanied by attached Chlorophycean and Chrysophycean epiphytes and contained within the colony cells of Aphanotheca (another blue-green algae). Oscillatoria was noted occasionally and Anabaena was found on two occasions in July and August throughout the loch. Microcystis has been found in the South station only while Hapalosiphon has only been recorded from the North station. Apart from planktonic algae a considerable number of non-planktonic type were recorded among them being Spirogyra, Stigeoclonium, Zygnema, Mougeotia, Bulbochaete, Navicula, Gomphonema, Ulothrix, Oedogonium and a large variety of desmids.

From net phytoplankton Loch Lomond might be described as mainly diatom-desmid in nature. Whilst quantitative study of phytoplankton gave a different picture of phytoplankton variation. During March and April more than 90% of the population in all three stations consisted of diatoms (Melosira, Cyclotella, Asterionella and Tabellaria). During the summer period blue-green algae constituted about 50% of the population at the South station decreasing to around 40% at the Middle station and reducing still further to less than 25% in the North. The remaining quantity of phytoplankton at all stations consisted mainly of diatoms accompanied by smaller numbers of Ceratium, Peridinium, Staurastrum. Mallomonas and Botryococcus. In autumn the phytoplankton populations was mixed. Mallomonas, which was found on all occasions from net samples, was only recorded in the quantitative survey in September and October. The total bulk of phytoplankton at the South Station was greater throughout the year than at any station (to the North). This is especially so during the spring increase when the South total was twice that of the Middle and more than 10 times that of the North Station. This phenomenon was not evident from the examination of net samples.

Net samples were taken from the four other Lochs investigated from October 1972 to September 1973. In Lake of Menteith the algal composition from net samples was generally similar to that of Loch Lomond although the quantity of phytoplankton was greater. Blue-green algae were the

LOCH LOMOND SOUTH BASIN SURFACE Fig 30



dominant phytoplankton in the lake. *Anabaena* and *Coelosphaerium* were recorded on all occasions after obscuring the other algae present. *Microcystis* was common during October and November while *Merismopedia* and *Aphanozimenon* were observed occasionally. Among the green algae, *Eudorina* was common and *Pediastrum* was noted occasionally. Generally the phytoplankton found in Loch Lomond was also recorded in Lake of Menteith with the exception of *Dinobryon* and *Mallomonas*. Phytoplankton from net samples in this lake could be described as blue-green or blue-green diatom in nature.

The general feature of net phytoplankton sampes were reflected in the quantitative data from Lake of Menteith. From October to January diatoms (*Melosira*, *Asterionella*, *Fragilaria* and *Cyclotella*) and blue-green algae (*Coelosphaerium* and *Anabaena*) constituted more than 99% of the total population although *Staurastrum* and *Botryococcus* were also recorded. During the spring there was also a predominance of blue-green algae (*Anabaena*) and diatoms (*Melosira*) which together constituted the bulk of the phytoplankton. *Staurastrum* and *Ceratium* were found in large numbers only in July and August. Nevertheless they constituted less than 10% of total phytoplankton.

In Loch Rusky the net phytoplankton displayed completely different characteristics with season. From October 1972 when sampling commenced, till January the phytoplankton was very mixed but was quantitatively less than in Lake of Menteith. The population during this period was composed of diatoms: *Asterionella*, *Melosira* and *Fragilaria*, desmids such as *Cosmarium*, *Xanthidium*, *Staurastrum*, *Closterium Roya* and the blue-green algae such as *Coelosphaerium* and *Anabaena*. *Mallomonas*, *Botryococcus*, *Ceratium*, *Peridinium* *Dictyosphaerium* and *Asterococcus* were also found during this period.

In spring, diatom predominated with *Melosira*, *Asterionella*, *Fragilaria*, *Tabellaria fenestrata* and *Tabellaria flocculosa*. Species of desmids and blue-green algae were also noted although diatoms tended to obscure the other phytoplankton. At the beginning of July the samples contained mainly desmids with a predominance of *Staurastrum*. Individuals of *Botryococcus* and blue-green algae were also noted.

From the end of July till the completion of sampling in September a variety of phytoplankton was observed, although the population was dominated by blue-green algae (Anabaena). Tabellaria was very abundant while a large number of other algae were also encountered, among them Ceratium, Peridinium, Staurastrum, Dictyosphaerium, Xanthidium, Eustrum and Mallamonas. However, Dinobryon was absent in Loch Rusky.

From the examination of net samples Loch Rusky could be classified as having a mixture of phytoplankton, with a changing composition from season to season. There were also seasonal differences in the density of net phytoplankton samples, particularly in spring and summer.

Quantitatively, Coelosphaerium and Anabaena were the main phytoplankton in Loch Rusky from October to Nobember. During the spring, diatoms (Melosira, Asterionella, Tabellaria and Cyclotella) were the main components. In May and June a predominance of Staurastrum was observed whereas in late summer and autumn a mixed plankton was noted. The commonest species at this time were Botryococcus, Staurastrum, Anabaena, Ceratium, Coelosphaerium, Mallomonas, Peridinium, Fragilaria and Tabellaria fenestrata.

Loch Achray was characterised by a very poor net phytoplankton population, mainly desmids and a few diatoms. Desmids generally predominated with Staurastrum, Cosmarium and Xanthidium,being found in all samples while Anthrodesmus, Spondylosium, Ankistrodesmus, Closterium and Eustrum were found less frequently. Large numbers of desmids were evident in August 1973 while Dinobryon, Mallamonas were noticed in July. Diatoms were represented by small numbers of Melosira, Asterionella and Fragilaria. Another feature of the net samples in this loch was the presence of large numbers of benthic algae among them Ulothrix, Mougeotia. Oedogonium and large numbers of Navicula and Gomphonema. Thus Loch Achray can be characterized as being mainly desmid in nature.

From the quantitative investigation of the phytoplankton of Loch Achray, it was found that Asterionella and Anabaena were dominant at the beginning of sampling in October 1972 while desmids contributed only 1% or less of the population. Cyclotella and Tabellaria were common in November. No significant increase occurred in spring but in May diatoms

(Tabellaria, Cyclotella, Asterionella and Melosira) predominated. Blue-green algae (Anabaena) were dominant from July till August when Cyclotella and Staurastrum became abundant.

The net phytoplankton in Loch Ard was similar to that of Loch Lomond and was mainly composed of diatoms and desmids which were both present throughout the year. The main desmids identified included Cosmarium, Xanthidium, Cosmocladium, Staurastrum and Arthrodesmus while the commonest diatoms were Asterionella, Tabellaria with Melosira occurring from October to March. In spring diatoms predominated while in summer and autumn a mixed plankton was recorded. At the beginning of summer Dinobryon was the dominant phytoplankton. Blue-green algae and desmids predominated throughout the rest of this period. Mallomonas, Peridinium, Dinobryon were also recorded on all dates till the completion of sampling. Other algae recorded include Fragilaria, Ceratium, Eudorina, Pediastrum and Botryococcus. Loch Ard could be classified as being mainly diatom-desmid in nature.

Quantitatively diatoms with Coelosphaerium, Staurastrum and Dinobryon predominated in the phytoplankton of Loch Ard at the commencement of sampling. Till May diatoms (Cyclotella, Asterionella, Melosira) constituted the bulk of the phytoplankton following which a mixed population (Anabaena, Coelosphaerium, Staurastrum, Peridinium, Ceratium, Mallomonas and Dinobryon), persisted till the completion of sampling in September 1973.

In Lake of Menteith, Loch Rusky, Loch Achray and Loch Ard, apart from the phytoplankton, a large number of non-planktonic algae were commonly observed. In Lake of Menteith Gomphonema, Zygnema were common while Cymbella, Navicula, Gomphonema, Spirogyra, Bulbochacta were recorded from Loch Rusky. In Loch Achray the benthic algae exceeded the number of phytoplankton in all net samples with the following being frequently observed: Mougeotia, Ulothrix, Zygnema, Oedogonium, Spirogyra and large numbers of Navicula. In Loch Ard there were frequent observations of Spirogyra, Ulothrix, Mougeotia, Gomphonema and Navicula. Of the planktonic algae Oscilltoria was found on occasions in all five Lochs.

The main phytoplankton identified from the five lochs are shown in the following table. (See overleaf.)

For the purpose of identification reference was made to the following authors: Desikachary (1959), Prescott (1951 and 1964), Smith (1950), West (1904 and 1916), West and Fritch (1927), Fritch (1935), Berit Asmund (1959), Huber-pestalozzi (1942) and Bourelly (1968).

The common phytoplankton were enumerated either as cells, chains or colonies for the purpose of quantitative study. Those phytoplankton which have been counted as cells are as follows: Melosira, Asterionella, T. fenestrata, Cyclotella, Kephyrion, Ceratium, Peridinium, Anabaena, Mallomonas.

The phytoplankton which have been counted as chains or colonies are as follows: Coelosphaerium, Dinobryon, Fragilaria, Botryococcus, T. flocculosa, Microcystis.

For the purpose of enumeration Staurastrum was counted as a single unit (two semi-cells equalling one unit) and quoted as cells.

In the tabulating data of phytoplankton in the five lochs, Cyclotella (1) is C. comta and Cyclotella (2) is C. glomerata. Anabaena in Lochs Ard, Lomond and Achray is A. circinales while in Loch Rusky it is A. flos-aquae while in Lake of Menteith Anabaena (1) is A. flos-aquae, (2) is A. circinales and (3) is A. spiroides. The common genera represented in the tables have the specific names given in Part (d) of this section (The discussion of common species of phytoplankton).

(b) The seasonal variation of phytoplankton and chlorophyll

The direct enumeration of phytoplankton which was commenced in March 1972 was augmented by chlorophyll a estimations from 25 October, 1972 onwards. It is clear from the graphical representation that the curves of total phytoplankton and chlorophyll follow each other very closely at all stations.

(i) South Station of Loch Lomond (Figs. 30, 31a, b and 32a, b and Appendix Tables 21, 23a, b, c and d)

Phytoplankton at the South Station was generally low in numbers at the

The Main Phytoplankton from the Five Lochs

(data based on net samples)

	Name of Phytoplankton	Lochs				
		Lomond	Menteith	Rusky	Achray	Ard
	Diatoms					
1.	Asterionella formosa Hassal	x	x	x	x	x
2.	Melosira italica (EHR.) Kütz Sub Sp. Subarctica O. Müll.	x	x	x	x	x
3.	Tabellaria fenestrata (Lynby) Kütz var. Asterionelloides Arun.	x	x	x	x	x
4.	Tabellaria flocculosa (Roth.) Kütz	x			x	x
5.	Fragilaria capucina Desmaz.	x			x	x
6.	Fragilaria crotonensis Kitton.	x	x	x	x	x
7.	Cyclotella comta (Ehrenb) Kütz	x	x	x	x	x
8.	Cyclotella glomerata	x			x	x
9.	Navicula spp.	x	x	x	x	x
	Blue-green algae					
1.	Anabaena circinales (Robenhorst) ex Born. et Flah.	x	x	x	x	x
2.	Anabaena flas-aquae (Lyngby) Breb.	x	x	x		
3.	Anabaena spiroides Klebahn		x			
4.	Aphanotheca nidulanas Richter var. endophytic varn.	x	x	x	x	x
5.	Aphanotheca spp.	x			x	x
6.	Aphanocapsa delicatissma W. & G.S. West	x			x	x
7.	Aphanozimnon spp.		x			
8.	Coelosphaerium spp.	x	x	x	x	x
9.	Hapalosiphan intricatus West	x	x	x		
10.	Microcystis flos-aquae (Wittr.) Kirchner	x				
11.	Microcystis aeruginosa Kutz		x	x		
12.	Oscillatoria agardhii Gomont.	x	x	x	x	x
	Green algae					
1.	Dictyosphaerium pulchellum Wood	x	x	x	x	x
2.	Cosmocladium saxonicum De Bary	x	x	x		x
3.	Spondylosium planum Nob	x	x		x	x
4.	Ankistrodesmus falcatus (Corda) Ralfs	x	x		x	

		Lomond	Menteith	Rusky	Achray	Ard
5.	Sphaerozosma granulatum Roy & Biss	x		x		x
6.	Pediastrum boryanum (Turp) Menegh	x	x	x	x	x
7.	Scendesmus bijugatus (Turp) Kütz	x			x	
8.	Botryococcus Braunii Kütz	x	x	x	x	x
9.	Hyalotheca mucosa Ehrenb.	x				x
10.	Staurastrum paradoxum	x		x	x	
11.	Staurastrum cingulum	x	x	x	x	x
12.	Arthrodesmus spp.	x			x	
13.	Xanthidium antilopaeum (Breb.) Kütz var. depauperatum W. & G.S. West	x	x	x	x	x
14.	Xanthidium subjastiferum West var. Murrayi W. & G.S. West	x			x	x
15.	Closterium Kutzingii Breb.	x	x		x	x
16.	Cosmerium spp.	x	x	x	x	x
17.	Chlorella vulgaris	x	x	x		
18.	Eudorina spp.		x	x		x
19.	Eustrum	x	x	x	x	x

Other phytoplankton

		Lomond	Menteith	Rusky	Achray	Ard
1.	Ceratium hirundinella O.F. Müller	x	x	x	x	x
2.	Ceratium spp.	x				x
3.	Peridinium willei Huitf-kass	x	x	x	x	x
4.	Dinobryon cylindericum Imhof. var. divergens (Imhof.) Lemm.	x			x	x
5.	Dinobryon spp.					x
6.	Mallamonas elongata Reverdin	x				x
7.	Mallamonas acaroides Perty.	x		x	x	x
8.	Kephyrion spp.	x			x	x

commencement of quantitative sampling with about 50000 units/l at the surface. More than 95% of the population consisted of diatoms dominated by Melosira which was twice as abundant at the surface as at 3 m depth. Asterionella showed five-fold increase with depth. A doubling of the total number of phytoplankton at the surface had taken place by 16 March and both Melosira and Asterionella reached their greatest abundance at 10 m depth.

The phytoplankton population exceeded 300000 units/l on 30 March, 1972 and rose to a peak of more than 910000 units/l on April the 14th. This bulk was almost purely diatom in nature of which Melosira constituted more than 90%. By the following week phytoplankton numbers had fallen by a quarter followed by a rapid decline to a total of about 50000 units/l at the surface on 27 April. On this date most diatoms were more abundant at depth with Melosira showing a gradient from 27000 cells/l at the surface to twice this number at 5 m depth. Cyclotella comta showed five-fold higher numbers at 5 m than at the surface. Phytoplankton remained scarce throughout May, never exceeding 40000 units/l.

The beginning of June saw the start of summer diatom increase when most of the phytoplankton showed a considerable rise. The total population reached 71000 units/l at the following week, of this Asterionella and T. fenestrata constituted about 80%. Although there was an overall decline in the total number of phytoplankton on 27 June both Asterionella and Cyclotella comta were increasing. The latter species showed larger numbers at the surface than at 3 m depth.

On 18 July, 1972 a total population of 59000 units/l was recorded. The bulk of phytoplankton doubled by 26 July with a peak of Anabaena making up more than 66% of the total. On 1 August the total number of phytoplankton was the same but the composition had changed with Anabaena showing a reduction to less than 50% of the total. Little difference was apparent between surface and depth samples taken on this date.

On 8 August, 1972 Anabaena had totally disappeared ~~at~~ from the surface samples while 20000 cells/l were recorded at 3 m depth. Generally the population was on the decline with a total number of 63000 units/l of which more than 90% was diatoms at the surface. Phytoplankton numbers were low at surface on 22 August although there was a considerably higher number at 3 m depth. On 12 September C. comta and C. glomerata constituted about 33% of the total phytoplankton. Subsequently a prominent increase of Tabellaria fenestrata was evident and contributed 75% of the population on 27 September. Asterionella attained its annual maximum on 11 October when it constituted almost half of the total population of 180000 units/l.

At the 25 October diatoms made up more than 95% of the total phytoplankton (112400 units/l) with a corresponding chlorophyll a reading of 0.09 μg/l. A continuous fall in the total number of phytoplankton occurred from October till 21st December when only 33600 units/l were recorded and chlorophyll a value of 0.04 μg/l. The decrease in phytoplankton on 4 January, 1973 to the lowest recorded total (10458 units/l) was not reflected in chlorophyll a levels which remained at 0.04 μg/l.

By 1 February, 1973 the total phytoplankton had doubled with corresponding chlorophyll a value of 0.05 μg/l. Little change was evident in the composition of the phytoplankton population although Melosira had increased by three-fold at the surface. This algae showed very marked increase with depth, tripling at 3 m depth and showed a five-fold increase at 5 m depth. The bulk of phytoplankton had almost doubled by 1 March while chlorophyll a had shown a marginal decline to 0.042 μg/l. The major part of surface phytoplankton was Melosira which showed greater numbers at depth with a maximum of 95300 cells/l at 5 m depth.

During March 1973 most diatoms reached a spring maximum which was reflected in the larger total cell counts and higher chlorophyll a levels. On 15 March 103900 units/l were recorded while chlorophyll a value was 0.15 μg/l. This value of chlorophyll a was almost tripled when total number of phytoplankton increased by almost four-fold on 28 March. Although Melosira was the main phytoplankton as it was in 1972 but the magnitude of the spring increase was almost half of the previous year and two weeks earlier.

A rapid decline in April the 12th reduced the total phytoplankton to almost a quarter and chlorophyll _a_ to 0.181 µg/1. The large reduction in _Melosira_ which was evident at the surface was absent at 3 m depth. A reduction in numbers continued till 10 May when a total of 20670 units/1 of phytoplankton were counted and chlorophyll _a_ had fallen to 0.09 µg/1. On 24 May, 1973 the chlorophyll _a_ value was the same while total phytoplankton counts had shown a slight increase, 95% of which was diatoms.

The beginning of June 1973 saw an overall increase in diatoms and chlorophyll _a_ (0.2 µg/1). The algae showing the most rapid increase at this period was _T. fenestrata_ which had increased from 3000 cells/1 to 37600 cells/1 in two weeks. By 24 June phytoplankton had increased to more than 200000 units/1, more than half of which was attributed to sudden pulse of _Anabaena_. This species was almost entirely confined to the surface water with only a quarter of the numbers at 3 m depth and none at 10 m depth. The peak of _Anabaena_ occurred one month earlier than in 1972 and was considerably larger. Chlorophyll _a_ value at this time (0.35 µg/1) was slightly higher than the spring peak. Although the total number of phytoplankton in the spring was double the June total, the population on the two dates was considerably different with diatoms constituting 99% of the spring outburst while blue-green algae contributed more than 50% of the total in June.

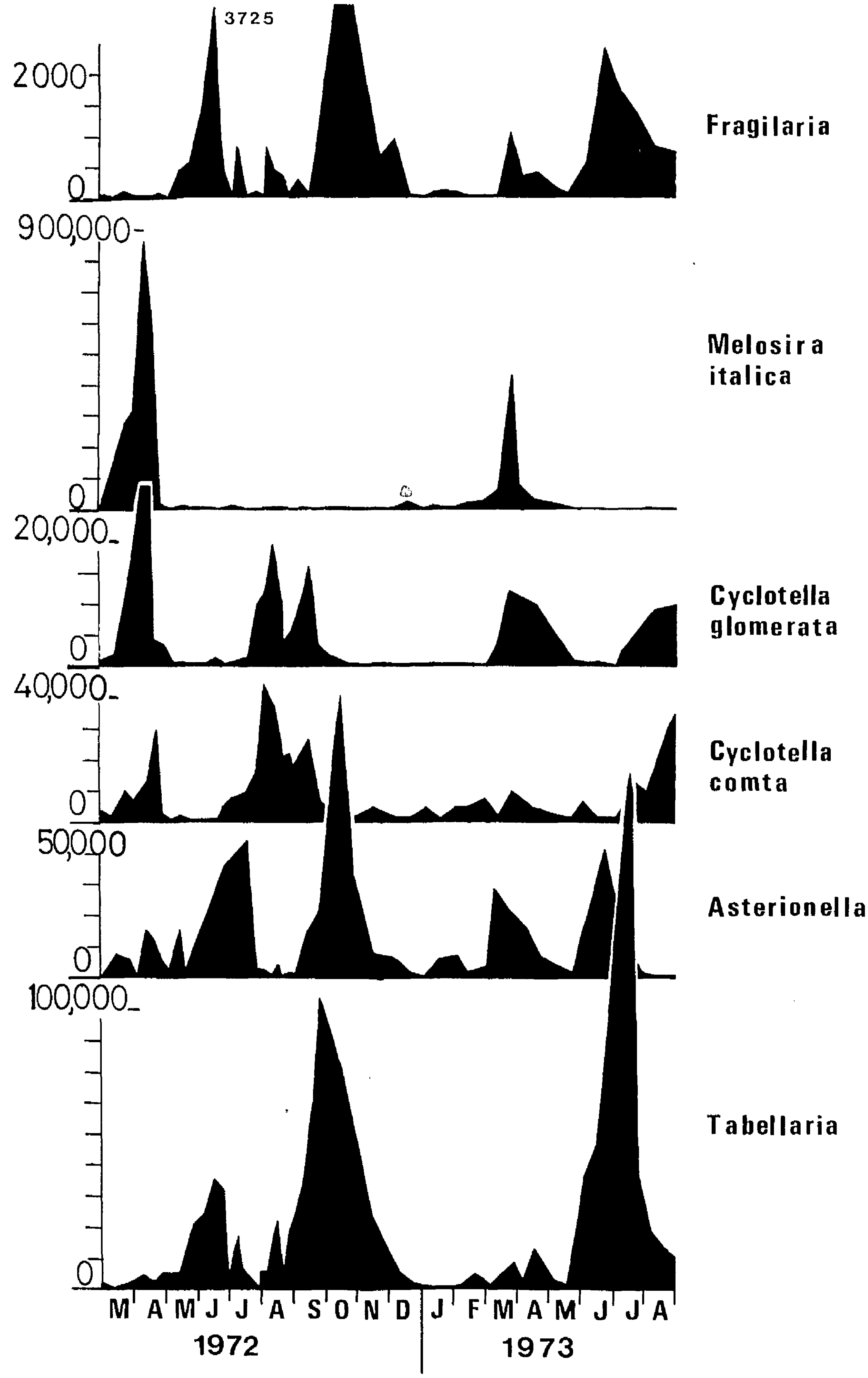
On 6 July, 1973 total numbers of phytoplankton reached 236000 units/1, two-thirds of which was _Tabellaria fenestrata_ with corresponding chlorophyll _a_ value of 0.36 µg/1. The total bulk of phytoplankton had reduced to half on 24 July and chlorophyll _a_ value had fallen to 0.204 µg/1. _Ceratium_, _Peridinium_, _Mallomonas_ and _Coelosphaerium_ all showed pulses during July.

August 1973 was characterized by decreasing numbers of phytoplankton falling to 68800 units/1 on 2nd and further to 58000 units/1 on 17th. This was accompanied by a regular change in chlorophyll _a_ values to 0.2 µg/1 and finally to 0.15 µg/1 on 4 September, 1973.

(ii) _Middle Station, Loch Lomond_ (Fig. 33, 36a, b and 37a, b, Appendix Table 21 and 24a, b, c and d)

At the beginning of March, 1972 the total number of phytoplankton was

LOCH LOMOND SOUTH BASIN SURFACE Fig 31a

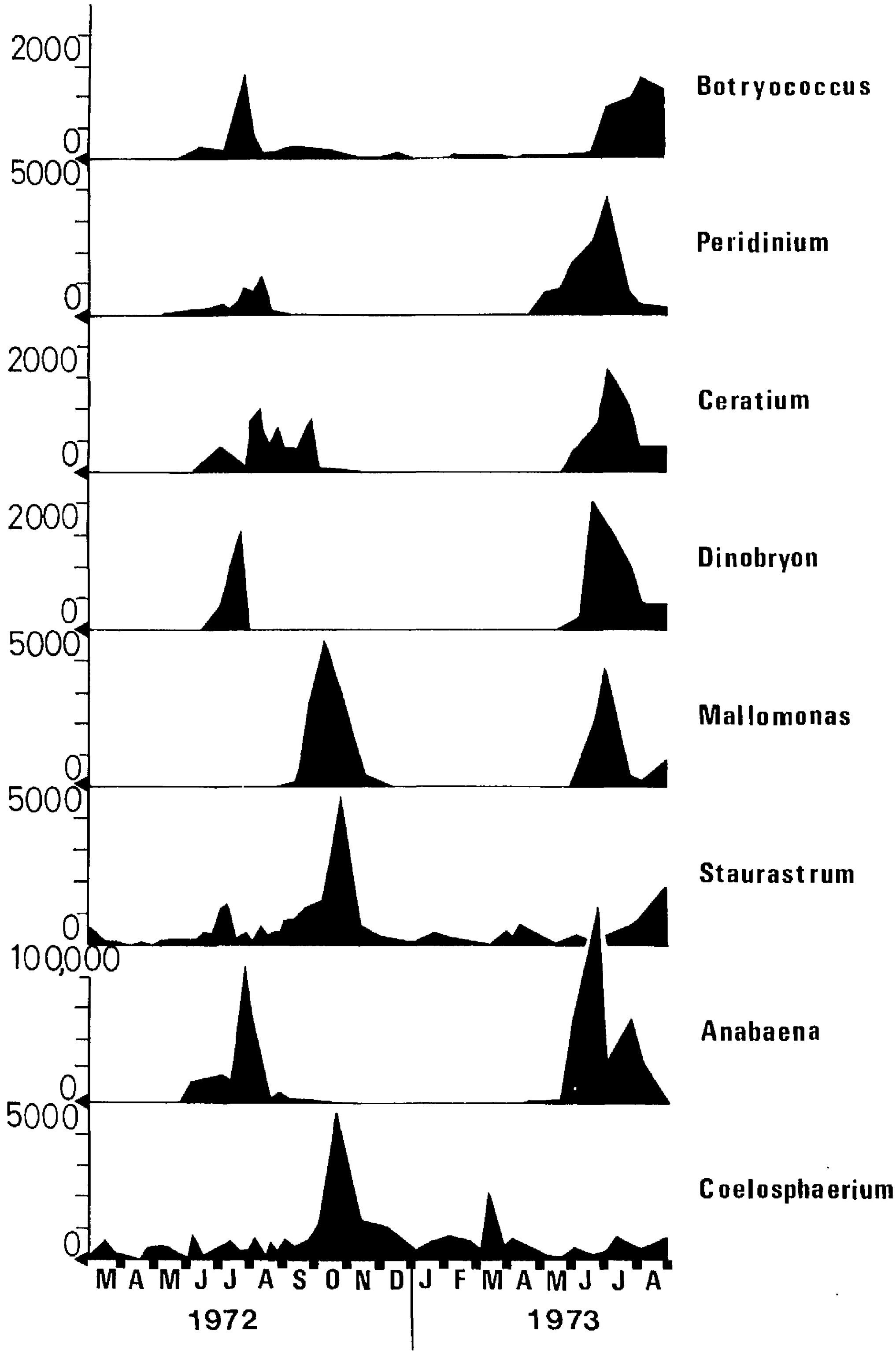


less than 50000 units/l. The population consisted mainly of diatoms. The dominant organism at this time was Melosira which alone made up about 90% of the total. During the following month a gradual rise in number of organisms occurred, doubling in numbers by 7 April, 1972 when 110000 units/l were recorded at the surface. The dominant phytoplankton was still Melosira (86900 cells/l), while Cyclotella comta reached a small peak of 4701 cells/l. Coelosphaerium was present in small numbers at the surface and depth whereas Staurastrum and Botryococcus were present at the surface only.

A spring maximum in the total number of phytoplankton occurred on 14 April when Melosira contributed about 75% of the total 175000 units/l. This peak of Melosira was reached on the same date as at the South Station. Cyclotella glomerata and T. fenestrata also reached their spring maxima whereas the spring peak of latter organism did not occur till June at the South Station. There was a general decrease in the numbers of phytoplankton at 3 m depth. Peridinium and Ceratium made their first appearance on 14th although they were only found in surface samples. On 20 April, 1972 the total phytoplankton had decreased to 120000 units/l. The only organism still on the increase was Asterionella which reached a peak of 7300 cells/l a week later than at the South Station. This species was absent at 3 m depth while Melosira which was declining showed a higher number below the surface. The magnitude of the individual peaks at the Middle Station was generally less than half that of the South Station, while the Melosira pulse was only one-sixth that of the South.

An overall fall in phytoplankton numbers to 84000 units/l was evident on 27 April, 1972 whereas Cyclotella comta reached a peak on this date (about 5000 cells/l). On 4 May, 1972 the phytoplankton total was down to 63000 units/l of which Melosira contributed more than two thirds. Asterionella and Tabellaria both remained relatively high while Fragilaria was on the increase and the two species of Cyclotella were falling. The picture at 3 m depth was similar and numbers were generally higher. On 16 May, 1972 a small peak in the total phytoplankton was recorded (70000 units/l); this was caused by the continuing high number of Melosira, and

LOCH LOMOND SOUTH BASIN SURFACE Fig 31b



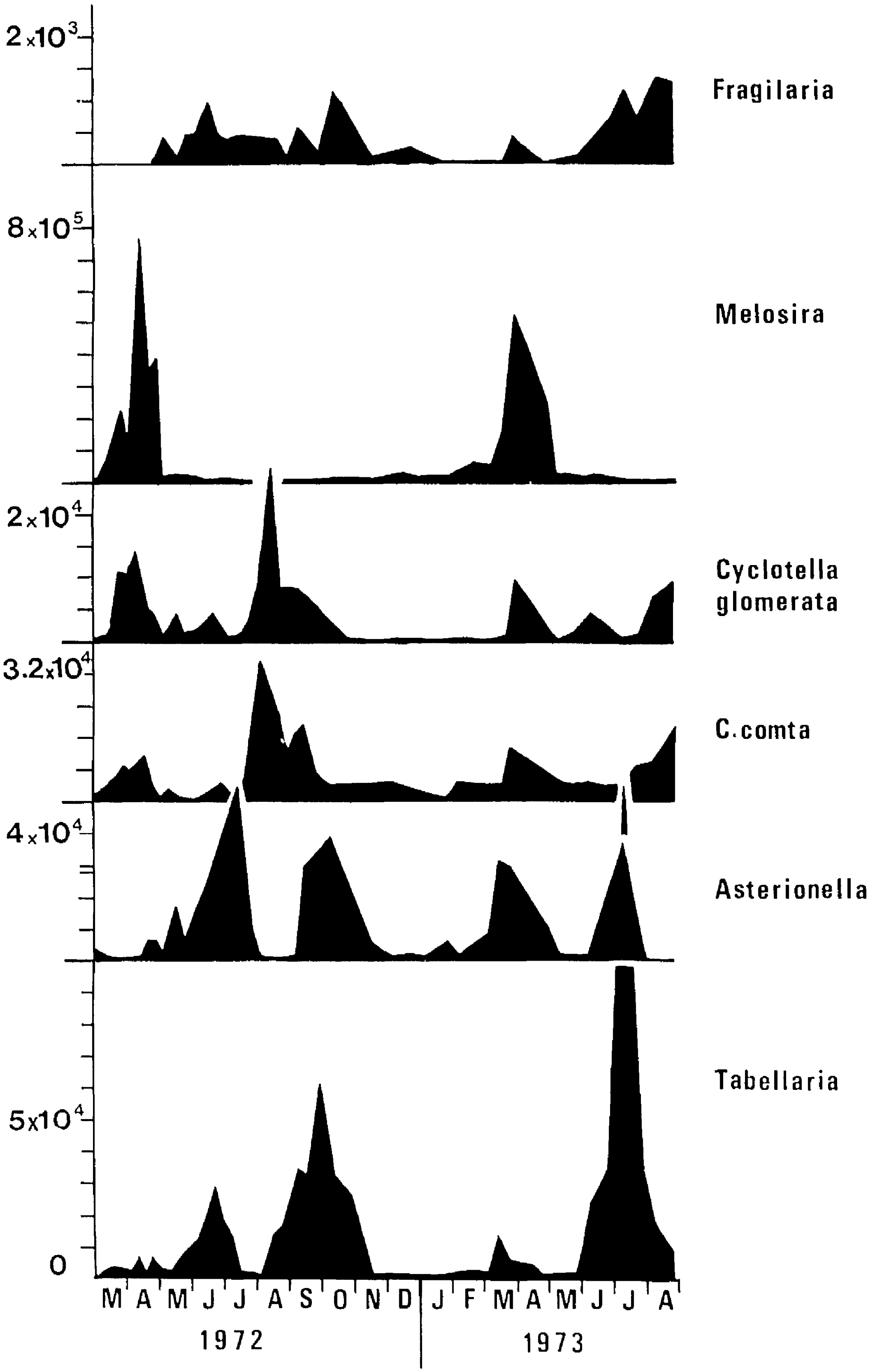
further peaks of Asterionella and Tabellaria. A corresponding pulse of Asterionella occurred simultaneously at the South Station. These three dominant diatoms were now more frequent in surface samples than at depth.

By the end of May 1972 a general decline was clear and numbers had fallen to a total of 55000 units/l. This decline continued till 12 June when only 30000 units/l were found. Melosira, Asterionella and Tabellaria were by now more numerous at 3 m depth while Cyclotella was commoner at the surface. In the South at this time a general increase in the number and type of organisms (which began on 16 May) had reached 68000 units/l with clear peaks of Asterionella, Fragilaria and Tabellaria. However, at the Middle Station a pulse of Tabellaria did not occur till 19 June while Fragilaria and Asterionella reached their maxima on 27 June. By this time Dinobryon was present at the surface and Peridinium and Ceratium at the surface and depth.

On 4 July, 1972 Anabaena made a sudden appearance, simultaneously with that in the South Station with 16488 cells/l being recorded at the surface, 2304 cells/l at 3 m depth and none at 5 or 10 m depth. 50% of the population on this date was Asterionella; this was accompanied by Tabellaria which produced a further pulse of 18804 cells/l at the surface. The total number of phytoplankton on this date (75000 units/l) declined to about 27000 units/l on 10 July, although Dinobryon attained a surface maximum of 4701 colonies/l and Peridinium reached 1044 cells/l. The low number of organisms found at this station was contrasted with the large number at the South Station (87000 units /l) where pulses of Asterionella and Fragilaria were evident. Total phytoplankton at the Middle Station rose to 37000 units/l on 18 July and further to 49000 on 26 when Anabaena reached its maximum of 28500 cells/l at surface and 3 m depth. The peak was observed simultaneously with maximum values of Anabaena at the South Station, although numbers were only one-third of those in the South. Another blue-green algae, Coelosphaerium, reached a maximum on this date accompanied by Ceratium and Staurastrum. Mallamonas made its first appearance in surface samples.

The total number of phytoplankton reached a peak of 90000 units/l on 1 August, 1972, about 50% of which was Cyclotella comta and C. glomerata.

LOCH LOMOND SOUTH STATION 3 metres depth Fig 32a

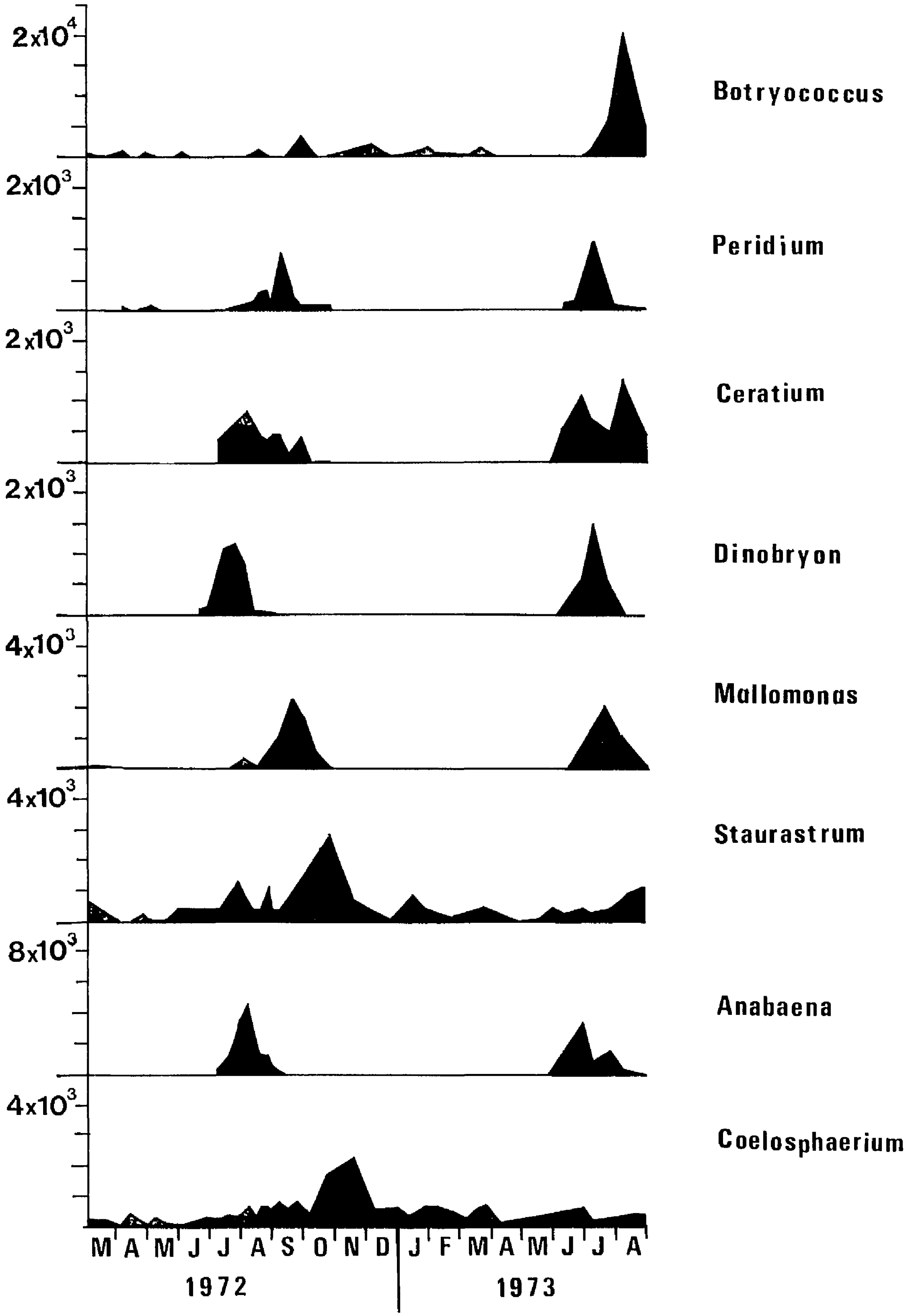


Anabaena remained at its July peak at the surface although depth samples showed a decline to 7600 cells/l. Botryococcus reached a surface maximum of 2213 colonies/l on this date. On 8 August the two species of Cyclotella still dominated the population with 75% of the total phytoplankton. By 22 August total numbers had declined to 25000 units/l of which 40% was C. comta; Coelosphaerium (1044 colonies/l), Mallomonas (4701 cells/l), and Peridinium (2231 cells/l) all reached their highest numbers at the surface on this date while a peak of Ceratium was recorded at 3 m depth on 15th.; Dictyosphaerium was recorded throughout August and September.

An overall increase in phytoplankton was evident at the beginning of September when the total of around 45000 units/l was recorded. Ceratium reached a surface maximum of 2000 cells/l but was very scarce at 3 m depth, while Dinobryon was no longer evident. On 12 September, 1972 an autumn maximum of 84000 units/l was recorded with Cyclotella comta and C. glomerata comprising more than 50% of the total. This occurred simultaneously with the highest number of Cyclotella at the South Station. Tabellaria reached a peak on 27 September when 27000 cells/l were found at the surface and depth. Asterionella produced a maximum of 42000 cells/l on 11 October, 1972. Both these peaks coincided with maximum of the same species at the South Station but were less than half in quantity.

October 1972 saw the disappearance of several species which were frequently found during the summer. These include Anabaena, Mallomonas, Dinobryon, Ceratium and Peridinium. From 11 October onwards chlorophyll a estimations were made as an additional estimate of standing crop, a value of 0.1 μg/l was recorded on this date when the total phytoplankton count was 77000 units/l. By the end of October (25th) the phytoplankton total had fallen by half and chlorophyll a had declined to 0.08 μg/l. The predominant phytoplankton on this occasion were still Asterionella and Tabellaria. On 23 November Melosira and Coelosphaerium were increasing while other organisms had decreased in number. The total number of phytoplankton was 40000 units/l of which more than 50% was Melosira; the chlorophyll a value had fallen to 0.04 μg/l. On 7 December, 1972 a small increase

LOCH LOMOND SOUTH BASIN 3m depth Fig 32b



in the total phytoplankton and a rise in chlorophyll a (to 0.06 μg/l) was due to a further increase in Melosira and Coelosphaerium, the latter reaching 1374 colonies/l in this date. By 21 December Melosira reached its winter maximum when it constituted more than 75% of the total phytoplankton recorded (40,000 units/l). As in previous weeks this plant was still more numerous at the surface than at depth. Coelosphaerium had shown a considerable decline to 300 colonies/l and the chlorophyll a reading had fallen to 0.02 μg/l. Total phytoplankton numbers fell by half on 4 January, 1973 while chlorophyll a showed little change at 0.025 μg/l.

The lowest total number of phytoplankton was recorded on 17 January, 1973 when only 10,000 units/l was observed. 20% of this total was made up by Coelosphaerium colonies which attained a winter maximum of 1814 colonies /l on this date. Chlorophyll a reading showed an increase to 0.045 μg/l. On 1 February, 1973 Coelosphaerium had declined while the total phytoplankton had increased to 27,500 units/l; Melosira and Tabellaria together constituted 75% of the total, and the chlorophyll a measurement was 0.06 μg/l. Total phytoplankton numbers doubled by 15 March, 1973 while chlorophyll a showed little change. On this date Melosira, Asterionella and Cyclotella comta were on the increase.

On 28 March, 1973 chlorophyll a had risen to 0.2 μg/l, followed by a slight fall to 0.17 μg when 75000 units/l were recorded. Phytoplankton reached a peak of 205000 units/l on 26 April, 1973 with a chlorophyll a reading of 0.19 μg/l. This spring diatom outburst was similar in magnitude to that of 1972 but occurred about 2 weeks later; it was also later by almost a month than the spring pulse at the South Station in 1973. As in 1972 at this station the predominant diatom was Melosira, about 66% of the total phytoplankton. Melosira was accompanied by Asterionella while in 1972 the spring pulse of Melosira was accompanied by Tabellaria. Melosira was considerably greater at 3 m depth whereas Asterionella was only marginally more below the surface.

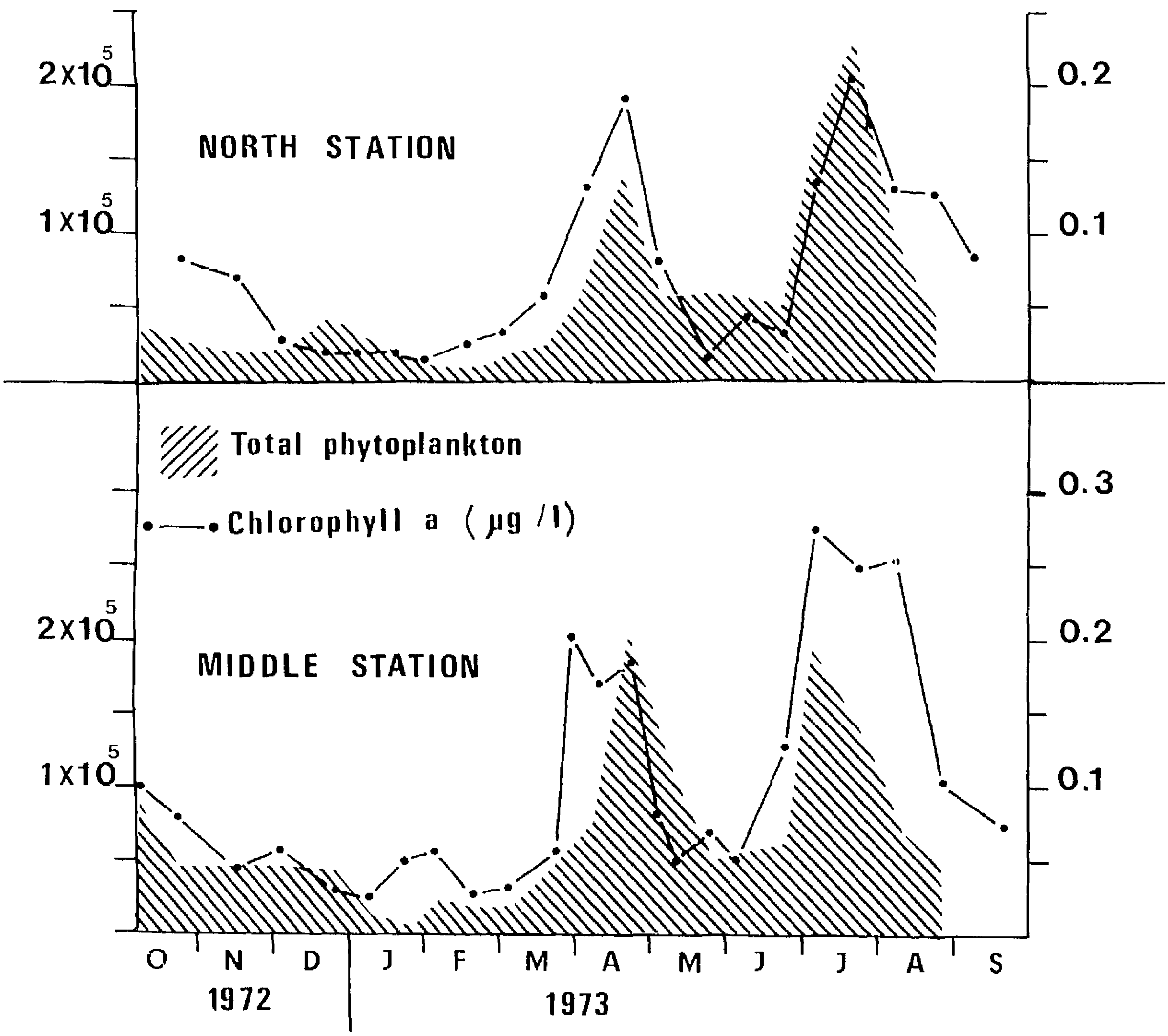
Chlorophyll a levels declined to 0.086 μg/l on 2 May, 1977 and subsequently to 0.059 μg/l on 10 May when the number of phytoplankton had fallen by half. Melosira made up more than half of the total population on this date while Tabellaria fenestrata and Fragilaria reached respective values of 21,800 cells/l and 357 chains/l. On 24 May, 1973 Melosira had fallen to low numbers at the surface but was still in evidence at depth. Asterionella was now the dominant phytoplankton. Coelosphaerium was relatively high at the surface. Organisms which made their first appearance during this month include Mallamonas, Peridinium. The total number of the phytoplankton on this date was 54,000 units/l while chlorophyll a was 0.08 μg/l.

Chlorophyll a fell to 0.05 μg/l on 7 June followed by a large increase on 21 June, 1973 to 0.12 μg/l. On this date the total number of phytoplankton was 64,000 units/l of which 66% was Asterionella. Dinobryon reached a peak of 4811 colonies/l at surface and 3 m depth. Anabaena made its first appearance on this date. 6 July, 1973 saw a summer maximum in the total number of phytoplankton (191,700 units/l) reflected in the high chlorophyll a level (0.275 μg/l). 90% of the total was attributed to Tabellaria fenestrata; the only other common diatom was Asterionella. Peridinium reached a maximum of 2213 cells/l at the surface while it was abundant at 3 m depth (1044 cells/l). An overall decline was evident on 24 July, 1973 when 142,000 units/l and a chlorophyll a value of 0.25 μg/l. were recorded. Anabaena attained a surface maximum on this date of 62,691 cells/l; this was one month later than the maximum at the South Station and only half the magnitude. Tabellaria still made up about 50% total quantity of the organisms. Among the other plants present, Ceratium attained a peak of 2213 cells/l at the surface.

2 August, 1973 saw little change in chlorophyll a values while phytoplankton fell by half, However, the composition of the population was considerably different. Peaks of colonial algae were evident with Botryococcus reaching 3162 colonies/l., Coelosphaerium reaching 806 colonies/l and Dictyosphaerium attaining a maximum of 718 colonies/l. Tabellaria still comprised about two-thirds of the total while Cyclotella comta and Cyclotella glomerata were both on the increase. On 17 August total phyto-

LOCH LOMOND

Fig 33

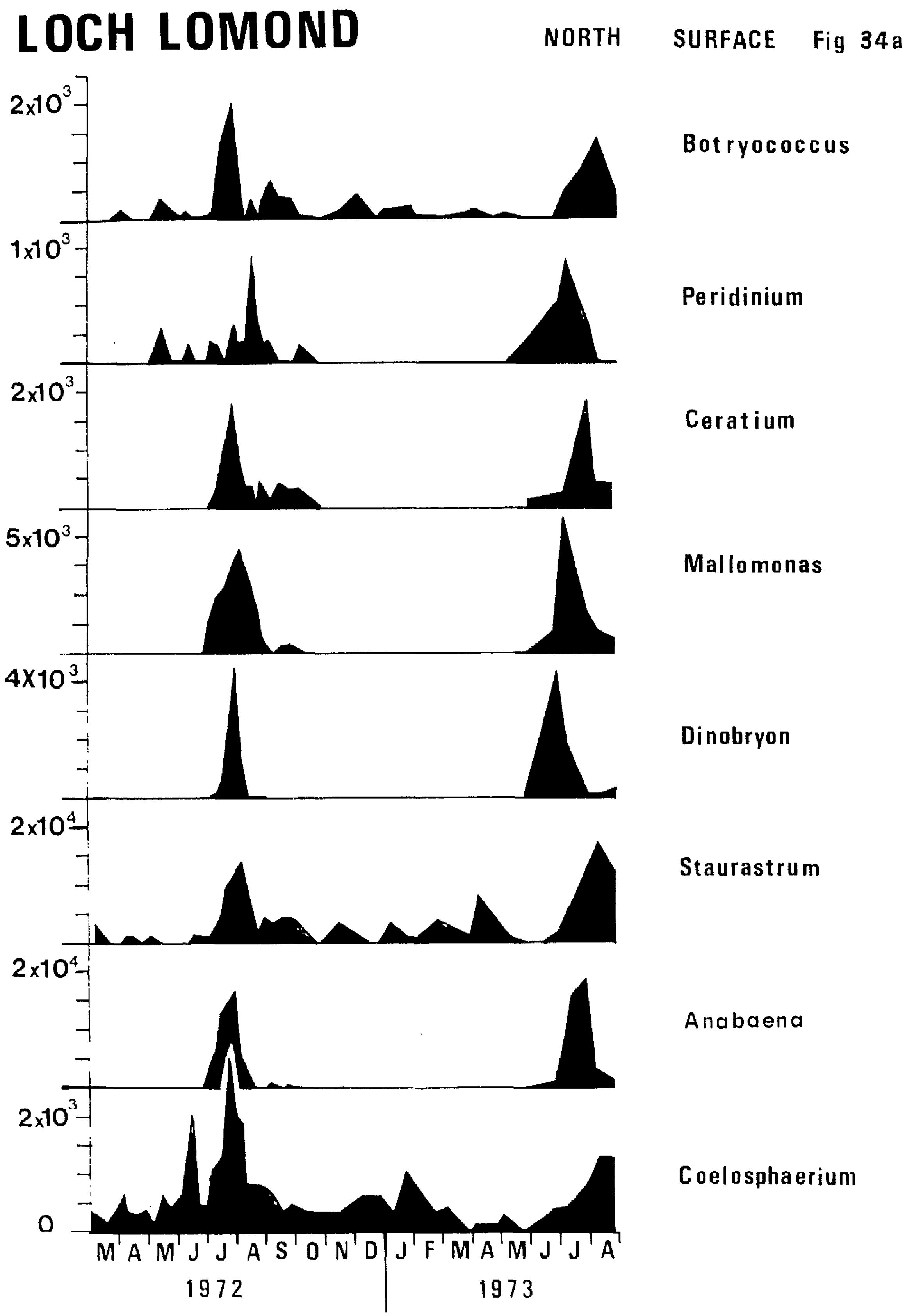


plankton fell to 44,000 units/l at the surface with a predominance of Cyclotella comta (19000 cells/l) and Cyclotella glomerata (12000 cells/l). Mallomonas recorded its highest number, 4701 cells/l at 3 m depth while only 1644 cells/l found at the surface. Chlorophyll a values fell from 0.104 µg/l on this date to 0.075 µg/l at the beginning of September 1974.

(iii) North Station, Loch Lomond (Fig. 33, 34a, b, and 35a,b; Appendix Table 21, 25a, b, c and d)

When sampling commenced on 2 March, 1972 the dominant phytoplankton was Tabellaria flocculosa, a species not found in any numbers at other stations. This species reached 11273 colonies/l at the surface while only 357 were recorded at 10 m depth. Other diatoms observed on this date include T. fenestrata (1704 cells/l) and Melosira (1510 cells/l). Cyclotella, Coelosphaerium and Staurastrum were the only other plants found at the surface, none of them exceeding 500 per litre. Asterionella was absent from surface samples but 1540 cells/l was found at 3 m depth. Throughout March T. fenestrata showed maximum numbers at 3 m depth whereas T. flocculosa exhibited maximum numbers at the surface.

During the following four weeks, numbers increased slowly to reach a total of 44,000 units/l at the surface on 7 April, 1972. The dominant organism at the surface was Melosira (26384 cells/l) while at 3 m depth Tabellaria fenestrata predominated (45092 cells/l) and reached its spring maximum. T. flocculosa and Cyclotella comta also reached spring peaks at 3 m depth on this date. By the following week (14 April, 1972) the total number of phytoplankton attained its maximum 80,000 units/l of which more than half was Melosira. This organism recorded a peak of 54,442 cells/l at the surface but was reduced to 25,000 at 3 m and 8850 cells/l at 5 m depth. This peak occurred simultaneously with the spring maximum at the other stations, although it was only half the size of the middle station peak and one-tenth that at the South Station. On 20 April, 1972 the total fell to 75,000 units/l, although C. comta reached a peak of 4701 cells/l and C. glomerata was on the increase. 27 April saw a further small decline in total numbers, mainly due to a fall in the amount of Melosira to around


LOCH LOMOND
NORTH
SURFACE
Fig 34a
2x10³
Botryococcus
1x10³
Peridinium
2x10³
Ceratium
5x10³
Mallomonas
4X10³
Dinobryon
2x10⁴
Staurastrum
2x10⁴
Anabaena
2x10³
Coelosphaerium
0
M A M J J A S O N D J F M A M J J A
1972
1973

25% of the total phytoplankton. This was partly compensated by an increase in Asterionella to reach a surface maximum of 37,608 cells/l with smaller numbers in evidence at 3 and 5 m depth. The Asterionella maximum was later at this station than at the Middle Station (20 April) which was in turn later than the pulse at the South Station on 14 April. Cyclotella glomerata also reached a maximum on this date with 7,064 cells/l being recorded at the surface.

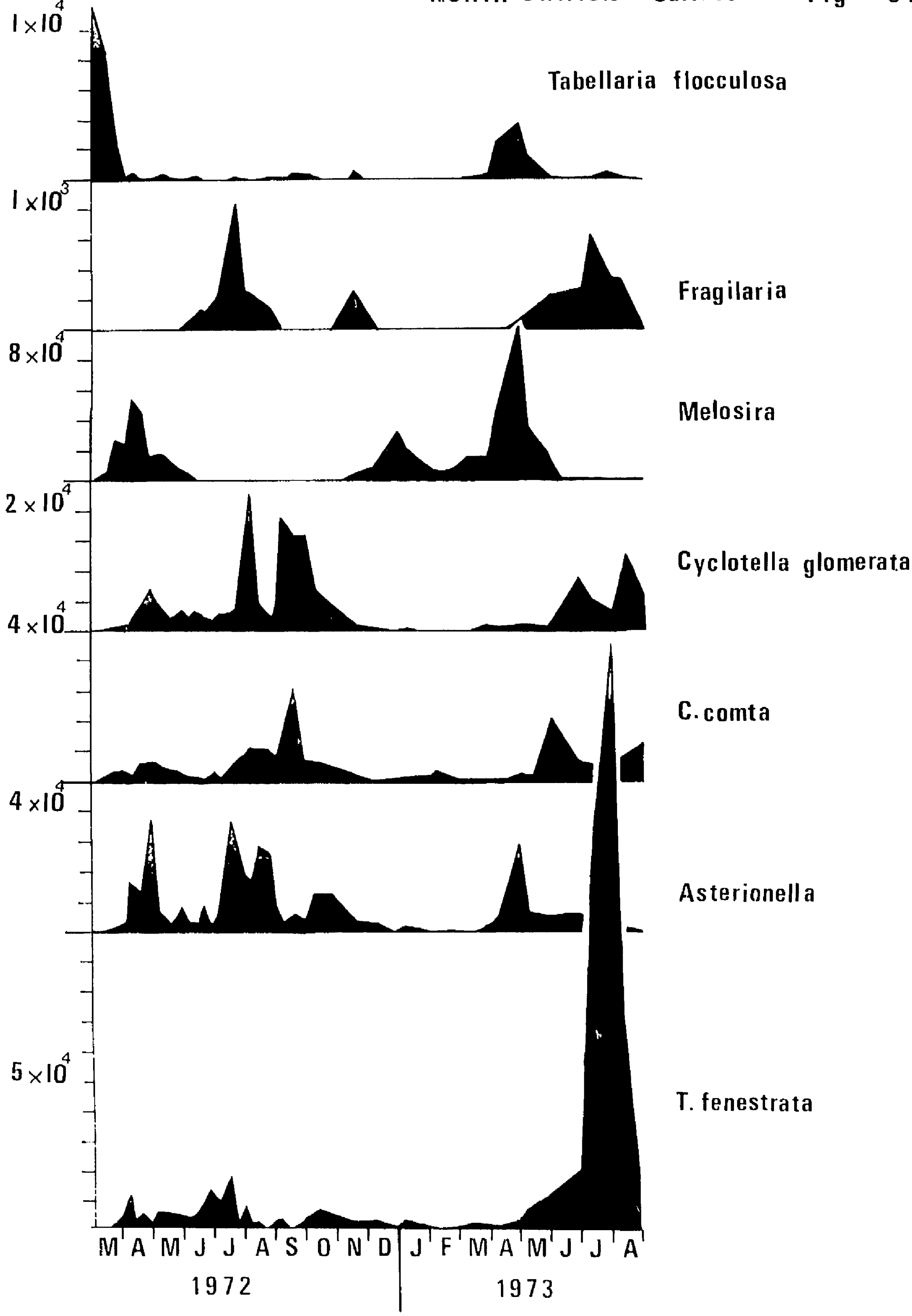
By 16 May, 1972 the total number of phytoplankton had fallen to 30,000 units/l of which more than 50% was Melosira. The total was the same on 29 May although the composition of the population was altered. Melosira had declined to 8412 cells/l, while Asterionella was 9128 cells/l, Other organisms present had shown little change. On 5 June, 1972 all phytoplankton except for Coelosphaerium had decreased at the surface to give a total of 18000 units/l. However at 3 m depth an overall increase was apparent and a total of 28,000 units/l was recorded. On 12 June, 1972 little change in the total was apparent although Melosira had almost disappeared and Tabellaria fenestrata had doubled in number to 8852 cells/l. On 19 June the total count was about 30,000 units/l of which T. fenestrata constituted about 40%.

From 27 June to 4 July, 1972 phytoplankton numbers were generally low, 15,000 to 23,000 units/l although a slight increase in C. glomerata, Asterionella, and T. fenestrata were evident on the latter date. Some plants made their appearance at the surface in this period, among them Anabaena, Mallomonas, Peridinium and Ceratium. A large increase was evident on 10 July, 1972 when the total number of phytoplankton was 80,000 units/l. The dominant plant was Asterionella with 37,608 cells/l at the surface and much lower numbers (6,928 cells/l) at 3 m depth. Tabellaria fenestrata also reached a peak on this date producing a total of 18,804 cells/l. Anabaena had increased to 12,528 cells/l while Dinobryon had appeared in surface and depth samples.

On 18 July, 1972 Fragilaria and Coelosphaerium reached respective num- of 1044 and 3162 colonies/l at the surface. However the Fragilaria max-

LOCH LOMOND

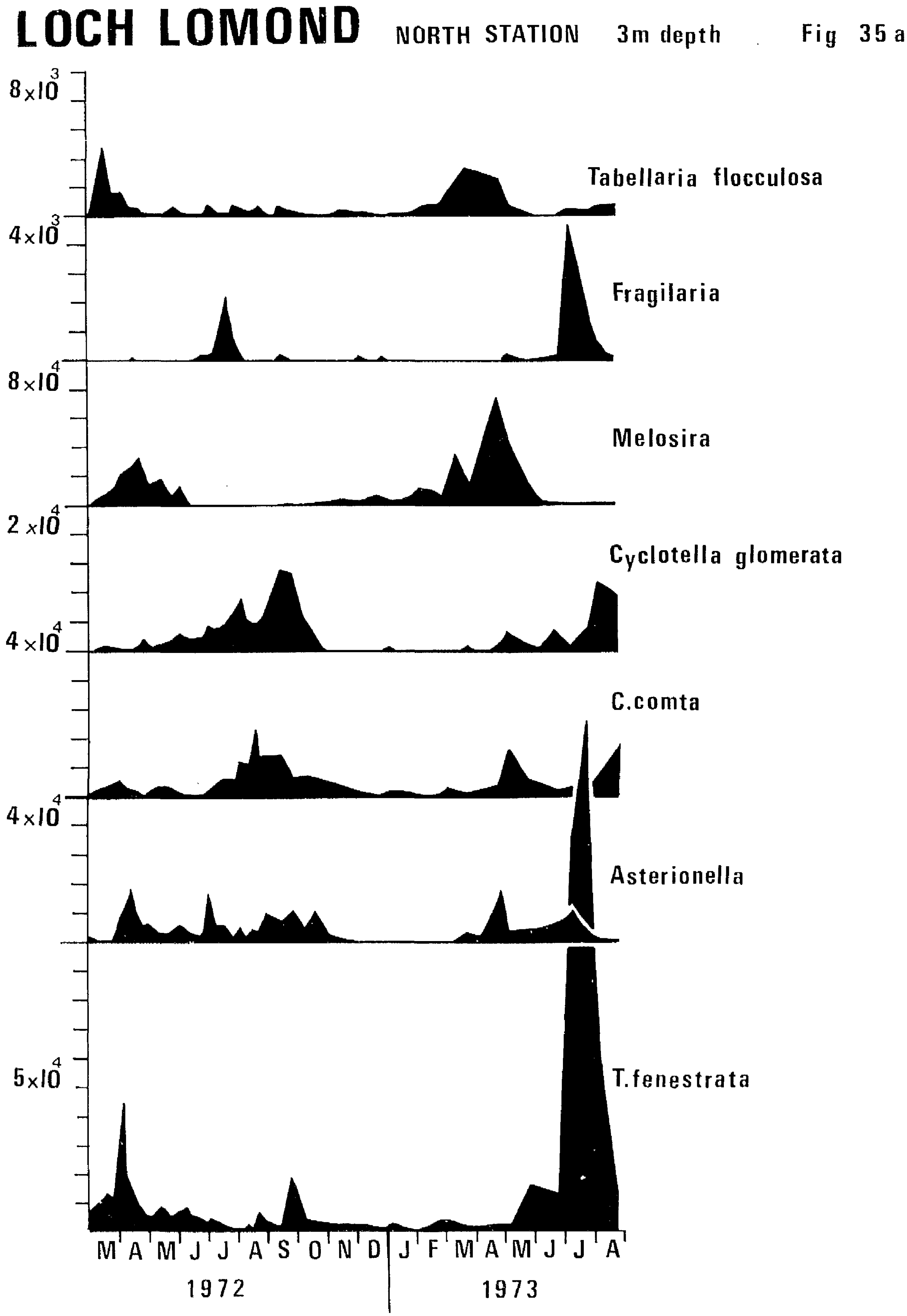
NORTH STATION Surface Fig 34 b



imum at 3 m depth was greater, 2007 chains/l. During the following week (26 July) Anabaena attained a maximum (17226 cells/l) at the surface and 25102 cells/l at 3 m., simultaneously with the Middle and South Stations. This was accompanied by a peak of Dinobryon (4701 colonies/l) and Ceratium (1814 cells/l). By 1 August the total number of phytoplankton had fallen to around 60,000 units/l. Cyclotella glomerata predominated and reached maximum on this date with 22,684 cells/l at the surface and less at depth. Pulses of Mallomonas and Staurastrum were also observed reaching 4701 and 1374 cells/l respectively. Mallomonas reached a maximum at 3 m depth one week earlier than the surface peak. Pulses of Mallomonas occurred progressively later passing southwards; 22 August at Middle Station, 11 October at South Station.

On 8 August, 1972 Asterionella was on increase and predominated in the phytoplankton, comprising about 40% of the total (55000 units/l), Cyclotella glomerata had fallen by half while C. comta was still increasing. Asterionella reached a summer maximum on 15 August of 29,800 cells/l at the surface, whereas Cyclotella attained a maximum of 18,606 cells/l at 3 m depth. A pulse of Peridinium was also observed on this date with 948 cells/ l at the surface. A decline in the number of most organisms resulted in a total population of only 30,000 units/l at the surface on 29 August. HOwever slightly higher numbers were recorded at 3 m depth (around 42,000 units/l). The magnitude of the summer and spring increase at the North Station was less than the total number recorded at the Middle Station which was in turn less than the maximum at the South Station.

In September an increase in phytoplankton (to 48,000 units/l) was observed on 6th when a peak of Cyclotella glomerata (18,743 cells/l) was recorded. Cyclotella comta had increased to more than 16,000 cells/l and a small peak of Tabellaria fenestrata was noted (4564 cells/l) at the surface. The highest number of Cyclotella comta (25,663 cells/l) was recorded on 12 September, accompanied by a small peak of Asterionella (6264 cells/l). T. flocculosa also made a short reappearance at surface and 3 m depth. The fall in the number of total phytoplankton to 35000

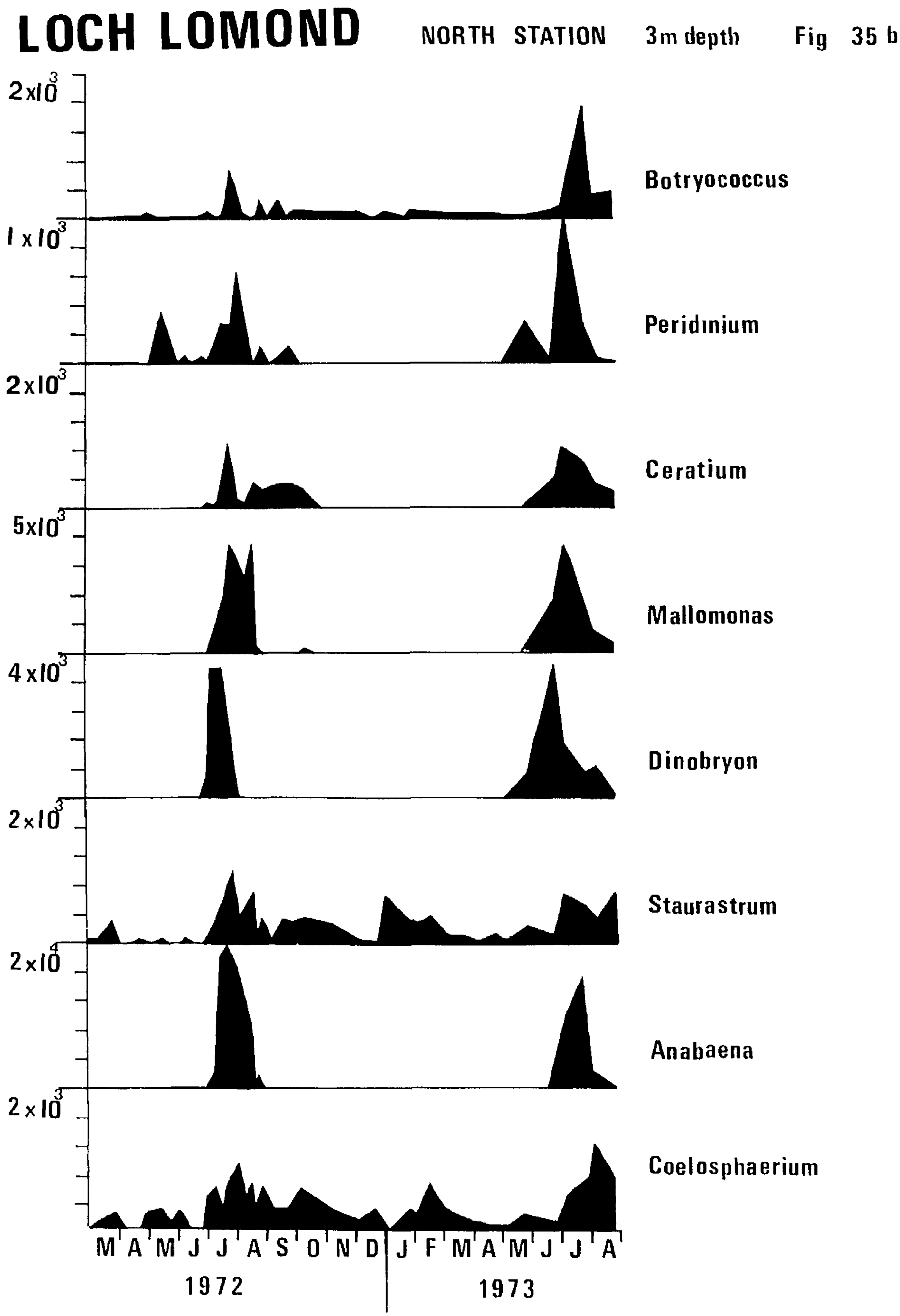

LOCH LOMOND NORTH STATION 3m depth Fig 35a
8×10³
Tabellaria flocculosa
4×10³
Fragilaria
8×10⁴
Melosira
2×10⁴
Cyclotella glomerata
4×10⁴
C.comta
4×10⁴
Asterionella
5×10⁴
T.fenestrata
M A M J J A S O N D J F M A M J J A
1972
1973

units/l on 27 September was mainly due to the large decrease in Cyclotella comta. Tabellaria fenestrata reached a maximum on this date at 3 m depth (18804 cells/l) not reaching a surface maximum till the following week.

From 11 October, 1972 estimates of chlorophyll a from surface samples were made as an additional measurement of standing crop. On this date the phytoplankton total was 35,000 units/l with a corresponding chlorophyll a value of 0.08 µg/l. The dominant organisms were Asterionella (13192 cells /l) and Tabellaria fenestrata (7256 cells/l) which both reached further peaks. By 23 November, 1972 the population had diminished to around 14,000 units/l and Mallomonas, Anabaena, Dinobryon, Peridinium and Ceratium were no longer in evidence. The dominant representative in the phytoplankton was Asterionella which reached 10,008 cells/l at 3 m depth. During the following month the only species which showed an increase was Melosira which reached a peak of 37,344 cells/l on 21 December. This organism was almost entirely confined to the surface where it represented more than 95% of the total phytoplankton. This winter maximum of Melosira was also observed at the Middle and South Stations but became progressively smaller passing southwards. Tabellaria flocculosa and Fragilaria were no longer in evidence on this date. The chlorophyll a reading was 0.015 µg/l.

The population fell still further till 17 January when a total phytoplankton of 16000 units/l and a chlorophyll a value of 0.014 µg/l were recorded. Melosira still dominated the population with more than 66% of the total and Coelospharium reached a peak of 1044 colonies/l at the surface. The only other plankton to exceed 1000 cells/l were C. comta and T. fenestrata. A total of 11,500 units/l were found on 1 February, 1973 of which 6426 was Melosira and 3162 was C. comta. Chlorophyll a reading gave 0.013 µg/l. A similar total number of organisms were found on 15 February when a rise in chlorophyll a to 0.026 µg/l was observed.

On 1 March, 1973 both the number of organisms and the chlorophyll a values had risen to 19,000 units/l and 0.035 µg/l respectively. More that three quarters of this total at the surface was contributed by Melosira while at 3 m depth Melosira numbers were even higher reaching 37,250 cells



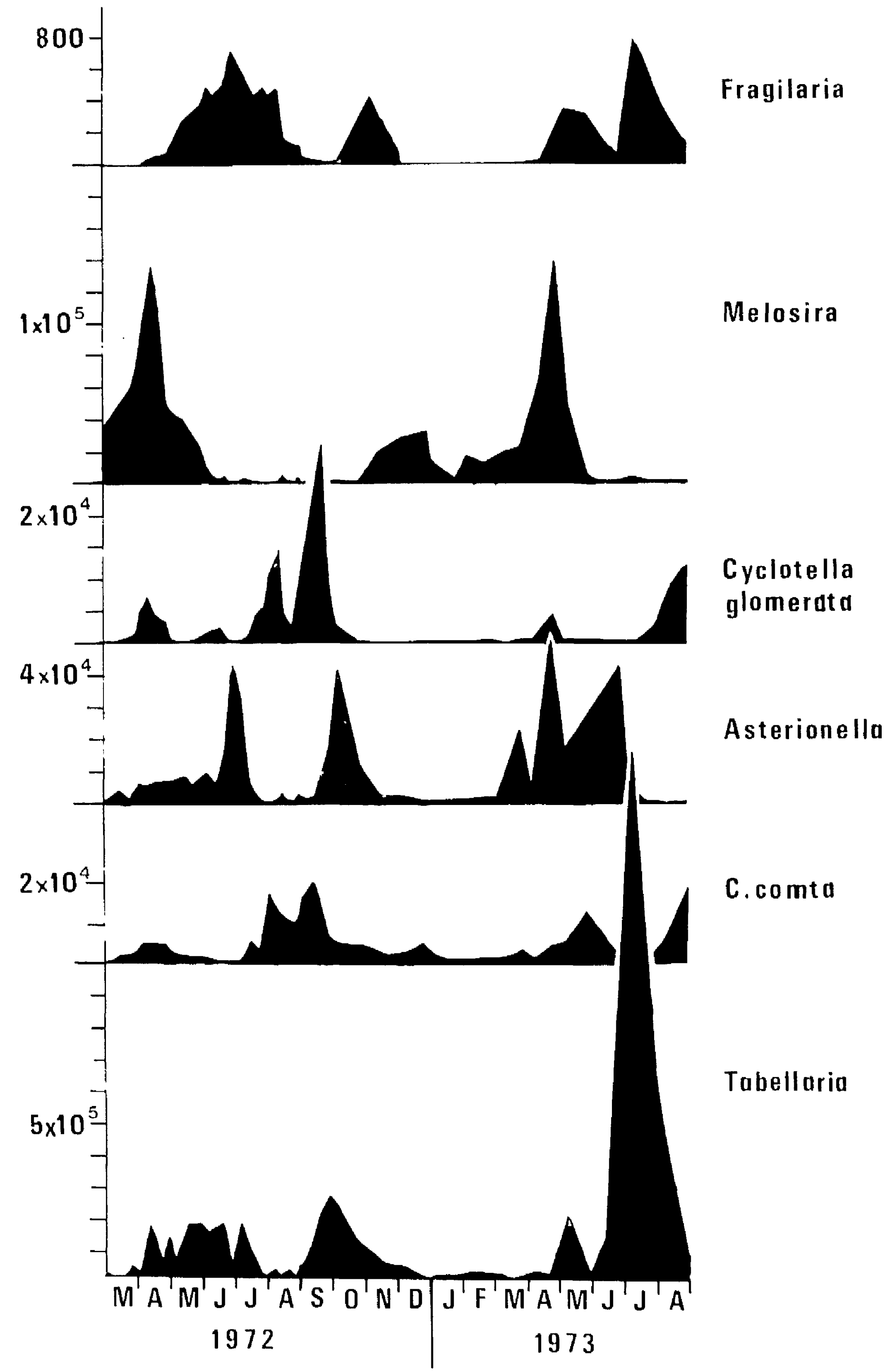
LOCH LOMOND
NORTH STATION
3m depth
Fig 35 b
2x10^3
Botryococcus
1 x 10^3
Peridinium
2x10^3
Ceratium
5x10^3
Mallomonas
4 x 10^3
Dinobryon
2x10^3
Staurastrum
2x10^4
Anabaena
2 x 10^3
Coelosphaerium
M A M J J A S O N D J F M A M J J A
1972
1973

/l. By 15 March Asterionella, T. fenestrata and Cyclotella were on the increase. The total phytoplankton had risen to 24,000 units/l and chlorophyll a to 0.063 μg/l. During April 1973 all the main diatoms except for Fragilaria showed increases, giving a phytoplankton total of 56,000 units/l and a chlorophyll a reaching 0.13 μg/l on 12th. Peaks of Melosira (103,422 cells/l, Asterionella (29,800 cells/l) and T. fenestrata (3725 cells/l) were reached on 26 April, 1973 giving a total of 143,000 units/l and chlorophyll a value of 0.2 μg/l. This spring maximum occurred on the same date as the pulse at the Middle Station but a month later than the South Station peak, the total numbers also became progressively larger passing southwards.

By 10 May, 1973 a considerable fall in phytoplankton was evident reaching a total of 54,000 units/l with a chlorophyll a reading of 0.078 μg/l. Melosira was still the dominant phytoplankton although both Tabellaria fenestrata and Cyclotella were on the increase. 24 May saw a peak of C. comta which reached 16,589 cells/l at the surface and the first appearance of Fragilaria, Dinobryon, Peridinium and Ceratium was evident on this date. The total numbers of phytoplankton was 56,000 units/l and the level of chlorophyll recorded was 0.013 μg/l. The chlorophyll a reading reached 0.04 μg/l on 7 June and declined slightly to 0.03 μg/l on 24th, when the total numbers of organisms were 50,000 units/l. The population on this date was dominated by Tabellaria fenestrata which reached 20,347 cells/l while Melosira had almost disappeared. Anabaena and Mallomonas made their first appearance on this date.

On 6 July, 1973 several algae recorded a summer maximum among them Mallomonas (5,865 cells/l), Dinobryon (2007 colonies/l), Peridinium (866 cells/l) and Fragilaria (783 colonies/l). The population was dominated by T. fenestrata which was more than two-thirds of the total phytoplankton (176,000 units/l). The chlorophyll a value on this date was 0.138 μg/l. The maximum number of phytoplankton was recorded on 24 July (229,000 units /l) with a corresponding chlorophyll a value of 0.2 μg/l. T. fenestrata was the single most important species (195,223 cells/l) accompanied by

LOCH LOMOND MIDDLE STATION SURFACE Fig 36a



Anabaena (20,784 cells/l) and Ceratium (1814 cells/l) which also reached its peak on this date. Anabaena showed the same number at 3 m depth while the other two organisms showed a decrease at 3 m and 5 m depth.

Total phytoplankton fell by half on 2 August, 1973 and chlorophyll a levels declined to 0.127 µg/l. Cyclotella glomerata reached a peak at the surface (12739 cells/l). Coelosphaerium and Staurastrum, the two plants which were always present, reached respective peaks of 1374 colonies/l and 1814 cells/l. On 17 August the number of organisms declined to 40000 units /l whereas chlorophyll a levels remained the same. C. comta predominated with a maximum at 3 m depth of 14,619 cells/l. The numbers at surface, 5 m and 10 m depth were around 9500 cells/l. The 4 September, 1974 saw a decline in chlorophyll a levels to half the August levels (0.081 µg/l).

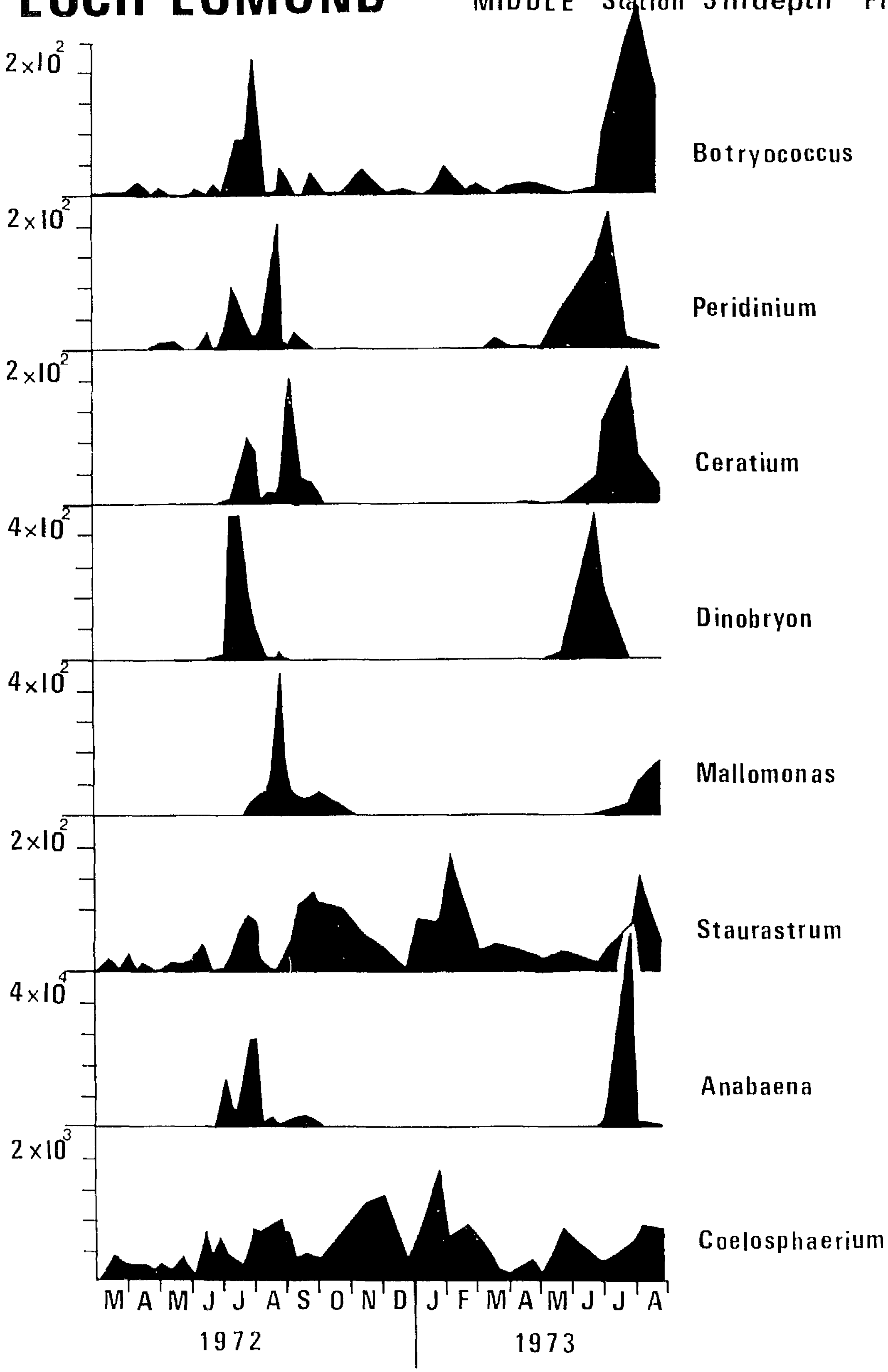
(c) Seasonal variations of phytoplankton and chlorophyll a in the four Lochs

(i) Lake of Menteith (Fig. 19, 38 a, b and 39 a, b: Appendix Table 22 and 26 a, b)

In Lake of Menteith the quantitative phytoplankton survey was continued from October 1972 to September 1973 and was augmented by chlorophyll a estimation throughout. In October 1972 phytoplankton was relatively low with a total population of 422,000 units/l and a chlorophyll a value of 0.138 µg/l. The population was dominated by Anabaena flos-aquae which constituted more than 75% of the total, accompanied by Fragilaria, Staurastrum and Coelosphaerium. However these organisms were almost entirely confined to surface waters where they were more than ten times as abundant as at 3 m depth. Low numbers of phytoplankton continued till 1 November, 1972 following which an increase occurred with A. flos-aquae as the dominant organism. A total of 1.043 millions units/l were recorded of which 85% was Anabaena. A small peak of Microcystis with 1695 colonies/l at the surface and 4701 at 3 m depth occurred simultaneously. Chlorophyll a reached a peak of 0.61 µg/l on this date (15 November, 1972). Asterionella increased on 29 November, 1972 (45093 cells/l) followed two weeks later by Melosira (413140 cells/l) accompanied by Tabellaria fenestrata (11108 cells /l) and Cyclotella comta (1251 cells/l). During this period the chloro-

LOCH LOMOND

MIDDLE Station 3m depth Fig 36b



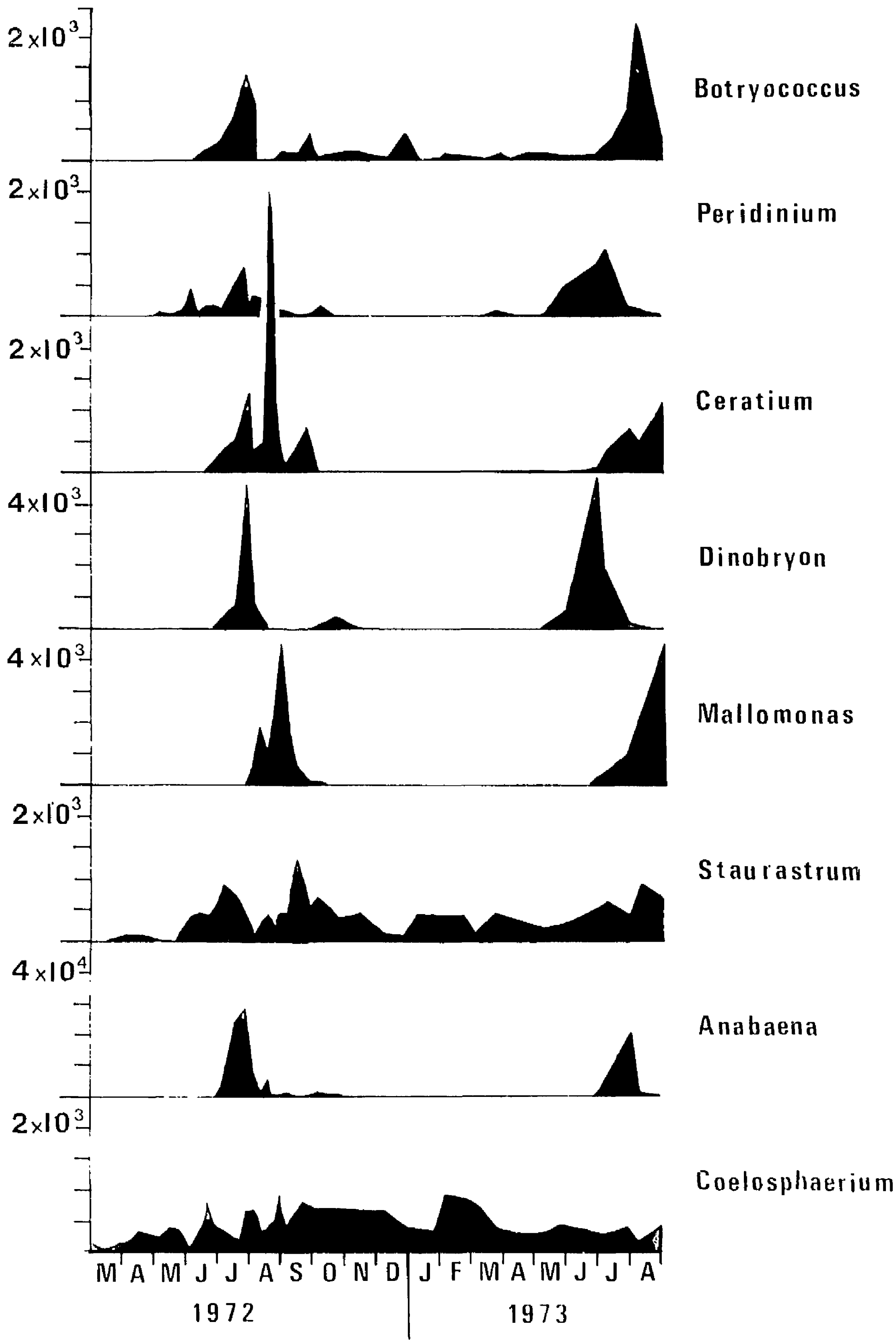
phyll *a* level fell to 0.12 μg/l and the phytoplankton total to 705,000 units/l. The bulk of algae fell by half on 27 December, 1972 and chlorophyll *a* dropped to its lowest recorded level (0.08 μg/l).

On 10 January, 1973 there was little change in the total phytoplankton (as units) although the water was visibly green and the chlorophyll *a* levels rose to 2.89 μg/l, the highest recorded value in this loch. This was due to a complete change in the composition of the phytoplankton which was now dominated by large colonial green and blue-green algae. *Coelosphaerium* produced a bloom of 72956 colonies/l, *Botryococcus*, 27037 colonies/l while *Microcystis* fell to 1374 colonies/l and *Anabaena* to 170000 cells/l. Thus these four algae constituted more than 90% of the total population (expressed in units) while *Coelosphaerium*, *Botryococcus* and *Microcystis*, if they had been expressed as cells would undoubtedly have constituted almost 100% of the population.

Anabaena circinales (49493 cells/l) was observed on 7 February, 1973. The dominant species at this time was *Melosira* (249115 cells/l). The total phytoplankton was down to 324,000 units/l and chlorophyll *a* had fallen to 0.34 μg/l. The first species to contribute to the spring increase was *Melosira* which reached 940645 cells/l on 8 March, 1973 and constituted about 95% of the total phytoplankton. *Cyclotella comta* reached its annual maximum (4078 cells/l) on 26 March, 1973 and *Melosira* showed a slight rise. The chlorophyll *a* levels rose from 0.8 on 8th to 0.93 μg/l on 26 March. The actual peak of *Melosira* was not reached till 20 April, 1973 when 1.09 million cells/l were recorded at the surface and slightly more (1.21 million cells/l) at 3 m depth. *Anabaena circinales* reached a peak (442597 cells/l) concurrently with *Melosira* maximum while *A. flos-aquae* bloomed a fortnight later (3 May, 1973), when 1.127 million cells/l were recorded. The total phytoplankton on this date reached its maximum of 2.13 million units/l with a chlorophyll *a* value of 1.9 μg/l. Both *Anabaena* species reached a maximum at 3 m depth on 17 May.

Following the appearance of *Anabaena* successive peaks of diatoms occurred starting with *Asterionella* followed by *Fragilaria*, after which

LOCH LOMOND MIDDLE STATION 3 metres depth Fig 37a



came Tabellaria fenestrata and Cyclotella. Asterionella formed a peak of 186974 cells/l on 17 May, 1973 when the total phytoplankton was 1.63 million units/l and the chlorophyll a level was 1.6 μg/l. A pulse of Fragilaria occurred on 1 June when 11273 chains/l were found. The total phytoplankton reached a summer minimum of 85000 units on 28 June; chlorophyll a fell to 0.26 μg/l. A peak of T. fenestratafollowed attaining a maximum of 47000 cells/l at the surface on 11 July, 1973 when the total population was 227000 units/l. A fortnight later a small peak of Cyclotella comta (1806 cells/l) was accompanied by Microcystis (17028 colonies/l, Ceratium (25200 cells/l) and Staurastrum (8127 cells/l). However the population on this date was dominated by Anabaena (A. circinales 52632 cells /l, A. flos-aquae 52212 cells/l, A. spiroides 528II cells/l). The total phytoplankton on this date (26 July, 1973) was 751656 units/l with a corresponding chlorophyll a value of 0.281 μg/l.

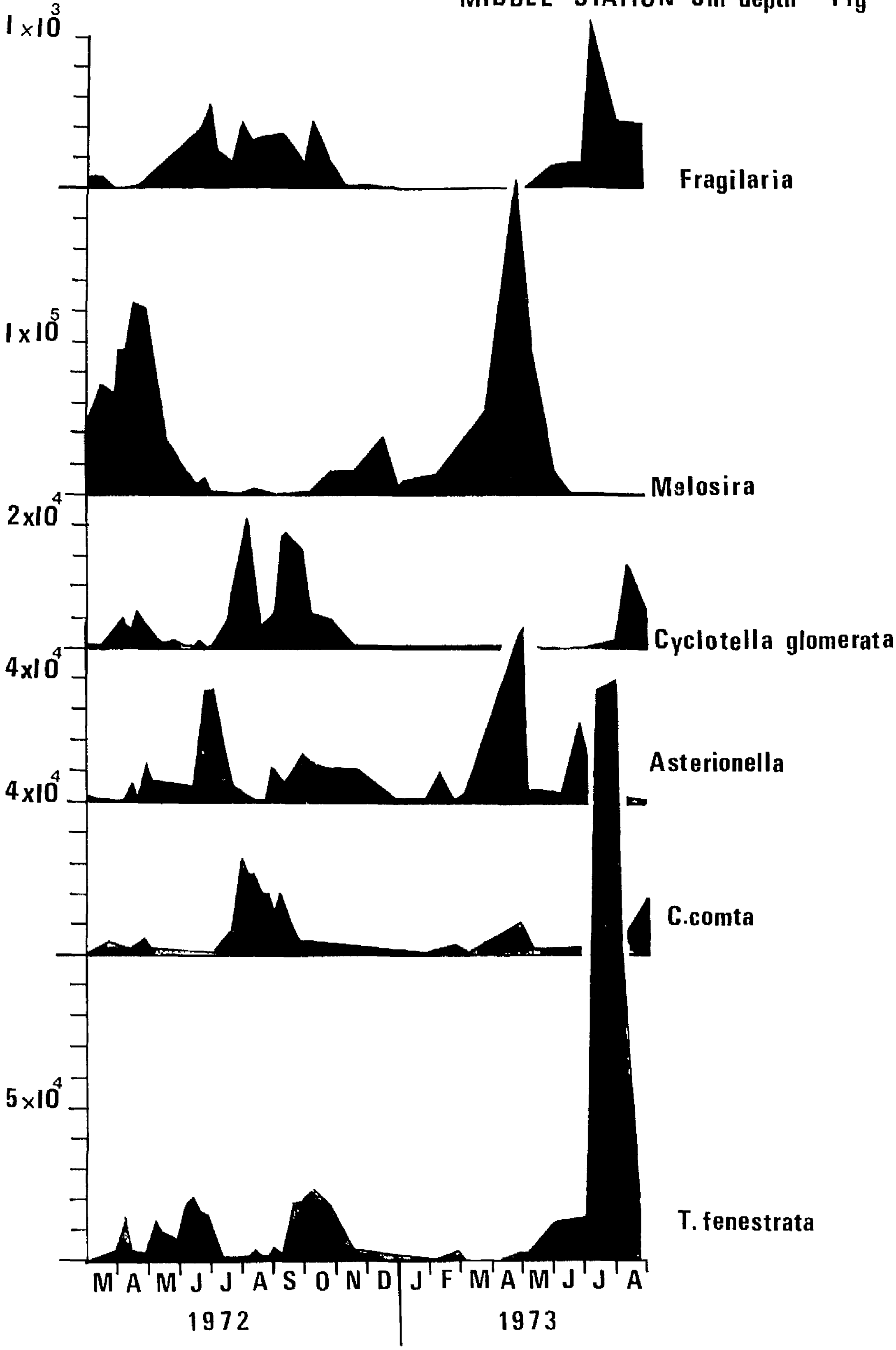
A. flos-aquae reached a surface maximum of 65990 cells/l on 8 August, 1973 while A. spiroides reached a peak of 1.96 million cells/l. The chlorophyll a values increased to 0.96 μg/l on this date. 23 August, 1973 saw the largest single peak (expressed as cells/l) recorded in Lake of Menteith when A. spiroides reached 3.24 million cells/l and chlorophyll a rose to its summer maximum of 1.96 μg/l. The Anabaena maximum at 3 m depth was only one-tenth of the surface numbers. The other phytoplankton which formed a peak was Asterionella reaching its second maximum of 169559 cells/l. On 20 September, 1973 A. spiroides had declined to 268,000 cells/l at the surface, a decrease of more than ten-fold from the previous sampling. The overall population total had declined to 558,000 units/l and chlorophyll a had fallen to 0.36 μg/l, although Fragilaria, Tabellaria, ~~Tabellaria~~ and Melosira were all on the increase. Asterionella decreased to 52632 cells/l at the surface while at 3 m depth the total number of Asterionella was higher than previous sampling 58824 cells/l.

(ii) Loch Rusky (Fig. 20, 40 a, b and 41 a, b. Appendix Table 22 and 27 a, b)

On 18 October, 1972 the population at the surface was dominated by

LOCH LOMOND

MIDDLE STATION 3m depth Fig 37 b

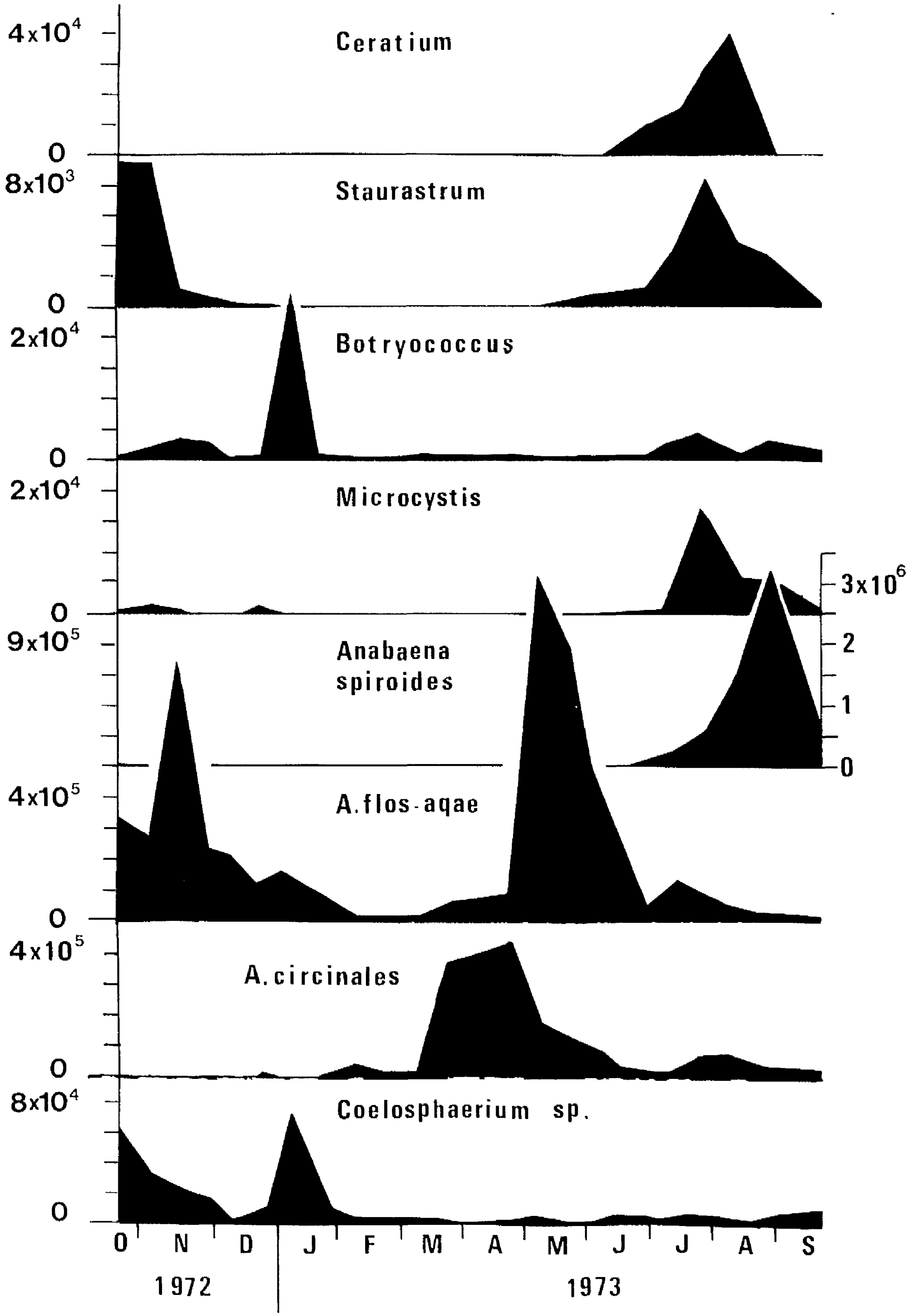


Anabaena flos-aquae (420141 cells/l), Coelosphaerium (6003 colonies/l) and Asterionella (80655 cells/l). Generally numbers were considerably reduced at 5 m depth, although *Asterionella* showed an increase. The total number of organisms found was 542000 units/l which gave a corresponding chlorophyll *a* reading of 0.18 μg/l. The total population declined to 185000 units/l on 29 November, 1972 while chlorophyll *a* fluctuated erratically reaching 0.14 μg/l. During this period small peaks of *Cyclotella*, *Fragilaria*, and *Tabellaria* occurred. Throughout the winter *Melosira* dominated the phytoplankton, never falling below 50000 cells/l. A peak of 212728 cells/l was observed on 13 December when the other phytoplankton were *Asterionella*, *Fragilaria*, *Tabellaria*, *Cyclotella* and *Coelospharium*, all present in small numbers. Chlorophyll *a* values declined along with the fall in total phytoplankton reaching 0.1 μg/l on 27 December and 0.09 g/l on 10 January, 1973. The lowest number of phytoplankton, 62000 units/l was found on 24 January when *Melosira* reached its minimum.

On 7 February, 1972 the total number of phytoplankton started to increase, reaching 150000 units/l with a chlorophyll *a* value of 0.0897 μg/l. A ten-fold increase in cell numbers was evident by 26 March when chlorophyll *a* levels reached 0.424 μg/l. On 20 April the spring pulse had almost reached its peak with 3.24 million units/l and chlorophyll *a* of 1.08 μg/l being recorded on this date. A maximum spring phytoplankton density of 3.32 million units/l and the highest spring chlorophyll value (1.53 μg/l) were recorded on 3 May, 1973. The first species to contribute to the spring outburst of phytoplankton was *Melosira*. This organism retained its dominant status throughout this period, reaching a peak of 2.43 million cells/l at the surface on 20 April. On 3 May, 1973 *Asterionella* succeeded *Melosira* as the dominant species attaining a maximum of 2.35 million cells/l. *Coelosphaerium*, *Anabaena*, *Bortyococcus* and *Staurastrum* all showed large rises on this date when chlorophyll *a* reached its maximum. On 17 May, 1973 the chlorophyll *a* levels declined slightly to 1.24 μg/l whereas the total population fell to 884000 units/l. However, *Anabaena* and *Staurastrum* displayed a further rise as did T. fenestrata which produced the final

LAKE OF MENTEITH

SURFACE Fig 38a



pulse of the spring outburst on this date (377200 cells/l).

Phytoplankton remained low throughout June 1973 and chlorophyll a values persisted around 0.20 μg/l. The first sign of a summer increase came on 11 July, 1973 when a total of 1.81 million units/l was recorded accompanied by a rise in chlorophyll a to 0.76 μg/l. From this time till the completion of sampling *Anabaena* was by far the most abundant representative of the phytoplankton. The first organisms to reach a peak during this period were *Mallomonas* (95892 cells/l), *Staurastrum* (17299 cells/l) and *Botryococcus* (11752 colonies/l) which all recorded their highest numbers on 26 July. Little change on the phytoplankton total or in the chlorophyll a levels was apparent on this date.

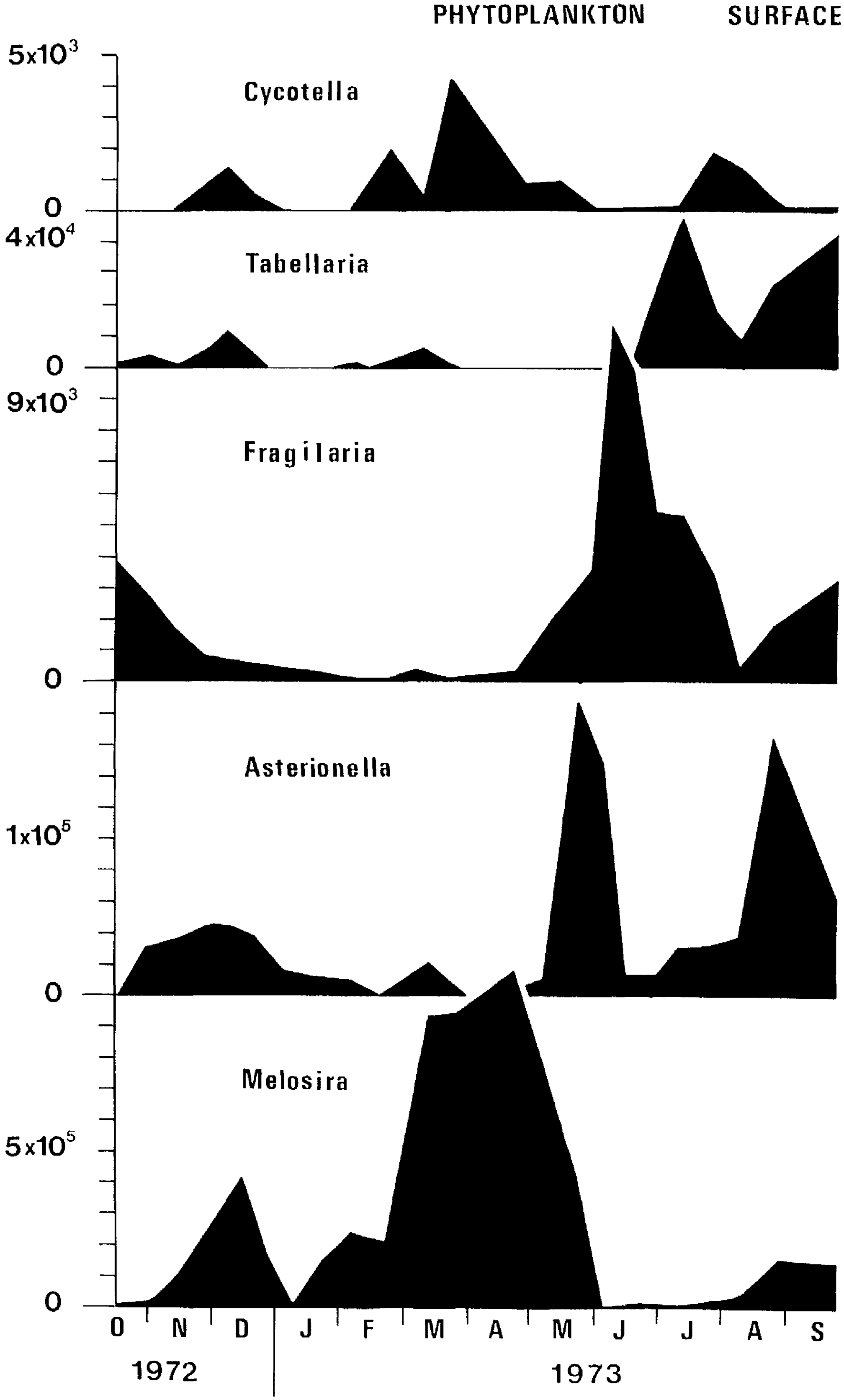
On 8 August, 1973 *Anabaena flos-aquae* showed a ten-fold increase to 15.84 million cells/l at the surface and 1.85 million cells at 5 m depth. On the following sampling date, 23 August, the highest single peak in any of the five lochs occurred when the number of *Anabaena* reached 16.5 million cells/l at the surface. The chlorophyll a levels also gave the highest reading ever recorded, 3.2 μg/l. During this period pulses of several algae ; were observed, with all except for *Tabellaria* reaching their annual maximum. The two species of diatoms which reached peaks were *Fragilaria* (11739 chains /l) and *Tabellaria* (296000 cells/l) although both organisms were less abundant at 5 m depth. *Botryococcus* and *Coelosphaerium* reached large peaks of 17987 and 14190 colonies/l respectively, while of the two dinoflagellates commonly recorded, *Ceratium* reached the largest peak (148800 cells/l) and *Peridinium* rose to only 16800 cells/l. All these plants were most dominant at the surface. On 20 September, 1973 when the sampling was completed the total number had fallen to 10.35 million units/l and chlorophyll a to 1.9 μg/l. This decrease was general among the phytoplankton present both at surface and at 5 m depth.

(iii) Loch Achray (Fig. 42 a, b and 43. Appendix Table 22 and 28 a, b)

At the commencement of sampling in Loch Achray on 18 October, 1972 the dominant phytoplankton at the surface were *Asterionella* (37608 cells/l), and *A. circinales* (24732 cells/l) which together constituted more than 80%

LAKE OF MENTEITH

Fig 38b

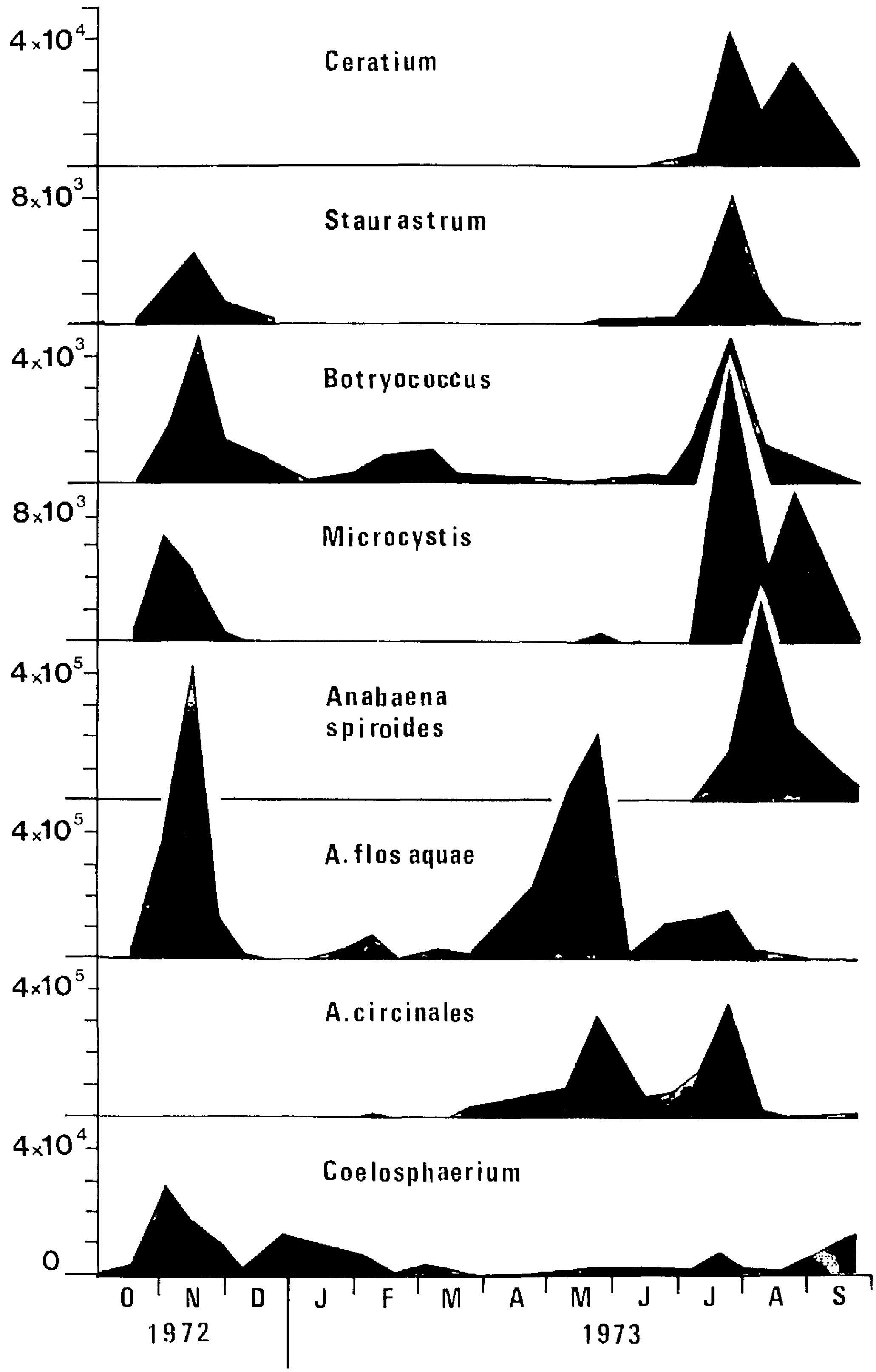


of the total population. At 5 m depth there was an exceedingly sparse population with a total of only 3000 units/l. By 1 November, 1972 the Anabaena had shown a considerable fall to 1728 cells/l at the surface while Kephyrion showed a small peak (5649 cells/l). The total population declined from 71000 units/l in October to 48000 units/l at the beginning of November, 1972 whereas chlorophyll a fell from 0.04 to 0.03 μg/l. 15 NOvember saw the appearance at the surface of Melosira which was co-dominant with Tabellaria fenestrata to make a total of 50000 cells/l with a chlorophyll a reading of 0.02 μg/l. The total (mainly Melosira) fell to around 10000 units/l on 29 November and persisted at this level until January 24th; clorophyll a fluctuated between 0.03 and 0.02 μg/l.

From 7 February Melosira and T. fenestrata started an irregular increase rising to 26544 and 1704 cells/l respectively on 26 March. This was followed at the beginning of April by increases in Asterionella, T. flocculosa, and Cyclotella comta. All these organisms reached a spring maximum on 17 May except for T. flocculosa which continued till 1 June. During this period chlorophyll a increased from 0.04 μg/l on 20 April when the total phytoplankton was 61536 units/l to 0.26 μg/l on 17 May when a maximum of 962 948 units/l was observed. Melosira was the predominant species with about 66% of the total. Kephyrion, which made a sudden appearance, was second in abundance constituting about 10% of the total. All species showed greater abundance at the surface than at 5 m depth. On 1 June, 1973 a considerable decline was in evidence at the surface resulting in a very small population dominated by T. flocculosa and Melosira. The phytoplankton total was 14000 units/l and the chlorophyll a value was 0.06 μg/l.

On 14 June, 1973 little change in total phytoplankton or chlorophyll a was apparent at the surface; however, the species composition had undergone a change with Anabaena now being the predominant organism. The situation at 5 m depth was quite different, the population being dominated by T. fenestrata whereas Anabaena was not in evidence. The summer increase of phytoplankton was first apparent on 23 June when the total had risen to 88000 units/l. The dominating organisms were Anabaena and Kephyrion which

LAKE OF MENTEITH 3 METRES DEPTH Fig 39a



produced a peak at the surface on this date. The total count was 1.1 million cells/l of which 70% was <u>Anabaena</u> and about 30% <u>Kephyrion</u>. The chlorophyll <u>a</u> reading was 0.31 μg/l.

During August, 1973 the total numbers of phytoplankton continued to decline, falling by half on 8 August and still further to 179000 units/l on 23 August; chlorophyll declined to 0.175 μg/l at the end of August. <u>Mallomonas</u> and <u>Staurastrum</u> both produced pulses in August of 44118 and 11783 cells/l respectively and both were more abundant in the surface waters. In September 1973 a further decline in most species was in evidence with the exception of <u>Cyclotella glomerata</u> and <u>Fragilaria</u> which both produced sudden peaks of 5155 cells/l and 3572 colonies/l respectively. The phytoplankton total had fallen to 126000 units/l while chlorophyll <u>a</u> had decreased by half to 0.08 μg/l.

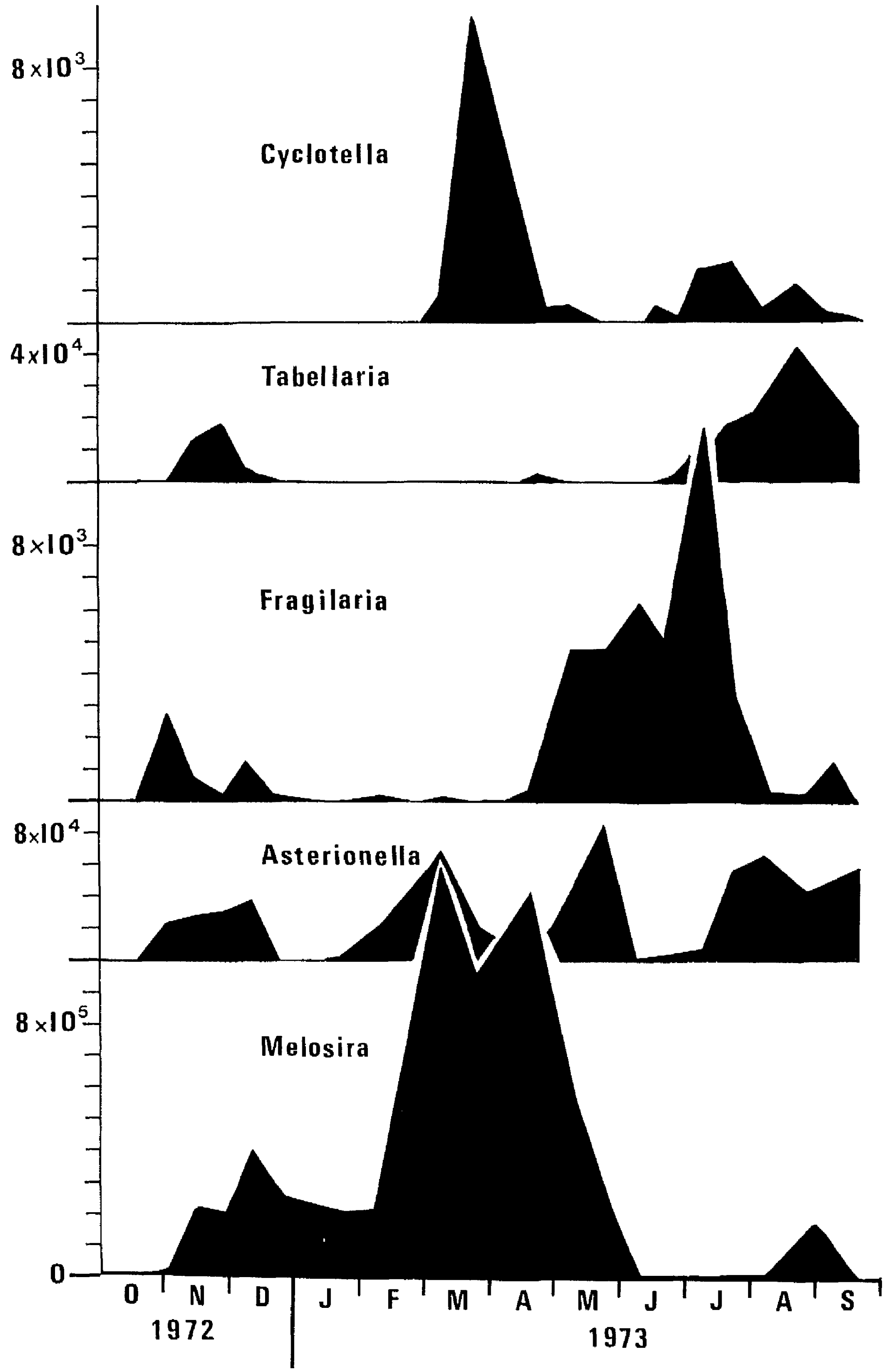
(iv) <u>Loch Ard</u> (Fig. 44, 45, and 46 a, b. Appendix Table 22 and 29 a, b)

At the commencement of sampling in Loch Ard in October, 1972 the population was dominated by <u>Asterionella</u> and <u>Cyclotella comta</u> which together formed 80% of the total bulk of phytoplankton (54000 units/l). At 5 m depth the numbers of <u>Asterionella</u> were reduced while <u>Cyclotella</u> showed greater abundance. A pulse of <u>Dinobryon</u> occurred at the beginning of November when 3162 colonies/l were recorded at the surface. However, the overall numbers of phytoplankton had declined by this time to 37000 units/l while chlorophyll <u>a</u> remained almost the same (0.035 μg/l.). On 15 November 1972 <u>T. fenestrata</u> showed an increase reaching a maximum on 29 November when it was co-dominant with <u>Asterionella</u> and <u>Cyclotella</u>. A small pulse of <u>T. flocculosa</u> was also observed on this date. These phytoplankton, together made up 90% of the total 41000 units/l which gave a chlorophyll <u>a</u> reading of 0.025 μg/l.

During the next two months the phytoplankton population was sparse, generally lying between 20 to30000 units/l with chlorophyll <u>a</u> values of 0.02 to 0.03 μg/l. The dominant species at this time was <u>Melosira</u> which reached a peak on 27 December, 1972. The first sign of the spring increase occurred on 8 March, 1973 when the total population doubled to reach 50000

LAKE OF MENTEITH

3 metres depth Fig 39 b



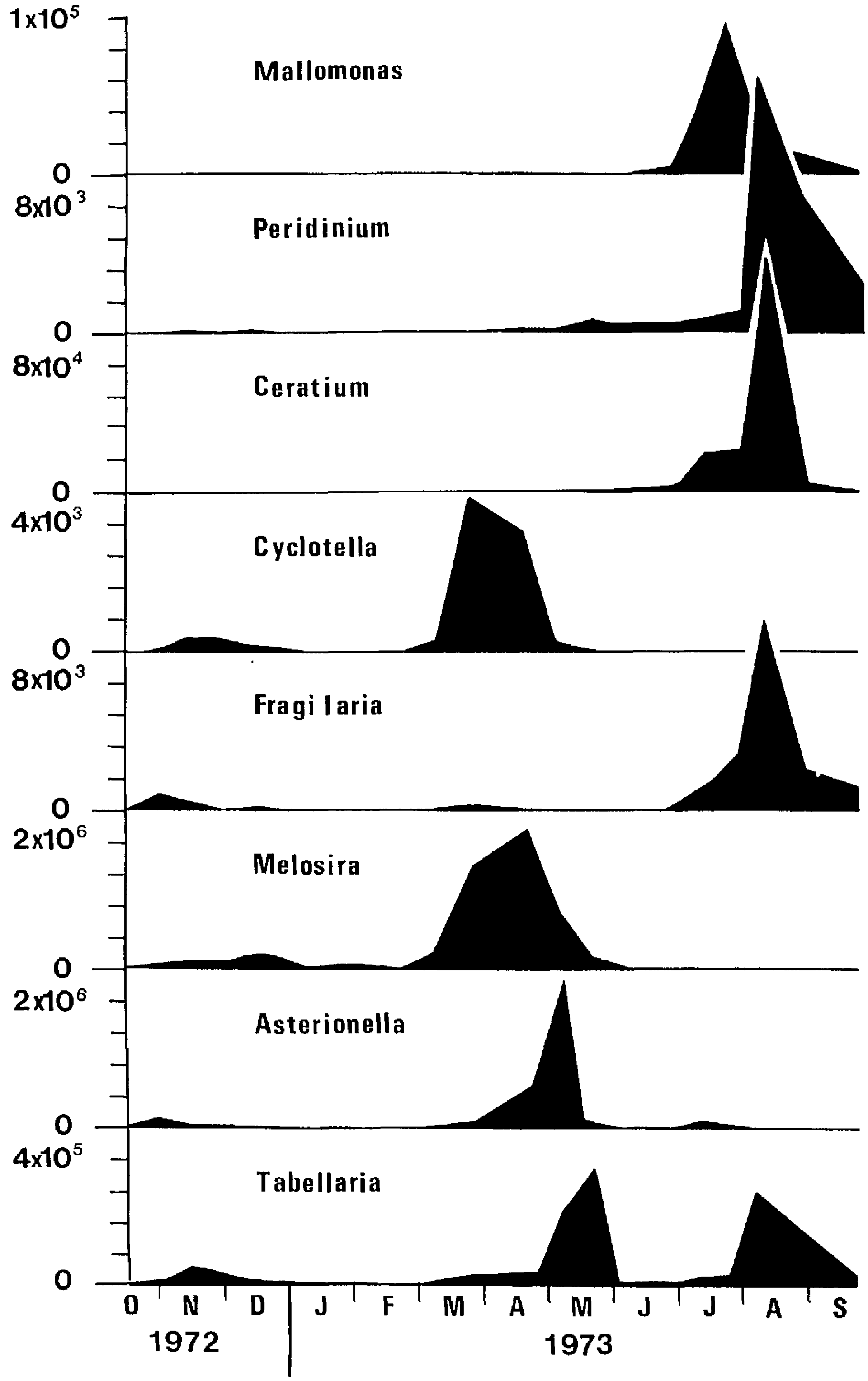
units/l at the surface. This rise was mainly due to Melosira with smaller numbers of Asterionella and T. fenestrata. Melosira reached its highest number on 26 March, 1973 while T. fenestrata did not display a maximum till 3 May. Both Melosira and T. fenestrata exhibited more than twice their surface numbers at 5 m depth. The total population reached an early spring maximum of 103000 units/l on 20 April with a corresponding chlorophyll a reading of 0.18 µg/l.

By 3 May, 1973 Anabaena was on the increase at the surface and depth. 17 May saw the first peak of Anabaena with 209000 cells/l at the surface and none at depth; this was accompanied by a small peak of Coelosphaerium (1141 colonies/l). The total population on this date was 267000 units/l with a chlorophyll a value of 0.27 µg/l. Numbers declined to 85000 on 1 June and still further on 14 June when the chlorophyll a values was 0.09 µg/l. A second, larger peak of Melosira occurred on this date constituting about 66% of the total. On 11 July, 1973 the total population reached a summer maximum of 575000 units/l of which more than 90% was Anabaena. Chlorophyll levels reached an annual maximum of 0.35 µg/l on this date. A pulse of Peridinium was also observed, reaching its greatest abundance at 5 m depth.

26 July, 1973 saw an overall halving in numbers and a reduction in chlorophyll a to 0.15 µg/l. Anabaena was considerably reduced at the surface while an increase was apparent at 5 m depth. Peaks of Dinobryon and Fragilaria were observed at the surface. On 8 August an increase in total number occurred, mainly due to T. fenestrata which reached 176000 cells/l. at 5 m depth and less at the surface. The pulse of Coelosphaerium and Ceratium reached their greatest magnitude at 5 m depth while maximum number of Staurastrum occurred at the surface. Chlorophyll a levels rose to 0.2 µg/l. Mallomonas reached its peak on 23 August when most other organisms were on the decline; Anabaena still greatly predominated in the population and chlorophyll a remained relatively high at 0.16 µg/l. At the completion of sampling on 20 September the only species which was increasing was Cyclotella comta; nevertheless the population was still dominated by

LOCH RUSKY

PHYTOPLANKTON SURFACE Fig 40a



Anabaena and T. fenestrata and chlorophyll a showed little change at 0.15 µg/l.

(d) Discussion on the seasonal occurrences of the common species of phytoplankton in Loch Lomond and the other four Lochs

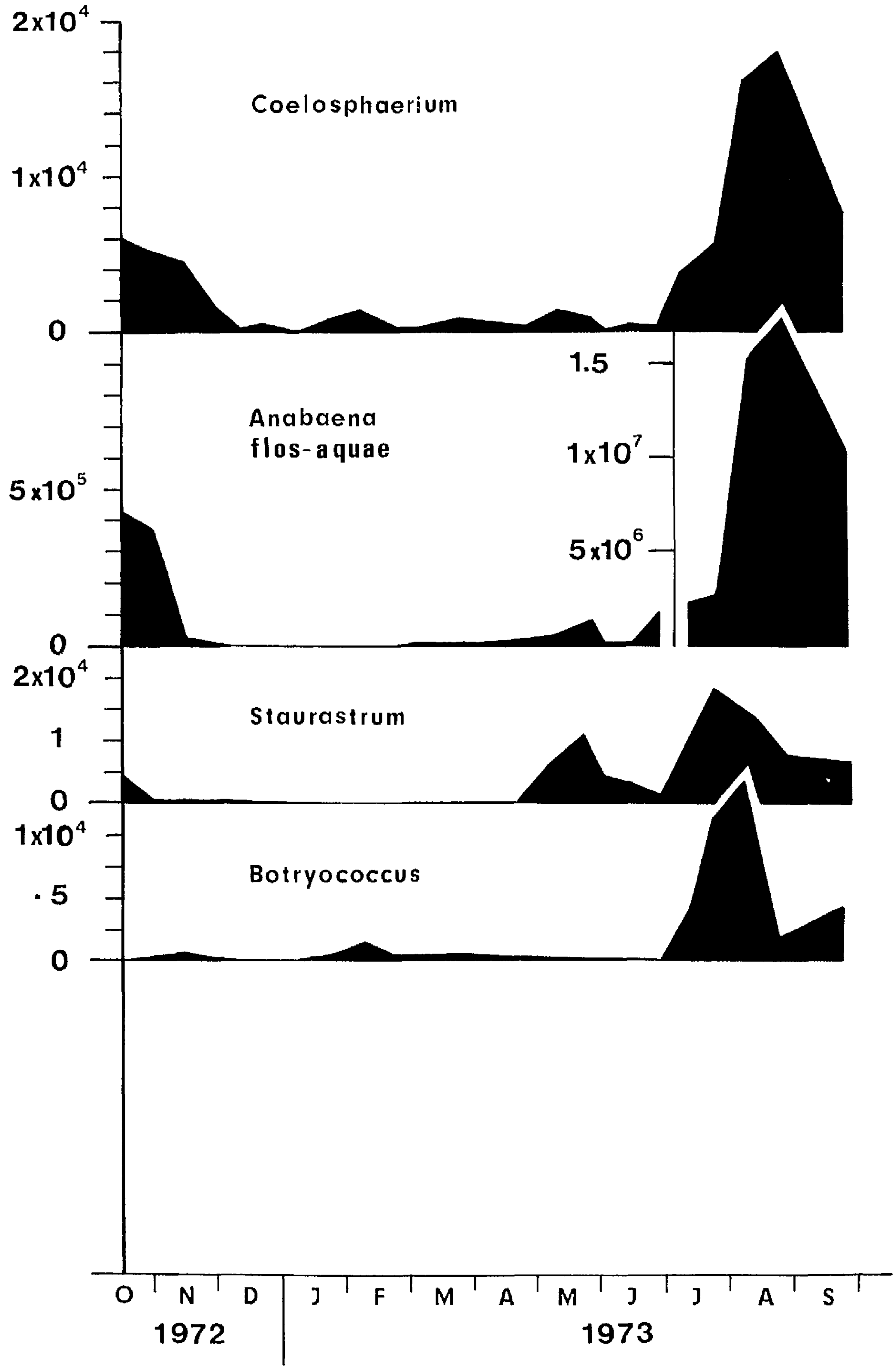
(i) Asterionella formosa Hassal

Asterionella was found in all lochs examined and in each produced at least two clear pulses during the year. In 1972 two peaks occurred at the South and Middle Stations of Loch Lomond between June and July and from September to the end of October. However, at the North Station three pulses were evident from April to mid-May, thorughout July and August and from the end of September to mid-November. In 1973 (till September) two pulses were recorded at all stations in Loch Lomond. These were from March to April and June to July at South and Middle while at the North Station the spring peak occurred later, April to May, and the summer peak from June to July (only obvious at depth). In Loch Ard and Loch Achray an October pulse of Asterionella coinciding with that in Loch Lomond was observed, while in Lake of Menteith and Loch Rusky a relatively small peak was noted slightly later. In Loch Ard the spring increase occurred from March to May. In Loch Rusky an increase occurred from April to May while in Lake of Menteith and Loch Achray the increase was later from May to June. A pulse in February - March was clear at 3 m depth in Lake of Menteith only. A clear peak of Asterionella was observed in Lake of Menteith from July to September, 1973. Loch Rusky showed a relatively small pulse in July.

Generally the magnitude of the peaks was fairly similar in Loch Lomond reaching 30 to 40,000 cells/l at the North Station, 40 to 50,000 cells/l at the Middle Station. At the South Station numbers lay between 30 to 60,000 cells/l with the exception of the autumn peak in 1972 which reached 90,000 cells/l at the South Station. The peaks of Asterionella in Loch Achray and Loch Ard lay between 20 to 50,000 cells/l whereas in Lake of Menteith numbers exceeded 150,000 cells/l. The maximum recorded abundance of Asterionella occurred in Loch Rusky where a peak of more than 2 million cells/l was recorded.

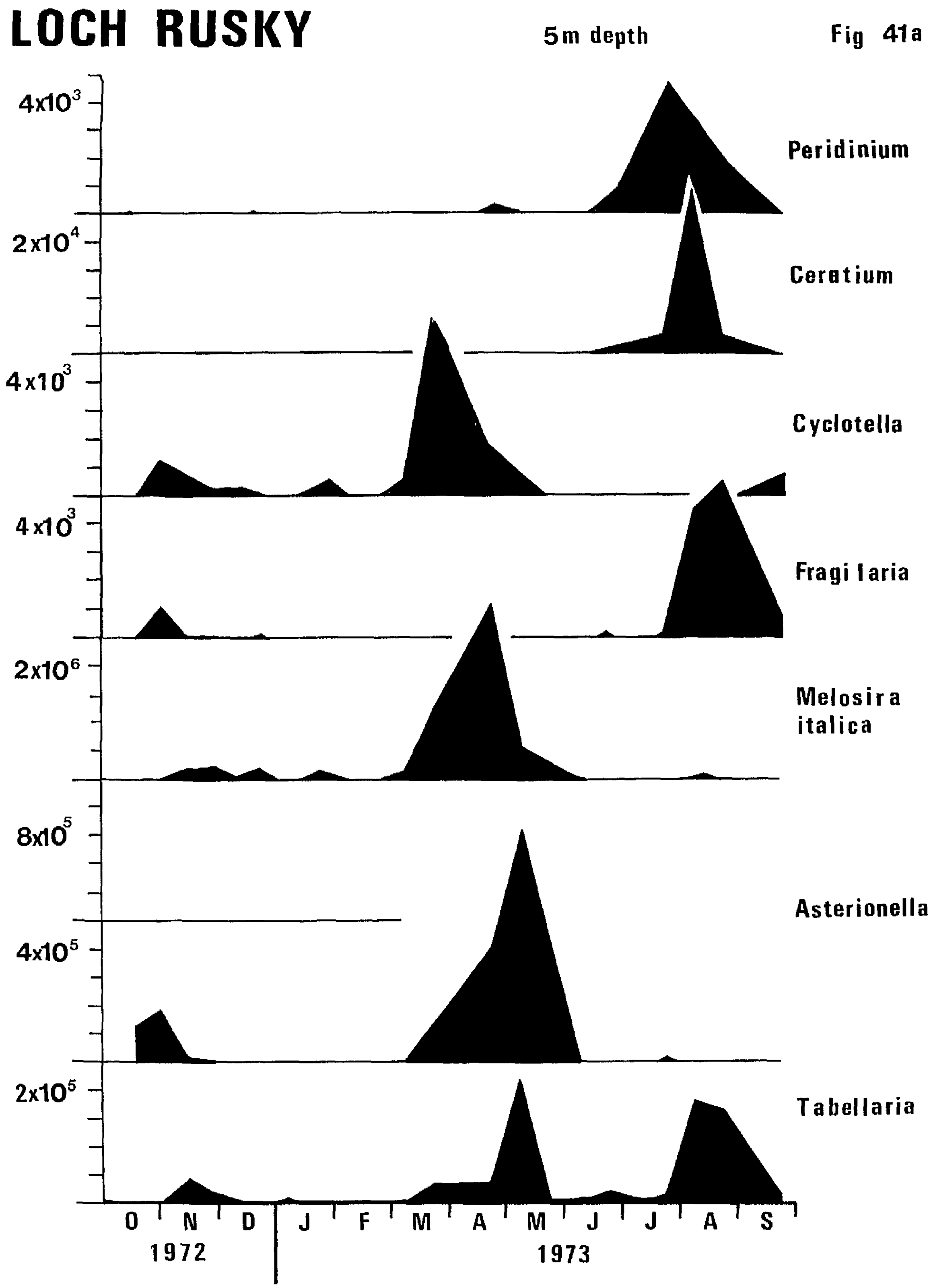
LOCH RUSKY

SURFACE Fig 40b



The domination of the population in Loch Rusky by Asterionella reached a maximum of 2.35 million cells/l at the surface on 3 May. During this period of domination the silicate level fell from 18 to 2 μg. at. Si/l phosphate from 0.3 to 0.1 μg at P/l and nitrate from 10 to 3 μg at. NO_3/l. HOwever, nitrite showed a rise from 0.03 to 0.08 μg at. NO_2/l. As in the other lochs the water during the spring increase was isothermal and the temperature (here) lay between 8 to 10°C. The pulse of Asterionella in Lake of Menteith (187000 cells/l) on 17 May coincided with a declining population of Melosira and Anabaena and occurred at a temperature of 8 to 10°C, whereas the second peak on 23 August (170000 cells/l) occurred when the temperature was between 18 to 20°C. The first pulse was accompanied by a similar decline in nutrient to Loch Rusky while the latter coincided with a large increase in silicate and phosphate towards the end of July. The small May peak seen in Loch Achray (26800 cells/l) accompanied a large pulse of Melosira with a corresponding decrease in nutrient. The temperature on this date was around 10°C with a distinct stratification of the water column. A second larger pulse in this loch occurred on 18 October, 1972 (38000 cells/l) when similar water conditions prevailed; however, silicate was on the increase and other nutrients were declining. The main pulse of Asterionella in Loch Ard reached 51000 cells/l on 20 April, 1973; the increase started when the water temperature was 6°C. A smaller increase in October 1972 occurred when the water column was weakly stratified and the temperature was around 11.0°C.

The spring increase of Asterionella in Loch Lomond occurred in all cases when Melosira was dominating the population. The spring Maximum in 1973 took place on 15 March in the South Station (28550 cells/l) and on 27 April in the Middle Station (51647 cells/l) and North Station (29800 cells/l). Respective water temperatures at the South, Middle and North Stations were 5, 7 and 7.0°C when the water mass was completely mixed. The summer pulse in 1973 was clear at all stations at 3 m depth and coincided with large numbers of Anabaena and Tabellaria fenestrata. At the south station the maximum number (41391 cells/l) occurred on 21



LOCH RUSKY
5m depth
Fig 41a
4x10³
Peridinium
2x10⁴
Ceratium
4x10³
Cyclotella
4x10³
Fragilaria
2x10⁶
Melosira italica
8x10⁵
4x10⁵
Asterionella
2x10⁵
Tabellaria
O
N
D
J
F
M
A
M
J
J
A
S
1972
1973

June simultaneously with the peak at the Middle Station (40740). Nutrient at both stations showed a clear decline. At the North Station the pulse (10000 cells/l) occurred when T. fenestrata predominated; here the silicate fell from 11 to 7 μg at. Si/l, Phosphate from 0.6 to 0.2 μg at. P/l and nitrate from 10 to 7 μg at. N/l. Temperature at all stations was around 13.0°C and only the South Station was not clearly stratified. The summer pulse in 1972 occurred roughly at the same time and was similar in size (to 1973) at the South and Middle Stations but larger (38000 cells/l) at the North Station.

The autumn pulse (in 1972) occurred after the September increase in phosphate (to around 0.12 μg at. P/l at all stations). The peak of this increase was recorded on 11 October throughout the Loch but the magnitude of the outburst decreased passing northwards. The highest number were recorded at the South Station (91000 cells/l) when the water was isothermal (11°C). Lower numbers were found at Middle (42000 cells/l) and North (13000 cells/l) both of which were stratified with surface water around 12°C. The only station which showed a clear decrease in silicate and nitrate was the South Station wile all stations displayed a decline in phosphate levels.

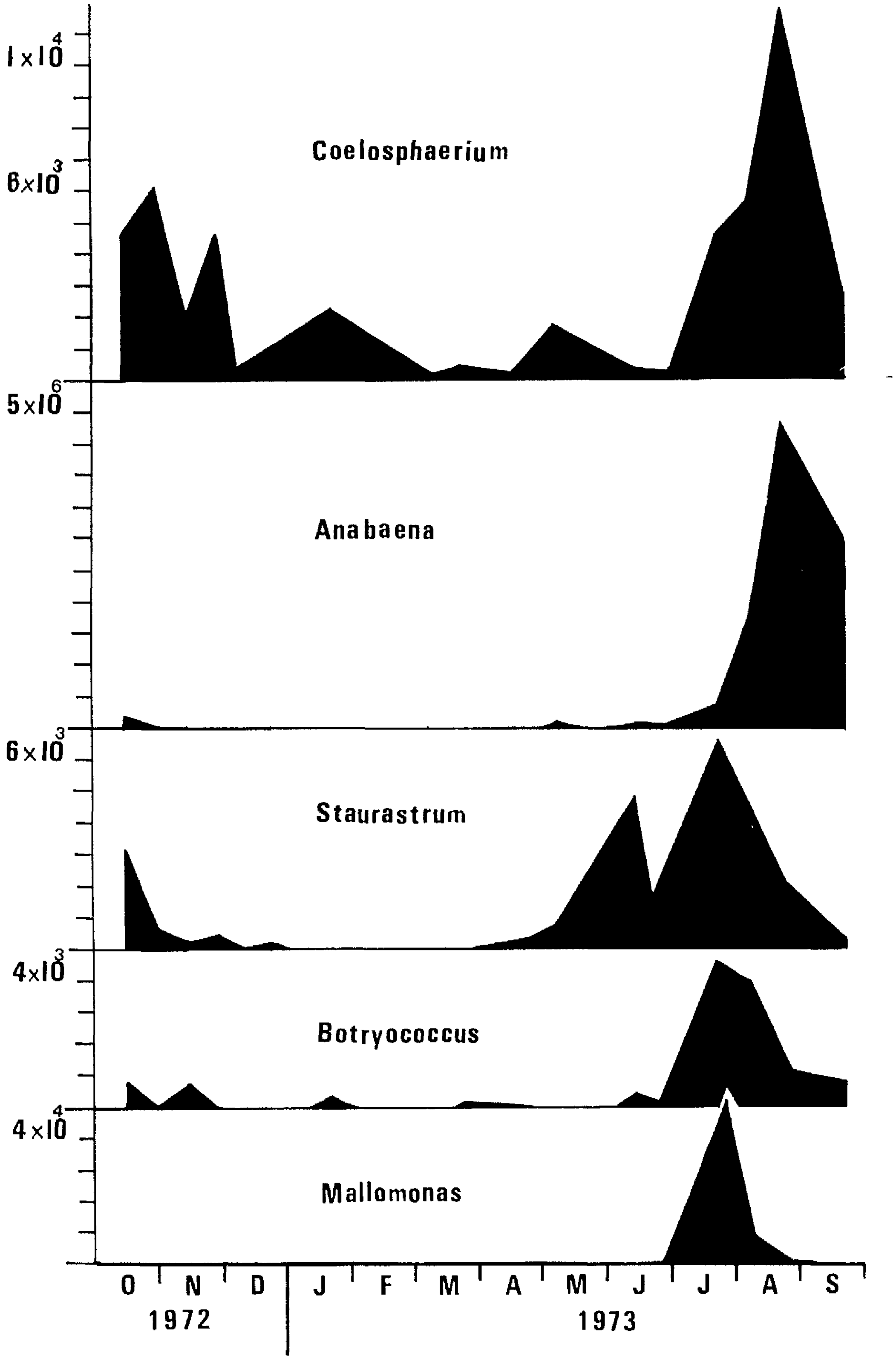
(ii) Tabellaria fenestrata var. Asterionelloides Grun.

T. fenestrata was found in all the Lochs examined, with at least two clear pulses in each body of water during the year. Generally this species accompanied pulses of Asterionella although the initiation of the Tabellaria increase and the timing of the maximum were usually later by one or two weeks. Loch Rusky, Lake of Menteith, Loch Achray and Loch Ard follow this pattern although in the latter loch a third pulse of Tabellaria occurred during July - September, in the complete absence of Asterionella. Throughout Loch Lomond in 1972 two clear pulses occurred (generally preceding the Asterionella outburst at South Station), one in May to June and the other during September to November (in the North Station the first peak occurred during April). These peaks were generally small (less than 40000 cells/l) except for the autumn increase (at the South Station) which reached 94000 cells/l on 27 September. However, in 1973 (during the period

LOCH RUSKY

5 m depth

Fig 41b

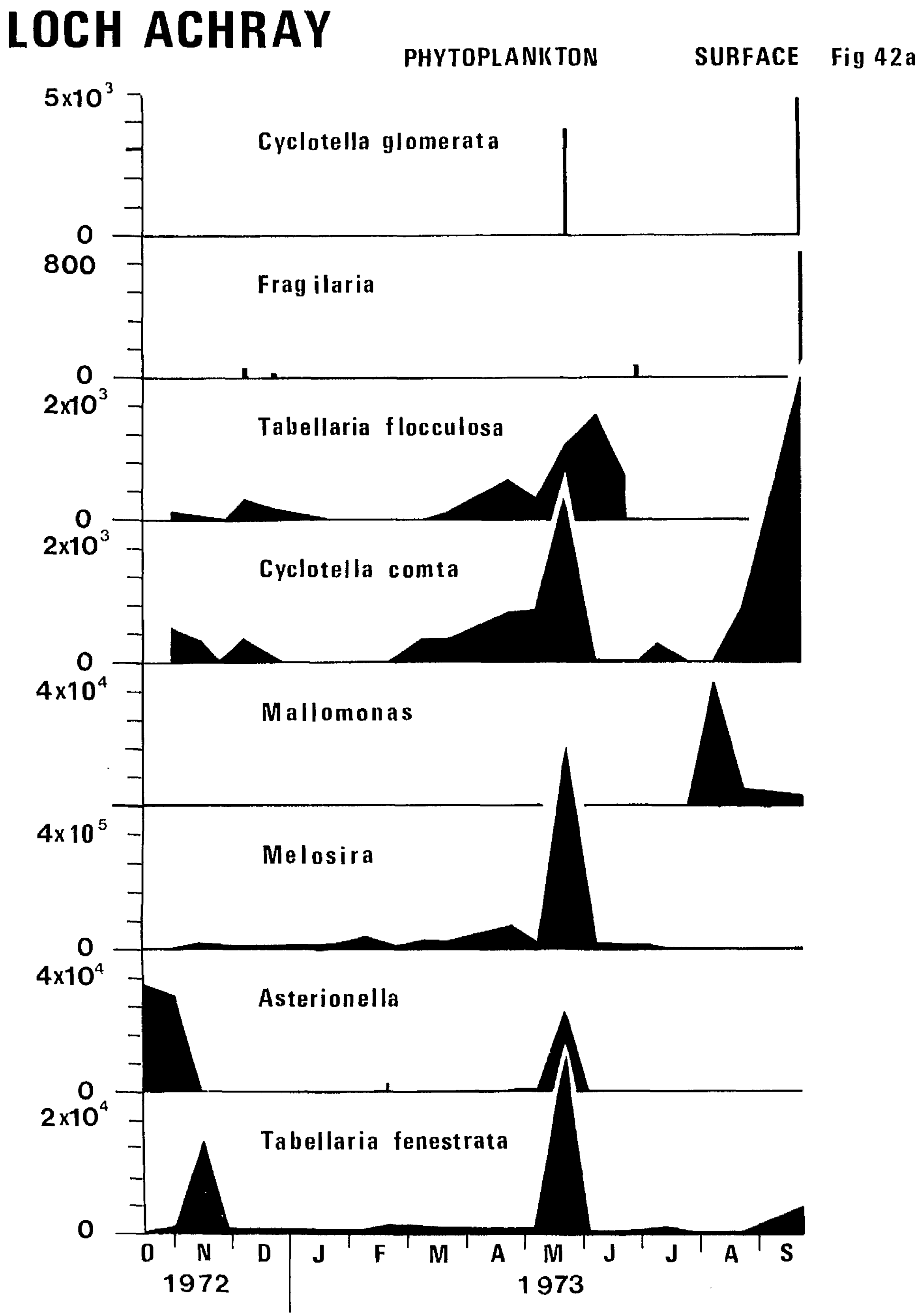


of sampling) a single large pulse was observed during the period June to August. On 6 July at the South Station the pulse reached 174000 cells/l while at the Middle Station 166000 cells/l was observed at the same date. The largest single peak recorded at the North Station (195000 cells/l) was found on 24 July (during the continuous 48 hours sampling experiment 17 to 19 July Tabellaria attained its greatest recorded density in Loch Lomond, when 612000 cells/l at 01.00 hrs on 19th July). During this period when Tabellaria completely dominated the population in Loch Lomond a distinct fall in nutrients (phosphate, silicate and nitrate) was evident.

The four other lochs all showed a small pulse of Tabellaria from November to December, 1972 (considerably later than the peak in Loch Lomond) when isothermal conditions prevailed and the water was at its coldest. The largest winter peak (37,000 cells/l) occurred in Loch Rusky on 29 November where the water temperature was 3.4°C, a pulse of 16500 was found in Lake of Menteith on 15 November, at 5.6°C while similar peaks occurred in Lochs Achray and Ard at 6-7°C. An overall rise in nutrient levels was occurring around this time in all the lochs examined.

The earliest rise in Tabellaria in 1973 occurred (during March) in Loch Ard reaching a peak of 28000 cells/l on 3 May. Respective maxima of 33000 cells/l and 377000 cells/l were recorded on 17 May in Loch Achray and Loch Rusky, the latter being the greatest recorded abundance of Tabellaria in any of the four lochs. The pulse of this species in Lake of Menteith took place between June and July reaching a maximum of 47000 cells/l on 11 July (two months later than the Asterionella maximum). The highest number of of Tabellaria was found in Loch Ard and Loch Achray when the stratification of the water column was first apparent and the temperature was around 10°C. In Loch Rusky and Lake of Menteith the water mass was unstratified when the pulse occurred although the temperature was much higher (19°C) in Lake of Menteith than in Loch Rusky (10°C). The silicate level in Loch Rusky during this pulse declined from 2.1 to 0.4 µg at. Si/l.

A further pulse occurred in the four lochs during August and September 1973 when all bodies of water were at their warmest and all except for Lake



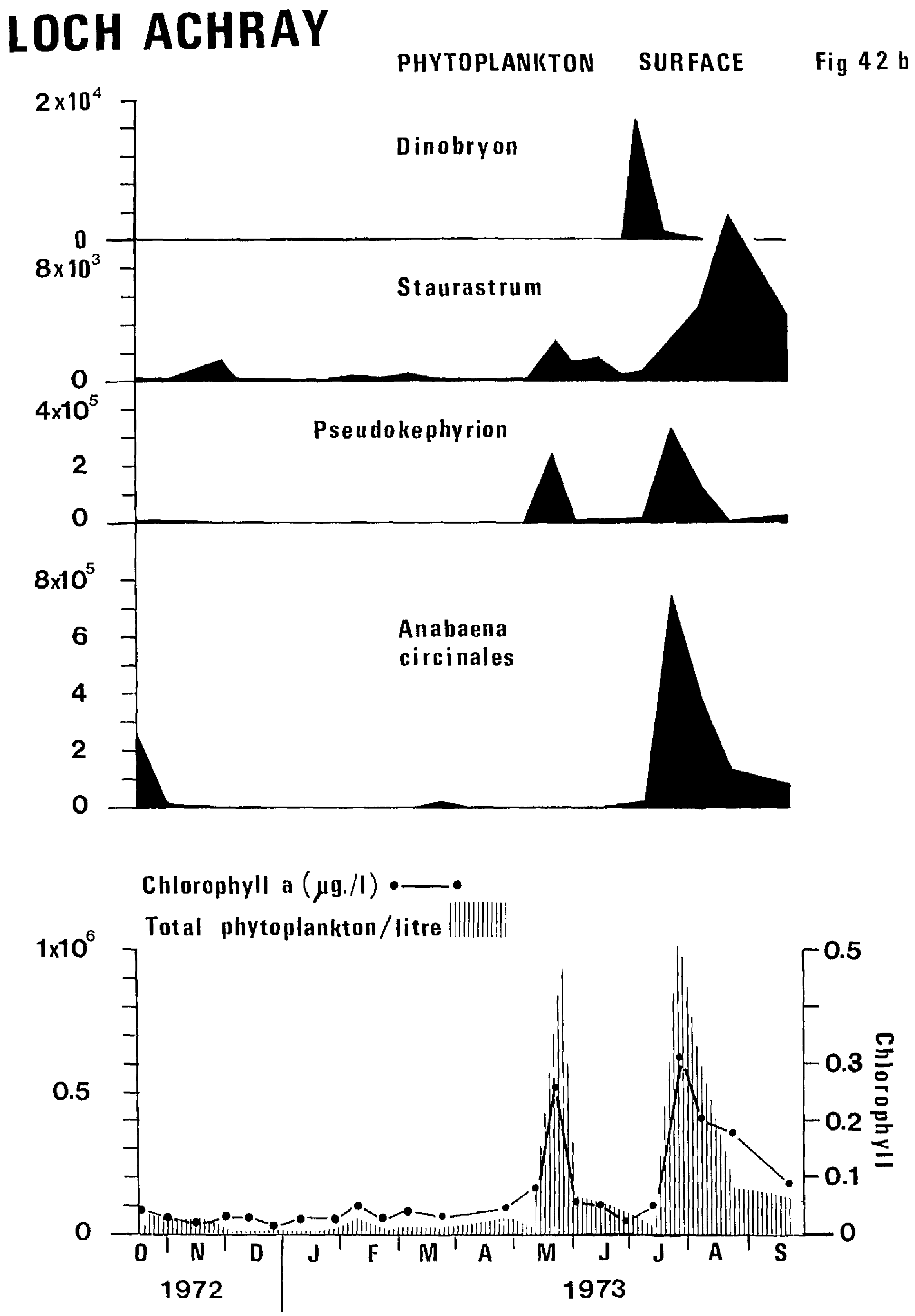
LOCH ACHRAY
PHYTOPLANKTON
SURFACE
Fig 42a
5x10³
0
Cyclotella glomerata
800
0
Frag ilaria
2x10³
0
Tabellaria flocculosa
2x10³
0
Cyclotella comta
4x10⁴
Mallomonas
4x10⁵
0
Melosira
4x10⁴
0
Asterionella
2x10⁴
0
Tabellaria fenestrata
O
N
D
J
F
M
A
M
J
J
A
S
1972
1973

of Menteith were still stratified. This peak was of similar magnitude to the summer pulse in the same loch with the exception of Loch Achray where it was much smaller. Silicate was on the increase in Lake of Menteith and Loch Rusky during this period while in the other two lochs levels remained fairly constant.

(iii) Tabellaria flocculosa (Roth) Kütz.

This species was commonly found in Loch Lomond, Loch Ard and Loch Achray, but was only occasionally observed in Loch Rusky and was not recorded from Lake of Menteith. The highest numbers of T. flocculosa were found at the North Station of Loch Lomond, which was characterised by a single pulse in the spring. This occurred during March to April 1972 and was the earliest phytoplankton pulse of the year whereas in 1973 it coincided with the spring increase of Melosira from April to May. At the Middle and South Stations of Loch Lomond only one pulse was observed throughout the period of sampling; this coincided with the outburst at the North Station in Spring 1972 but the numbers were less. Loch Ard displayed two pulses in 1973, one from May to June and the other from August to September (these were clear at 5 m depth). Loch Achray showed a slow increase from March to May 1973 when the peak was observed and another minor pulse in December 1972 at the surface.

The maximum number of T. flocculosa in Loch Lomond (11000 colonies/l) was found on 2 March, 1972 at the surface at the North Station when the water column was isothermal and the temperature was 5.0°C. The maximum numbers recorded at the Middle Station was 5545 colonies/l while at the South Station 4701 colonies/l were recorded (both on 2 March, 1972). However in 1973 3725 colonies/l were found on 26 April at the North Station only when the water mass was stratified and the temperature of the surface water was 8.0°C. The highest number of T. flocculosa in Loch Ard (5545 colonies/l) was found on 1 June while a second peak occurred on 8 August (2300 colonies/l) at 3 m depth only. In both cases the water column was stratified and the temperature of surface water was 11°C during the first pulse and 15.5°C during the second. In Loch Achray the maximum (1800



LOCH ACHRAY
PHYTOPLANKTON SURFACE
Fig 42 b
2x10^4
0
Dinobryon
8x10^3
0
Staurastrum
4x10^5
2
0
Pseudokephyrion
8x10^5
6
4
2
0
Anabaena circinales
Chlorophyll a (µg./l)
Total phytoplankton/litre
1x10^6
0.5
0
0.5
0.3
0.2
0.1
0
Chlorophyll
O
N
D
J
F
M
A
M
J
J
A
S
1972
1973

colonies/l) was found on the 1 June. By this time the loch was stratified with a surface temperature of about 11°C. The other peak (357 colonies/l) was much smaller and occured on 13 December 1972 when the water was cold (5°C and isothermal).

(iv) Cyclotella comta (Ehrenb.) Kütz.

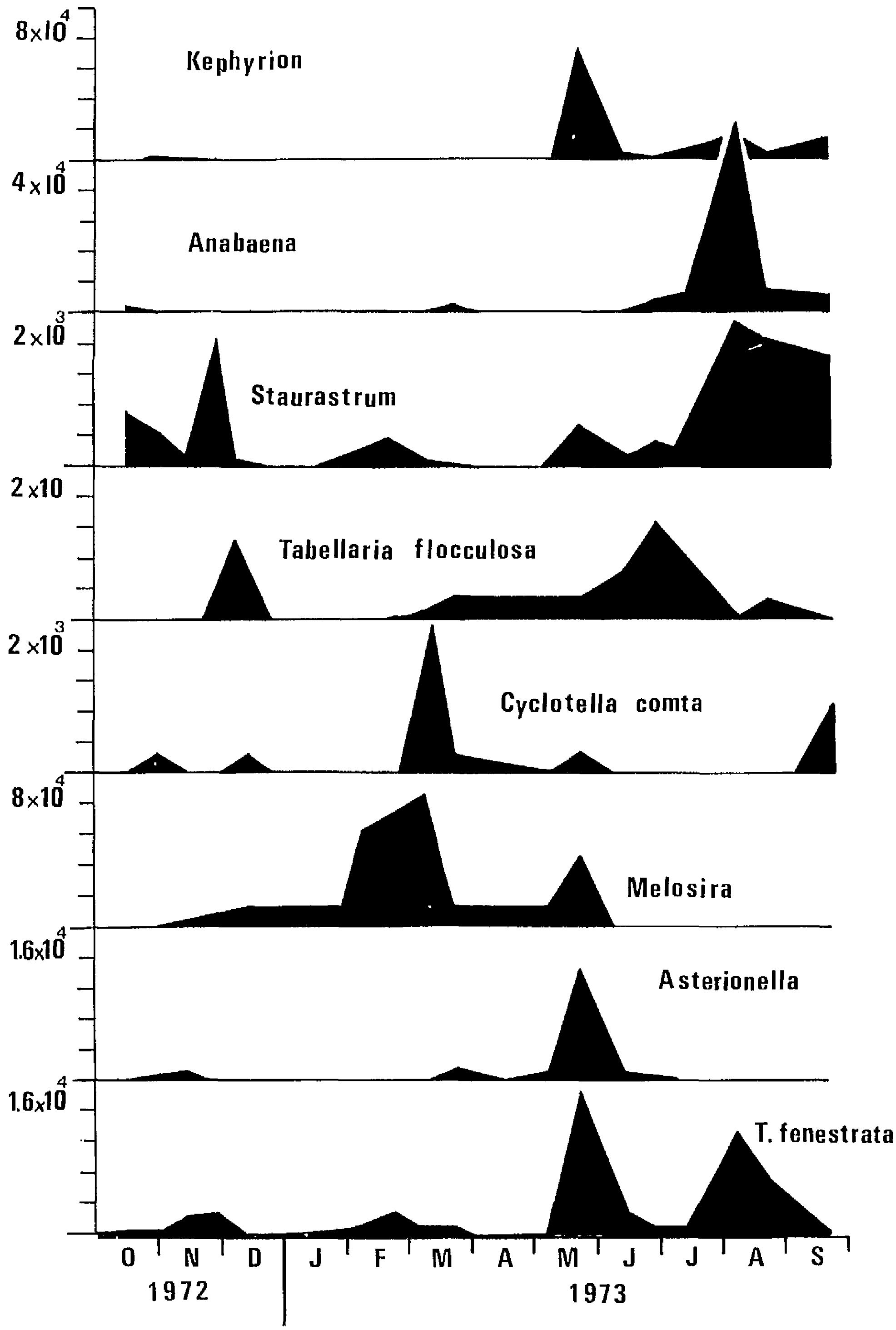
Cyclotella comta was found in all the lochs examined with the largest numbers being found in Loch Lomond and Loch Ard. Two pulses were evident thorughout Loch Lomond in both 1972 and 1973. A small peak occurred from March to April at the South Station (in both years) while at the Middle and North Stations the spring peak occurred slightly later. This pulse invariably coincided with the spring outburst of Melosira and was generally accompanied by a pulse of C. glomerata. The late summer increase started towards the end of July throughout both Loch Lomond and lasted till September. The accompanying phytoplankton was C. glomerata in all cases. In Loch Ard only a single peak was evident, beginning in September and continuing to November. Loch Achray displayed two pulses, one from March to May 1973 (with a peak in May) and a larger pulse from August to September. In Lake of Menteith and Loch Rusky numbers of C. comta were generally low with the largest pulse occurring from March to May and a small one during November and December. A further pulse was observed in Lake of Menteith from July to August. Thus Loch Ard was the only body of water in which a spring peak of C. comta was absent.

Generally, in Loch Lomond, the magnitude of the summer peak of C. comta was greater than the spring pulse. In 1972 C. comta reached its greatest abundance on 1 August throughout the loch with 3500 cells/l at both the Middle and South Stations. However, the peak at the North Station was considerably less, at 10,000 cells/l. A similar picture was evident in 1973 when the recorded maximum occurred at all stations on 17 August with the largest number of C. comta being recorded at the South Station (25000 cells/l) less at the Middle and least at the North Station. All stations were warmest at this time (15 - 17°C) and were clearly stratified. Nutrient levels were generally less than half their maximum winter

LOCH ACHRAY

5 m depth

Fig 43



values. The spring peak in 1972 occurred during the middle of April throughout Loch Lomond with 25000 cells/l at South Station and 5000 cells/l at the Midd-e and North Stations, while in 1973 the spring peaks ranged from 13000 to 17000 cells/l with the largest number at the North Station. The pulse of C. comta was evident at the South Station (23 March) while in North and Middle it was not evident till 24 May. Temperature generally lay between 7 to 10°C except for the South Station in 1973 where the water was at 5°C.

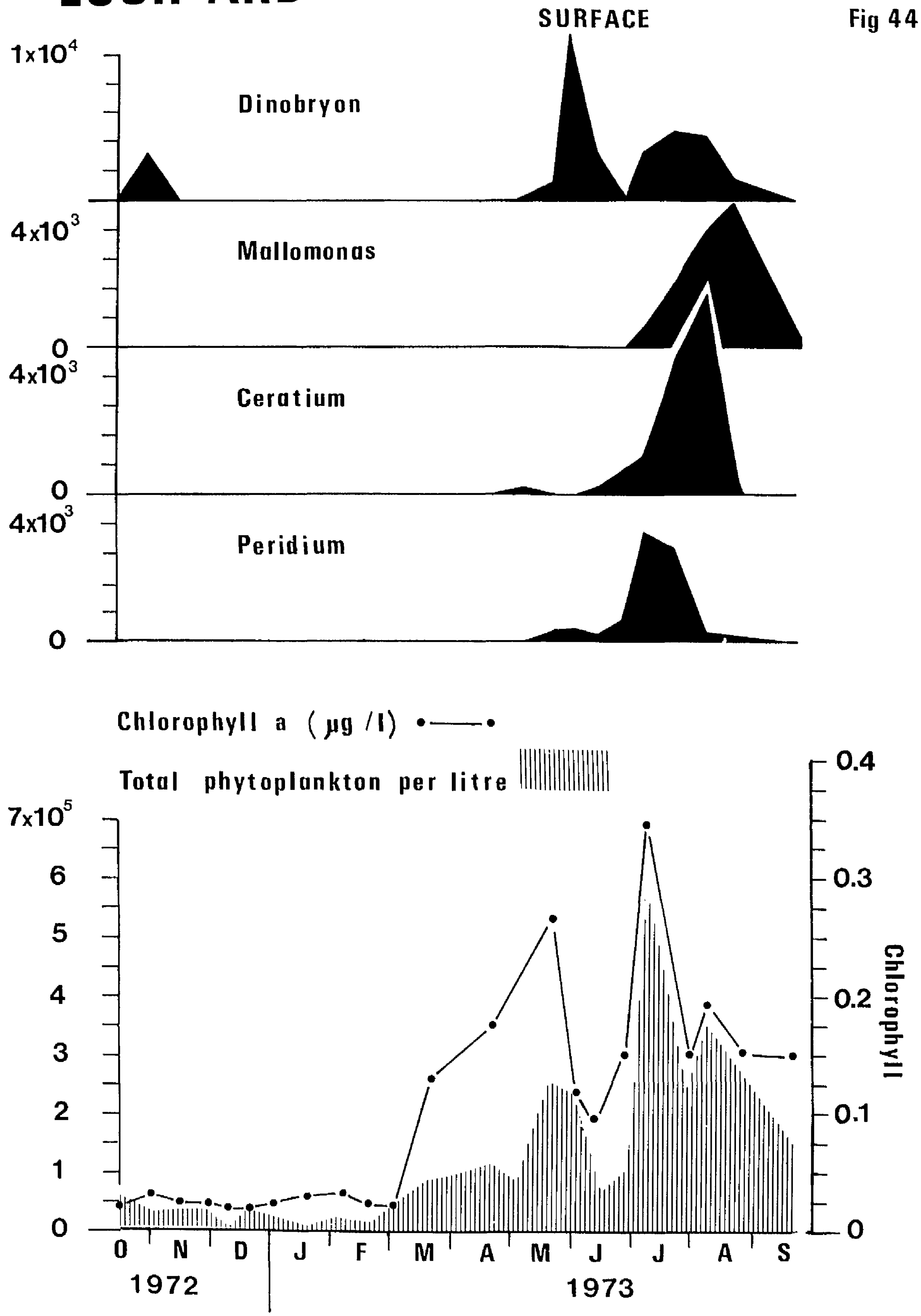
The greatest abundance of C. comta in other lochs was found in Loch Ard where a maximum of 27000 cells/l were recorded at 5 m depth on 18 October, 1972. Here the water was around 12.0°C with distinct stratification and nutrients were less than half of winter maximum. A smaller pulse occurred during February when the water was at its coldest, 4.5°C, and nutrient at the highest. In both Loch Rusky and Lake of Menteith the maximum was recorded on 26 March, 1973 at 5 and 3 m depth respectively with 6000 cells/l in the former and twice that in the latter. This occurred simultaneously with the maximum of Melosira. Both bodies of water were at 7.0°C and isothermal. In Loch Achray the spring pulse occurred on 17 May, 3000 cells/l coinciding with maximum of Melosira, Asterionella and T. flocculosa. The greatest abundance of this species was not recorded till 20 September, 1973 (5000 cells/l) when the water was warm (15°C) and stratified. This was simultaneous with Fragilaria and C. glomerata.

(v) Cyclotella glomerata Buchmann

C. glomerata was found throughout the year in Loch Lomond and on occasions in Loch Achray and Loch Ard but was entirely absent from Loch Rusky and Lake of Menteith. Two pulses were evident throughout Loch Lomond in 1972 and 1973. An early spring pulse occurred in March - April at the South and Middle Stations and a little later at the North Station. A later pulse occurred in the period July to September throughout the loch. Two short-lived pulses of C. glomerata were found in Loch Achray in May and September 1973 while only a single pulse was observed in Loch Ard during July to August. In these three lochs a pulse of C. comta was always accompanied

LOCH ARD

Fig 44



by C. glomerata (either at the surface or at depth) and by Melosira in the spring only.

The maximum numbers of C. glomerata (29000 cells/l) was recorded at the South Station of Loch Lomond on 7 April, 1972; this almost equalled the summer maximum of 2[illegible]000 cells/l on 8 August. However, the summer pulse was larger than the spring outburst at the Middle and North Stations. At the latter station 23000 cells/l was recorded on 1 August while the spring pulse reached only one third of this. The picture was similar in 1973 with the summer pulse exceeding the spring pulse at the South Station whereas at the Middle and North Stations the reverse obtained. In Loch Ard a single pulse of C. glomerata of 8000 cells/l was recorded in September coinciding with the increase of C. comta. In Loch Achray two transient pulses were observed reaching 4000 cells/l in May (along with Melosira and C. comta) and 5000 cells/l on 20 September, 1973 with C. comta and Fragilaria.

(vi) Melosira italica (EHR Kütz sub sp. Subarctica. O. Müll

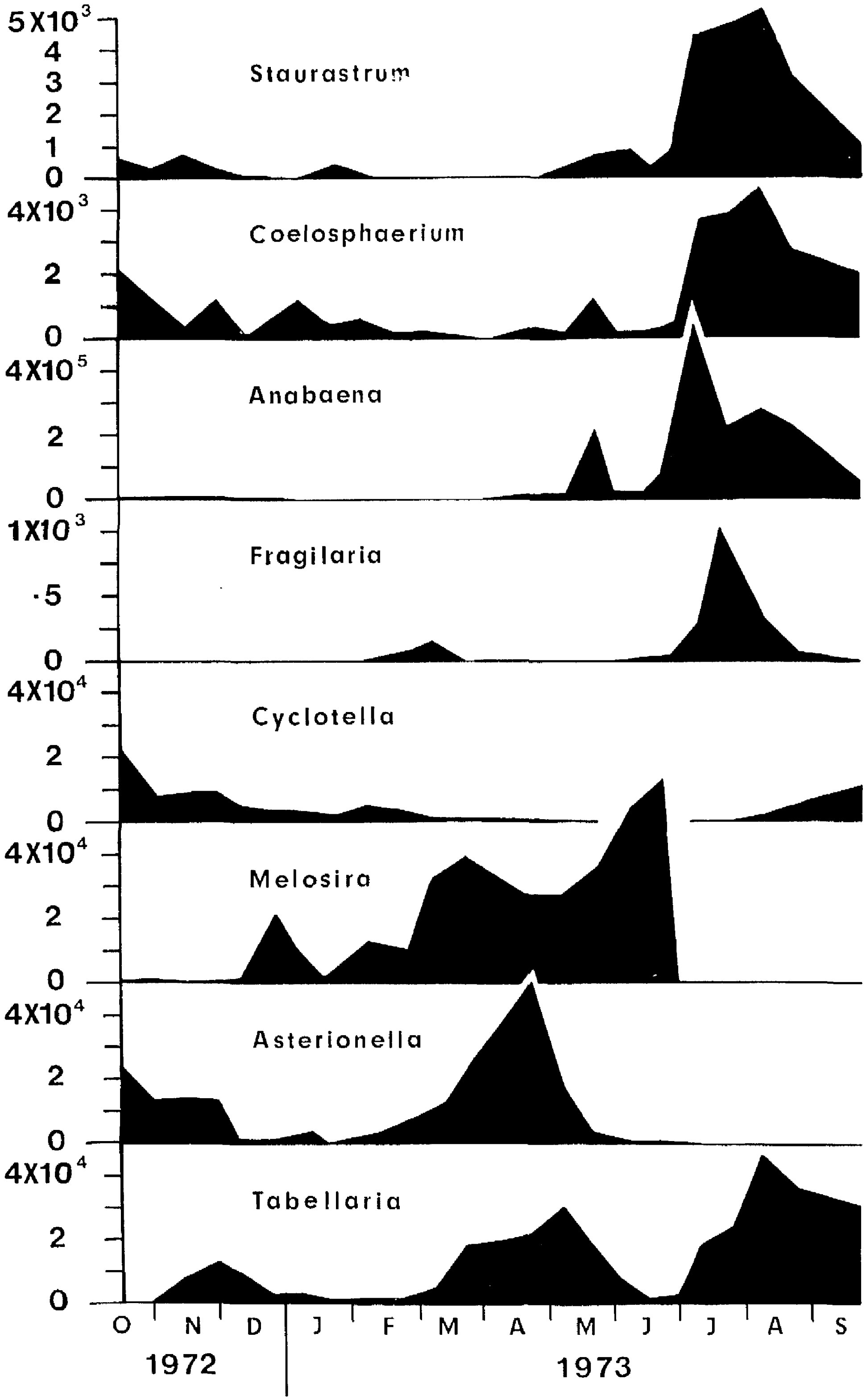
Melosira was found in all bodies of water examined. In the three stations of Loch Lomond, Loch Achray and Loch Rusky a single annual pulse in the spring was clear. In Loch Ard Melosira displayed two periods of increase, one from December 1972 to January 1973 and the other from February till the end of June. In Lake of Menteith a pulse was observed from November to December 1972 and one from January to May 1973, a further increase began in August and September 1973. In all bodies of water, Melosira achieved a position of domination during the spring.

The greatest abundance of Melosira was found in Loch Rusky where 2.43 million cells/l was recorded at the surface and 3.04 million cells/l at 5 m depth on 20 April, 1973. The increase began during November 1972, reached 213000 cells/l on 13 December and then fell again. From the beginning of March 1973 to the peak of Melosira, silicate fell by 75 µg at. Si/l, nitrate fell by 9 µg at. N/l at the surface, while phosphate showed no overall change during this period. The temperature increased from 2°C in January to 5.0°C in April remaining isothermal throughout. The end of the Melosira pulse

LOCH ARD

Surface

Fig 45



in June coincided with the initiation of water stratification.

In Lake of Menteith a peak of 1.1 million cells/l was also recorded on 20 April, 1973. This increase started during November 1972 and reached 413000 cells/l on 13 December following a decline on 10 January, 1973. Numbers rose again and increased five-fold from 21 February to the Melosira maximum. During this period silicate fell by 60 μg at. Si/l, phosphate from 0.2 to 0.15 μg at. P/l and nitrate by 11 μg at. N/l. Temperature during this period ranged from 3.4°C in December to 9°C in April and reached 14°C in the middle of June. On all occasions the water column was mixed. A further pulse of Melosira started in August and was still continuing on completion of sampling in September. This coincided with a considerable rise in silicate, phosphate and nitrate.

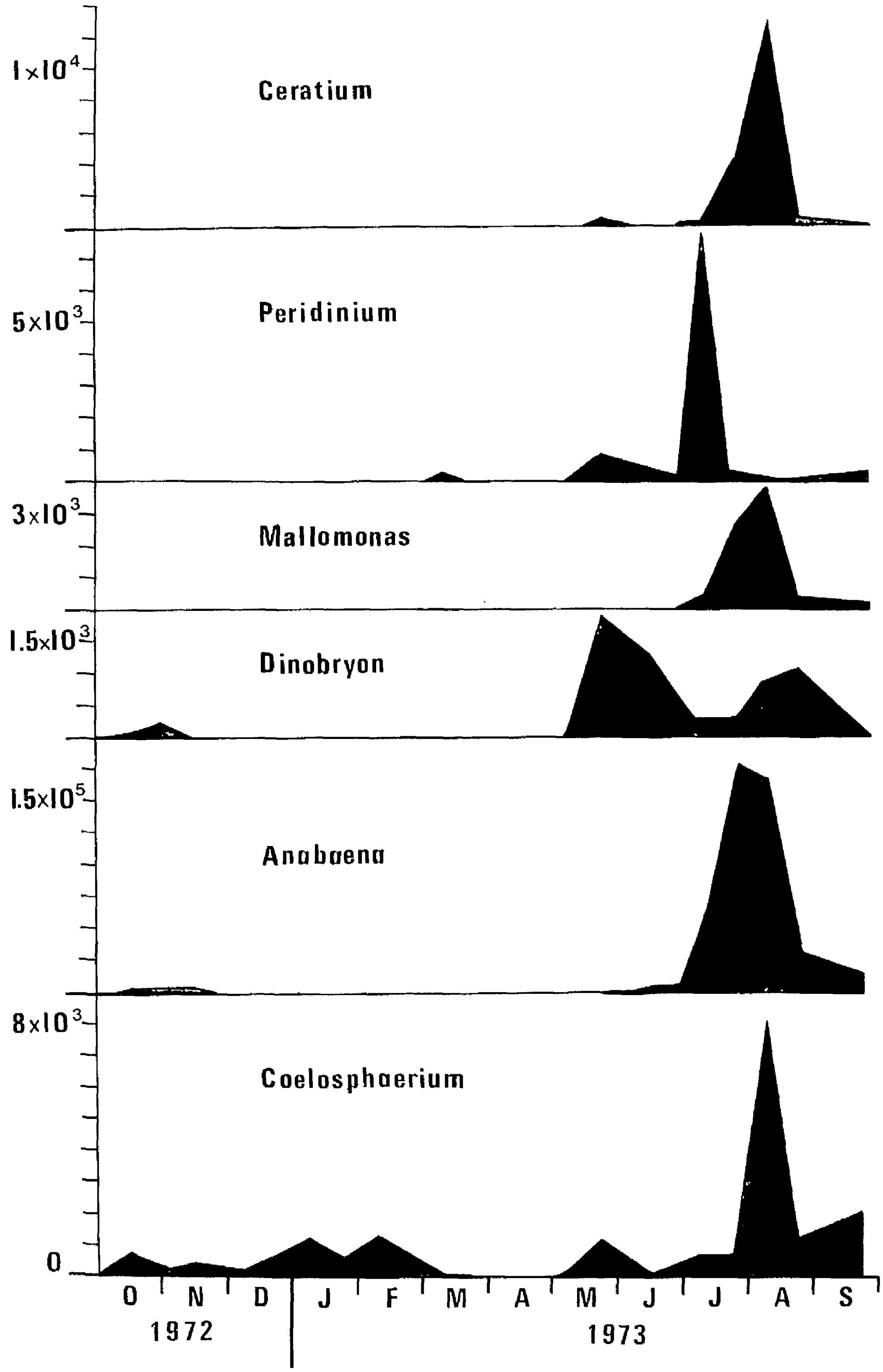
The greatest abundance of Melosira in Loch Lomond was recorded at South Station when 852000 cells/l were recorded on 14 April, 1972 while in 1973 only half this quantity was observed on 28 March. The maximum at the Middle Station occurred slightly later with the highest recorded number being about 200000 cells/l in 1972 (at 3 m depth) and 137000 cells/l in 1973. At the North Station the respective maximum in 1972 and 1973 were 54000 and 103000 cells/l which occurred on 26 April. During the spring pulse of Melosira in South Loch Lomond (400000 cells/l) silicate fell from 22 to 16 μg at. Si/l, phosphate from 0.2 to 0.08 μg at. P/l and nitrate from 22 to 16 μg at. N/l, whereas the nutrient decline was substantially less elsewhere in the Loch. Throughout Loch Lomond the pulse occurred when the water column was cold (4 - 7°C) and well mixed. A gradual disappearance of Melosira was evident as the water became warmer and the water column stabilized.

In Loch Achray Melosira first appeared in the middle of November as the water became isothermal. Numbers remained low till 17 May, 1973 when an abrupt increase reached 700000 cells/l simultaneously with most other diatoms. During this pulse silicate fell from 16 to 8 μg at. Si/l, phosphate from 0.14 to 0.07 μg at. P/l and nitrate from 16 to 8 μg at. N/l (nitrite also registered a decline from 0.05 to 0.035 μg at. N/l). Melosira

LOCH ARD

5 metres depth

Fig 46a



disappeared from the water in June when the temperature exceeded 13°C and the water column became stratified. The smallest numbers of Melosira were found in Loch Ard, where a maximum of 85000 cells/l (at 5 m depth) was recorded on 26 March, 1973. A surface maximum of 61000 cells/l was reached on 14 June. The first increase in Melosira came during November as the water column became isothermal. At the spring maximum the water temperature was 6.0°C while on 14 June the water had warmed to 13°C. The rapid decline in the abundance of this species at the end of June coincided with the establishment of stratified layers.

(vII) Fragilaria crotonensis kitton

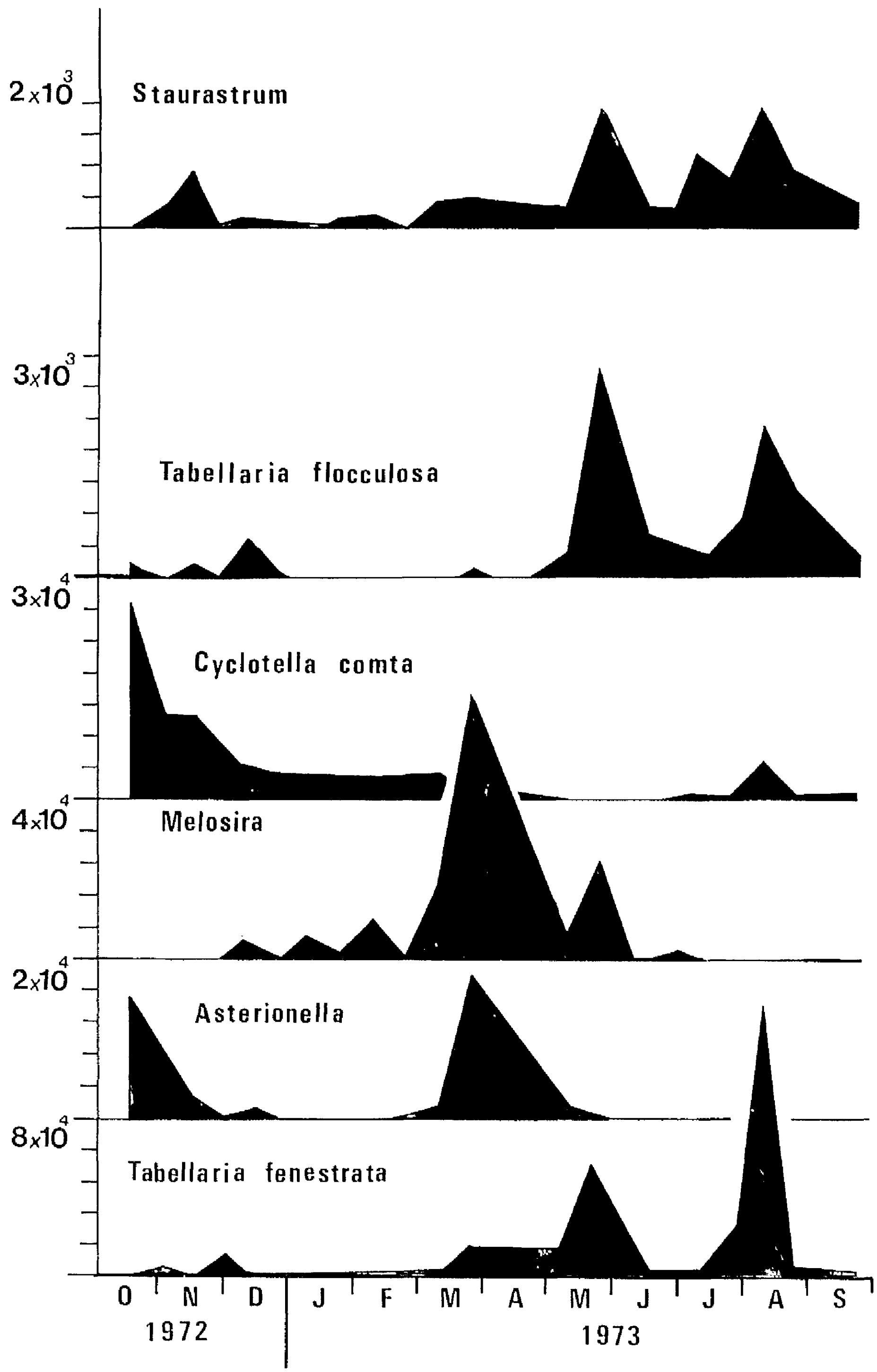
Fragilaria was found in all bodies of water examined. Throughout Loch Lomond and in Lake of Menteith two pulses in a year were clear, an early pulse in June - July and a later pulse in October - November. Generally the summer peak was greater than the autumn maximum. The other lochs displayed a single clear peak in late summer or early autumn.

The greatest abundance of Fragilaria was found in Loch Rusky and Lake of Menteith. In Loch Rusky 11800 chains/l were recorded on 8 August, 1973 when the population was dominated by Anabaena flos-aquae. Throughout the period of increase the temperature ranged from 20 to 15°C and the water column was thermally stratified. Nutrients were generally low, silicate 7 to 2 μg at. Si/l, Nitrate 2 to 4 μg at. N/l, and phosphate 0.2 to 0.1 μg at. P/l. A small pulse in November 1972 reached 426 chains/l when the water was cold, 3°C, and isothermal.

The Fragilaria maximum in Lake of Menteith reached 11300 chains/l on 1 June when the dominant organism was again A. flos-aquae. Nutrients were low at the time of the maximum (silicate 1.5 μg at. Si/l, nitrate 0.6 μg at. N/l and phosphate 0.15 g at. P/l). The water column was warm (12°C and isothermal). The autumn pulse reached 3000 chains/l on 20 September, 1973 when the water temperature was falling and nutrients were on the increase. A single short-lived pulse of Fragilaria was observed in Loch Achray on 20 September when 893 chains/l were recorded at the surface. This coincided with pulses of C. glomerata and T.

LOCH ARD

5 metres depth Fig 46b



flocculosa. The only clear peak of Fragilaria in Loch Ard occurred on 26 July when 948 chains/l were found at the surface; this coincided with the peak of A. circinales. At this time the water column was stratified with a surface temperature of around 18°C.

In Loch Lomond the greatest abundance of Fragilaria was found at all stations in the summer. At the South Station 3725 chains/l were found at the surface on 12 June, 1972 while in 1973 2383 chains/l were observed on 24 June. In both years the water was stratified with surface temperature between 12 - 14°C. The autumn peak occurred on 25 October, 1972 under isothermal conditions and reached a maximum of 3300 chains/l. At the Middle Station a maximum of 701 chains/l was reached on 27 June, 1972 and 1141 chains/l (at 3 m depth) on 6 July, 1973. Both pulses occurred under stratified conditions. The autumn pulse reached 426 chains/lon 23 November when the water mass was completely mixed. At the North Station the highest recorded number of Fragilaria in Loch Lomond was recorded, 4700 chains/l at 3 m depth, on 6 July, 1973; a maximum of 2000 chains/l was recorded at this station on 18 July, 1972. On both occasions the water column was clearly stratified. Generally there was a close relationship between pulses of Fragilaria and Asterionella in Loch Lomond.

(viii) Dinobryon cylindricum Imhof var. divergens (Imhof) Lemm.

Dinobryon was found only in Loch Lomond, Loch Ard and Loch Achray. In Loch Lomond and Loch Achray a single annual pulse was evident in June and July while in Loch Ard the largest pulse occurred in June with a small pulse in the autumn. Generally this organism was found in higher density at the surface than at depths.

The highest recorded number of Dinobryon (16841 colonies/l) was found in the surface water of Loch Achray on 11 July, 1973. At this time the water was clearly stratified with a temperature (in the epilimnion) of 17°C. Phosphate reached its lowest recorded level, 0.026 μg at. P/l on this date. In Loch Ard the main pulse of Dinobryon reached a peak of 10952 colonies/l on 1 June, 1973 and persisted till the end of August in numbers exceeding 1000 colonies/l (except for a fall to 137 on 28 June, 1973). Throughout this period phosphate lay below 0.04 μg at. P/l, falling to 0.015 on 26 July when a second pulse was observed, 4701 colonies/l. A lesser peak, 3162 colonies/l, occurred on 1 November, 1972 when phosphate reached its lowest recorded level (0.0125 μg at. P/l). On all occasions the water was warm (10 - 18°C) and clearly stratified.

The greatest abundance of Dinobryon in Loch Lomond in both 1972 and 1973 was recorded at the North and Middle Stations with values of about 4760 colonies/l. However at the South Station the density of this species never exceeded 2000 colonies/l. In 1972 the pulse of Dinobryon occurred throughout the loch between 10 and 26 July whereas in 1973 the increase was earlier by about a month (from 7 June to 6 July). The pulse was evident in the South and Middle Stations before it was observed in the North. Generally, the pulse of Dinobryon was observed when the water was warm (12 - 19°C) and stratified, and when the concentration of phosphate was 0.06 g at. P/l or less. Dinobryon usually coincided with a pulse of Fragilaria.

(ix) Mallomonas acaroides perty

Mallomonas was found in Lochs Lomond, Achray, Ard and Rusky and formed a single annual pulse in all of them. In 1973 this pulse began in July in Loch Ard, Loch Rusky and Loch Achray. In Loch Lomond, however, no regular pattern was evident during the two years.

The greatest abundance of Mallomonas was found in Loch Rusky where a pulse occurred from July to August, 1973 reaching a maximum of 95892 cells/l on 26 July. The water temperature (19°C) was at its highest on this date and stratification was clear. The surface concentration of phosphate was almost the lowest recorded for this loch (0.11 μg at. P/l). The maximum density of Mallomonas in Loch Achray was reached on 8 August when 44118 cells/l were observed at the surface. This increase was extremely sudden since only 1200 cells/l were recorded on 26 July, 1973. The water column was stratified and warm (17°C) while the phosphate value was 0.09 μg at. P/l at the time of the peak. In Loch Ard (as in the previous two lochs) Mallomonas was present from July to September with the maximum numbers being recorded on 23 August (4701 cells/l). Phosphate levels did not exceed 0.04 μg at. P/l during this period while the temperature of the surface water reached 18°C at the time of the peak.

In Loch Lomond in 1972 Mallomonas first appeared at the North Station at the end of June, at the Middle Station at the end of July and at the South Station on 12 September. In each case, however, the magnitude of the peak was the same, 4701 cells/l, occurring on 20 July, 22 August and 11 October, 1972 respectively. The water temperature at North and Middle was 15 - 16°C with clear stratification of the water mass, while at the South Station the water was cooler (12°C) and unstratified. Phosphate was 0.04 at the North and Middle Stations but reached 0.12 μg at. P/l at the South Station. In 1973 Mallomonas appeared on 24 June throughout the loch and reached a peak on 6 July at the North and South Stations and on 17 August at the Middle Station. Phosphate ranged from 0.02 to 0.04 μg at. P/l and the water was warm (12 - 19°C) and stratified at all Stations. At the North Station Mallomonas generally accompanied Dinobryon but this feature was not clear elsewhere in the loch.

(x) Kephyrion spp

Kephyrion was only recorded in abundance from Loch Achray although small numbers were found in Loch Ard and at the North Station of Loch Lomond. In Loch Achray two pulses were evident, both of which appeared very suddenly. A surface maximum of 114379 cells/l was recorded on 17 May while on 26 July a concentration of 132200 cells/l was found. The first peak occurred as the water became stratified and this species continued to be present throughout the period of stratification. The water during this period had a temperature between 10 and 19°C.

(xi) Ceratium hirundinella O.F. Müller

Ceratium was found in all lochs examined with a single annual pulse in each of them. Maximal numbers were observed during July to August although Ceratium appeared as early as the beginning of June (in Loch Rusky) or remained till October (in North, Loch Lomond). Pulses occurred during periods in which the water was warm (12 - 20°C) and stratified.

The greatest abundance of Ceratium was found in Loch Rusky where a peak of 148800 cells/l was recorded at the surface on 8 August, 1973. A smaller pulse was observed on 26 July in Lake of Menteith where 44118 cells /l were found at 3 m depth. In Loch Ard and Loch Achray pulses of Ceratium reached a maximum on 8 August when respective values of 12900 and 20769 cells/l were recorded.

The greatest concentration of Ceratium in Loch Lomond was encountered at the Middle Station where the maximum was 4701 cells/l on 15 August, 1972 and 2213 cells/l on 24 July, 1973. At the North Station the maximum was 1814 cells/l at the end of July in both years. The lowest density of Ceratium,was found at the South Station where 948 cells/l was recorded on 8 August, 1972 and 1649 cells/l on 6 July, 1973. It is clear that in 1973 Ceratium made its first appearance in Loch Lomond on 7 June at the South, on 21 June at the Middle and did not appear till 6 July at the North Station.

In general Ceratium came immediately after Dinobryon and was usually accompanied by Peridinium, Staurastrum and Botryococcus. This species usually reached its maximum abundance in the surface waters.

(xii) Peridinium willei, Huilf-Kass

Peridinium was found in all lochs investigated and had one pulse during the year. It generally coincided with pulses of Ceratium but was first apparent about a month earlier. The maximum abundance of this species was found in Loch Rusky where 16800 cells/l were recorded at the surface on 8 August. In Loch Ard 7905 cells/l were found on 11 July (at 5 m depth). The maximum in Loch Achray was 5385 cells/l on 23 August while in Lake of Menteith a peak of only 1650 cells/l was recorded.

In Loch Lomond in 1973 the greatest abundance of Peridiniumwas found on the same date throughout the Loch, 6 July. This pulse became progressively larger passing southwards; 1374 cells/l at the North, 2213 cells/l at the Middle and 3725 cells/l at the South Station. The pattern in 1972 was less clear, with the peak of the Peridinium increase occurring first at the North on 15 August then at the Middle on 22 August and finally at the South Station on 6 September. The magnitude of the increase was the same at the North and South Stations (948 cells/l) with the highest density being recorded at the Middle Station (2231 cells/l). Generally the highest numbers of this organism were found in the surface layer of warm, stratified bodies of water.

(xiii) Microcystis aeruginosa Kütz

Microcystis was found in Loch Rusky and Lake of Menteith. Throughout the summer and autumn (June - November) Microcystis existed in Lake of Menteith. The main pulse observed on 26 July, 1973 (17028 colonies/l) was the highest recorded number of this organism. On this date the water had reached its annual maximum (20°C) temperature at all depths. Phosphate (0.11 µg at. P/l) and nitrate (2 µg at. N/l) were around their lowest values. A smaller pulse (1970 colonies/l) was observed on 1 November, 1972 when the temperature had fallen to 8.0°C at all depths. In Loch Rusky only a single pulse was evident on 18 October, 1972 when a total of 3482 colonies/l was found, and the water temperature was 11.0°C.

(xiv) Anabaena circinales (Robenhorst) ex Born et Flah

A. circinales was found in all lochs examined. In Loch Lomond Anabaena appeared in both years, between the last week in June and the first week in July and persisted till September, 1972. The maximum concentration was always recorded before the end of July. The earliest appearance of A. circinales (February 1973) and the earliest peak (April) was observed in Lake of Menteith. In Loch Ard A. circinales was first noticed in March and in Loch Achray in June.

The greatest abundance of A. circinales was found in Loch Achray where 749000 cells/l were recorded on 26 July, 1973. This was only a fortnight later than the peak in Loch Ard where Anabaena reached 527000 cells/l. Both these lochs were stratified at this time with a surface temperature of around 19.0°C and very low phosphate levels. The pulse of A. circinales increased gradually to reach 443000 cells/l at the surface on 20 April, 1973 and then persisted till September with a further small pulse of 66000 cells/l on 8 August. A transient pulse of 72000 cells/l was recorded in Loch Rusky on 26 July, 1973.

In Loch Lomond the greatest abundance of *Anabaena* was noted at the South Station in both years. In 1972, when the peak of *Anabaena* was recorded throughout the loch on the same day (20 July) 87000 cells/l were found at the South Station, 290000 cells/l at the Middle and 25000 cells/l at the North Station. Phosphate ranged from 0.04 to 0.02 g at P/l and water temperature from 16 to 18°C; all stations showed clear stratification of the water column. In 1973 the earliest and largest peak occurred at the South Station where 122000 cells/l were recorded on 24 July. The pulse was observed a month later at the Middle and North Stations where maxima of 63000 cells/l and 21000 cells/l were found. *Anabaena circinales* generally exhibited its greatest abundance in surface waters.

(xv) *Anabaena flos-aque* (lyngby) Breb

A. flos-aquae was found only in Lake of Menteith and Loch Rusky often in very great abundance. In Lake of Menteith *A. flos-aquae* was present throughout the year with two clear pulses while in Loch Rusky *A. flos-aquae* was present from March to November with a single large pulse. Fairly high numbers of *Anabaena* were present in Loch Rusky from March until the end of July following which a sudden bloom occurred. On 8 August, 1973 15.84 million cells/l were recorded at the surface rising to 16.5 million cells/l on 23 August. During the period of rapid increase, phosphate rose from 0.11 to 0.22 µg at. P/l whereas nitrate remainted constant, aroung 2 µg at. N/l. The loch was stratified and warm (15 - 19°C) during this period.

In Lake of Menteith two pulses of similar magnitude (around 1 million cells/l) occurred on 15 November and 3 May. The summer pulse of *A. flos-aquae* came after the pulse of *A. circinales* in both bodies of water.

(xvi) *Anabaena spiroides* Klebhan

A. spiroides was found only in Lake of Menteith where it was present from 28 June till the end of September 1973. A bloom of *A. spiroides* was evident on 23 August, 1973 when 3.24 million cells/l was recorded at the surface. The water temperature was around 16°C.

(xvii) Coelosphaerium spp.

Coelosphaerium was found in Loch Lomond and the four other lochs throughout the period of sampling. A bloom accompanied by Botryococcus was clear in Lake of Menteith in January 1973 when the temperature was at its lowest, and in Loch Rusky the peak of Coelosphaerium was accompanied by A. flos-aquae during August and September when the temperature was at its highest while in Loch Ard the accompanying algae was Staurastrum. A pulse of Coelosphaerium observed in Loch Lomond in October 1972 while in Loch Achray, although this genus was present, it never produced a peak. Large green patches which often accumulated in the shore zones of Loch Lomond and Lake of Menteith during summer afternoons consisted of nothing but colonies of Coelosphaerium.

West (1912) identified C. kuetzingianum Näg. in Loch Lomond. From an extensive study of the genus Coelosphaerium carried out during the present investigation on Loch Lomond, it is clear that at least two distinctive forms exist which may be of species rank. The description of these will be published in a separate paper.

Coelosphaerium in Loch Lomond showed variations in the diameter of the colony and in the width and structure of the sheath; the arrangement of the cells within the colony, the total number of cells and their length and ; breadth were also variable. The individual cells varied in the number of gas vacuoles and the thickness of the cell sheath. Various methods of reproduction of this colonial plant were observed and the mode of feeding of Vorticella upon it was recorded for the first time. There was also a distinct seasonal variation in the epiphytic and endophytic algae associated with the colony.

The endophyte Aphanotheca nidulanus was identified within Coelosphaerium (in Loch Lomond) by West (1912) while Stylosphaeridium stipitatum, Stipitococcus apiculalus, Stipitococcus capense and Characium spp (private communication, Desikachary) have been identified for the first time as being epiphytic on Coelosphaerium in Loch Lomond, This is the first reported identification of the latter two algae as being epiphytic on

Coelosphaerium (private communication, Desikachary).

From the study of the ecology of Coelosphaerium it was clear that the number and composition of the attached algae varied at different times of the year. From the end of July 1972 till January 1973 the number of Coelosphaerium colonies with attached Stylosphaeridium was more than twice the numbers with S. capense. During the period January to March the number of Coelosphaerium colonies with the two epiphytes was similar whereas from April to July the number of colonies with S. capense exceeded the number with attached Stylosphaeridium.

Coelosphaerium colonies in Loch Lomond may be found with or without any endophytic or epiphytic algae. If other algae are present all species or some of them may be found. Generally the number of colonies with endophytic algae is far larger than those without, a phenomenon which was also evident in the other lochs studied.

In all bodies of water Coelosphaerium persisted throughout the year producing a single annual peak in each one with the exception of Loch Achray. The greatest abundance of Coelosphaerium was recorded in Lake of Menteith on 10 January, 1973 when 73000 colonies/l were found at the surface at a time when the water was cold (4°C) and isothermal. A smaller pulse was observed on 18 October, 1972 (53000 colonies/l) when the water temperature was 12°C. Peaks of Coelosphaerium were observed in Loch Rusky and Loch Ard (18000 and 8000 colonies/l respectively) during August when the water column was stratified and warm (16 - 17°C). In Loch Achray the number of colonies never exceeded 1000 colonies/l and a clear pulse was not apparent at any time.

In Loch Lomond each station had its own particular pattern which was different from one year to the next. The largest numbers (4701 colonies/l were found at the South Station on 25 October, 1972 when the water was warm (11.5°C) and isothermal. This was accompanied by a pulse of Staurastrum. A pulse of 3162 colonies/l were recorded at the North Station on 18 July, 1972 at the same time as Staurastrum increased. At this time the water column was stratified with a surface temperature of around 16°C. At the

Middle Station the numbers of colonies fluctuated considerably with a peak of 1314 colonies/l being recorded on 17 January, 1973 when the water was cold (5°C) and isothermal. At the rest of 1973 the maximum numbers of Coelosphaerium at the North and South Stations were substantially less than in 1972. A pulse of 1649 colonies/l was observed at the North Station a peak of 2210 colonies/l was reached on 15 March, 1973 at the surface.

(xviii) Botryococcus braunii Kütz

Botryococcus was found in all lochs investigated and was generally present throughout the year. A single pulse was evident at each station. The largest recorded pulse of Botryococcus, 27037 colonies/l, was found in Lake of Menteith on 10 January 1973 when the water column was isothermal and the temperature was around 4°C. The greatest density of Botryococcus in other lochs was found during the summer period when the water was at its warmest and the thermal structure had stabilized.

In Loch Rusky this species was present throughout the year with a single, distinct peak on 3 August, 1973 when 14000 colonies/l were present. Botryococcus was intermittently present throughout the year in Loch Ard with a distinct peak of 5000 colonies/l on 11 July. In Loch Achray it only appeared from June to September 1973 with a single pulse reaching 5000 colonies/l on 8 August. In the latter three lochs pulses of Botryococcus occurred simultaneously with peaks of Anabaena.

At all stations in Loch Lomond Botryococcus was present throughout the year in surface water. A single annual pulse was clear in both years between the last week of July and the first week of August. This peak generally coincided with the maximum abundance of Staurastrum. In both 1972 and 1973 the highest numbers of Botryococcus were found at the Middle Station where 2213 and 3162 colonies/l respectively were observed. The concentration of this algae never exceeded 2000 colonies/l at the South Station or 1251 colonies/l at the North Station.

(xix) Staurastrum cingulum var. obseum

Staurastrum was found in all bodies of water examined and was present throughout the year in Loch Lomond, Loch Achray and Loch Ard whereas in

Lake of Menteith and Loch Rusky it was not in evidence during the winter period. Staurastrum attained its maximum quantitative importance in Loch Rusky where a pulse of 17300 cells/l was recorded on 26 July, 1973. While on the same date in Lake of Menteith a pulse of 3000 cells/l occurred. The temperature in the two lochs was at its maximum, 19 -20°C. A slightly larger peak, 9400 cells/l, was observed in Lake of Menteith on 18 October, 1972, when the water was much cooler, 12°C.

The greatest abundance of Staurastrum in Loch Achray and Loch Ard came during August when a pulse of 11783 was observed in the former loch and 5000 cells/l in the latter. Both lochs were stratified with the surface temperature between 16 and 18°C. During this period (July and August), all four lochs reached their lowest recorded nutrient values.

In Loch Lomond in 1972 the pulse of Staurastrum earliest at the North Station (1 August) later at the Middle Station (27 September) and latest at the South Station (25 October). The magnitude of the pulse was similar at the Middle and North Stations (1300 - 1400 cells/l) while the highest density of Staurastrum (4700 cells/l) occurred at the South Station. The picture was different during 1973 when all pulses were observed during August with numbers ranging from 1500 to 1800 cells/l. In general increases of Staurastrum coincided with pulses of Botryococcus.

CHAPTER 4

Diurnal variation in Loch Lomond

Introduction

The daily variations of light and temperature make themselves felt in all but very deep water and it is to be expected that many communities will exhibit periodocities which are related to the 24 hour day-night period. Persistent patterns of diurnal variation of water chemistry, algal numbers and photosynthetic capacity, zooplankton numbers and physical factors have been reported by many authors both for lotic, lentic and marine water, and for planktonic and benthic communities.

The diurnal rhythms of phytoplankton communities have generally been demonstrated from regular measurement of the role of photosynthesis (from Carbon 14 incorporation or oxygen light and dark battles) or from chlorophyll estimation or by direct enumeration of phytoplankton. The smallest sampling interval taken was 20 minutes (Kramer, Allen, Baulne and Burns, 1970) and the largest was 10 hours (Bamforth, 1962). Although diurnal studies on standing crop variation have often been made from chlorophyll and productivity measurement, fewer investigations have involved phytoplankton enumeration or have considered physical and chemical parameters and the role of zooplankton grazing.

The timing of the daily maximum phytoplankton standing crop, as detected by different authors is very variable and may occur at almost any time of the day. Nijayaraghavan (1971) in studies on Teppakulam tank (India) demonstrated a peak abundance of net phytoplankton and chlorophyll at mid-day in surface water. He further showed that Bacillariophyceae, Cyanophyceae and Chlorophyceae all attained their maximum surface accumulation at mid-day whilst zooplankton achieved their maximum surface accumulation at midnight. This inverse relationship was attributed to the night-time grazing by the zooplankton. The phenomenon of night-time migration of zooplankton into the surface water has been described by Odum (1953). Ferguson Wood and Corcoran (1966) in their studies of diurnal variation in the sea, found that the mean chlorophyll level and phytoplankton count (averaged over the entire water column) reached a maximum at mid-day. They, too, considered the fluctuation of numbers to be due to zooplankton grazing but added that the generation time of the smaller phytoplankton (nannoplankton) must be much shorter than previously thought.

Saksena and Adoni (1973) found no evidence of diurnal variation for Microcystis but showed a maximum of Trachelomonas at 9 p.m. due to its diurnal movement. Hasle (1954) explained the accumulation of large numbers of dinoflagellates in surface waters of the Olso Fjord by phototactic diurnal migration. He found that they exhibited vertical migration on a 24 hours period with a daytime maximum at the surface. On the other hand, Lund (1965) stated that flagellates commonly show diurnal movement, often migrating downward by day (in the shade of macrophytes) and return to the upper waters at dusk. Persistent vertical migration rhythms have also been reported in fresh water epipelic population (Brown, Gibby and Hickman, 1972). These are intertidal populations with diatoms, flagellates and blue-green algae reaching a maximum at the mud surface at 1000 hrs.

Doty and Oguri (1957) reported regular daily variation in the Carbon 14 uptake of phytoplankton populations from pacific surface water with a maximum in the morning. Although no direct measurement of standing crop was attempted they discounted the possibility of phytoplankton migration or zooplankton grazing. From further, more detailed experiments Newhouse, Doty and Tsuda (1967) found that the photosynthetic standing crop was maximum at 16.00 hrs, decreasing steadily to a minimum at 06.00 - 0800 hours. Glooschenka, Curl and Small (1972) found that the chlorophyll content in surface marine waters was at its highest at midnight; they attributed this to leaching in high light intensities during the day and synthesis in the evening. On the other hand Lorenzen (1963) found a chlorophyll a maximum at mid-day coinciding with the daily maximum of phosphate and minimum of nitrate. Talling (1966) in his studies on the English Lake district found that diurnal changes in photosynthetic pigments appeared to be small or absent.

In the Lake Erie time study (Kramer et al., 1970) a chlorophyll maximum in surface waters occurred at approximately 1800 hours, simultaneously with the highest daily dissolved oxygen concentration. However, the dominant phytoplankton, Aphanizomenon, reached its greatest surface abundance at 1200 hours and showed a ten-fold decrease by 1700 hours. Malone (1971) in his study of tropical oligotrophic surface water (nitrogen limited) demonstrated that nanoplankton had a morning maximum in C^{14} assimilation rates while the net plankton had an afternoon maximum. He explained this on the basis of different response to low nutrient regimes, nanoplankton should be able to photosynthesise more efficiently and attain a maximum earlier than the net plankton. Baker et al. (1969) demonstrated that in an almost monospecific natural population of Oscillatoria agardhii the maximum productivity at the surface occurred at twilight and the maximum at 5 m depth at solar noon.

A further cause for periodic variation in cell numbers may be the time of cell division. Doty and Oguri (1957) recalled the frequently reported onset of reproductive activities in the evening and the termination of these events with the onset of grazing or daybreak. This view is supported by Lund (1965) who stated that the nucleii of many algae generally or almost always divide at night.

The sampling programme in any body of fresh water usually allows for maximum areal coverage, but gives little indication of the dynamic phenomenon that may occur on an hourly or even daily basis. The present study was initiated to ascertain the extent and the time period of the major chemical and biological variables in Loch Lomond. The period 18 July to 20 July was chosen for maximum productivity and as a time in which calm weather interrupted by windy periods might be expected. Apart from investigating the diurnal changes in phytoplankton and chlorophyll in Loch Lomond it was also possible to study whether or not the lower part of the hypolimnion which is almost always saturated with oxygen, acts as a source of nutrient supply to the overlying water.

Most investigators have taken samples from surface waters only over a period of twenty-four hours and from this, diurnal periodicities of phytoplankton numbers, chlorophyll levels or productivity have been described. There are almost no reports of experiments involving samples taken at many depths for two successive 24 hour periods to ascertain whether the described daily rhythms persist. The present investigation is the first field study of diurnal variation of phytoplankton, chlorophyll and chemical factors to be carried out in Loch Lomond or any other Scottish loch.

Organization and sampling programme for study of diurnal variation

For the purposes of study of diurnal variation in Loch Lomond a continuous 48 hours sampling programme was undertaken with the assistance of nine other people. The programme of intensive sampling continued from 0000 hours on 18 July to 0000 hours on 20 July, 1973. The catamaran "Fiona" belonging to the University of Glasgow Field Station was used as a platform for the present study and was anchored in 47 m of water at the Middle Station of Loch Lomond. This station was chosen for its proximity to the shore laboratory (University of Glasgow Field Laboratory at Rowardennan) which was about 3 km away. For the purpose of transferring personnel, samples and equipment to and from the field laboratory two small boats powered with outboard motors, were used.

The special equipment on board the catamaran for the duration of this experiment included a portable 1 kw, petrol-powered generator, which supplied electrical power for the vacuum pump and lighting. The vacuum pump supplied the suction for ten filtration units. Five of these were used for the filtration of 1 litre samples (through glass-fibre filter) for chlorophyll estimation while the other five were used for the millipore filtration of 100 ml sample aliquots for enumeration of phytoplankton.

Two separate series of samples were taken regularly throughout the investigation. The first series was taken at the following discrete depths on a 2-hourly basis, 00cm (surface), 25 cm, 50 cm, 75 cm, and 100 cm. This allowed a study to be made of the variation of phytoplankton within the top metre of the water column (the Van Dorn sampler gives an integrated sample over 1 metre of the water column). The small volume bottles used for sampling were described by Rodina (1961) and consist of a 500 ml weighted bottle provided with a rubber stopper containing two holes through which two glass tubes, one short and one long were passed. A small piece of rubber tubing joins the two glass tubes and is connected to the surface by a light weight line. When the bottle has been lowered to the discrete depth on a rope line, a pull on the light weight line removes the rubber tubing and water enters the bottle through one of the glass tubes. Complete series of 5 samples were taken every 2 hours accompanied by oxygen-temperature profiles throughout the 48 hour period and filtered for chlorophyll and phytoplankton estimations.

The second series of samples were taken at the surface (with a bucket) and at 1 m, 2 m, 10 m, 15 m, 18 m, 20 m, 30 m, 40 m and 47 m (bottom) with a Van Dorn sampler. Analysis (in duplicate) of major chemical nutrient (silicate, nitrate, nitrite and phosphate) were made for all samples, in addition to which the chlorophyll and phytoplankton estimations were made on surface, 1, 2, 10, 15 m samples to supplement the estimations made at 25 cm intervals. These depths were chosen according to the thermal structure of the water column recorded at the commencement of the continuous sampling periods. Surface to 2 m was the epilimnion, 10 m was the top of the thermocline, 15 m was the middle of metalimnion, 18-20 m was the clinolimnion while the hypolimnion was represented by 30, 40 and 47 m. At the commencement of sampling 3 sets of samples were taken on an hourly basis, that is 0.30, 0230 and 0330 hours. These samples (30 in all) were then returned to the field laboratory for immediate analysis. This cycle of triplicate sampling repeated every eight hours. starting at 01.30 hours, 0830, 1830 on 18 July and 0100, 0800 and 1830 on 19 July.

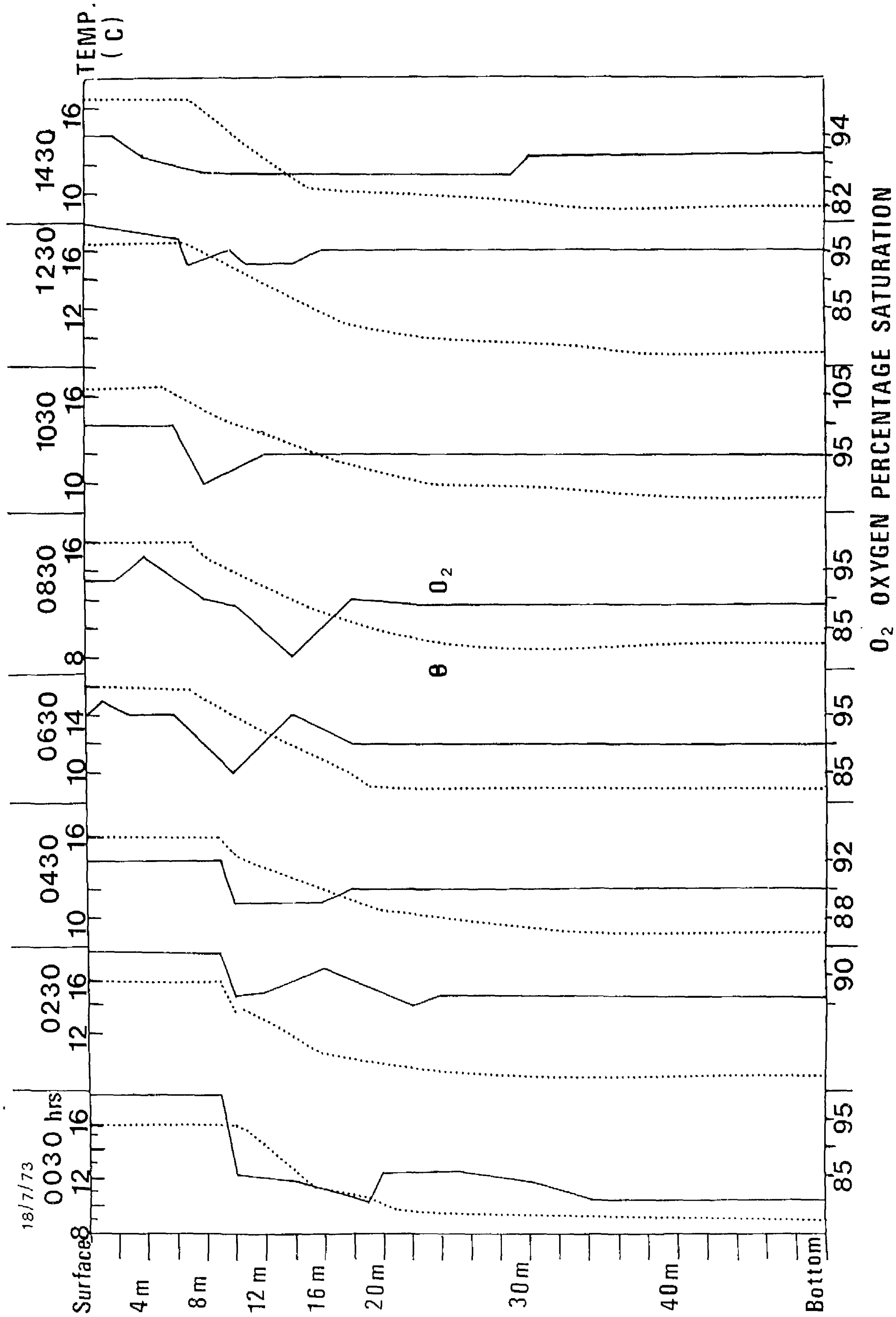
The organisation of manpower in the field for sample collection, the analysis of samples in the shore laboratory and the transportation of the samples required a strict integration of individual contributions to the overall programme. The full co-operation of the ten people involved under the 48 hour work plan was an essential element in the success of the operation.

Acknowledgements

I would like to offer my sincere thanks to Dr. R. Tippett for putting the facilities of the Field Station at Rowardennan at my disposal,

DIURNAL VARIATION

Fig 47a



including the laboratory, sleeping and cooking facilities and the use of the boat for a 48 hour period. I would also like to express my gratitude to J. Johnston for his indispensable help throughout the operation. The following people were an important ingredient in the success of the operation and I would like to express my thanks to them: Dr R. Tippett, Messrs J. Johnston, G. Hinton, J. Flanagan, J. Clokie, N. Kidd, R. McMath, C. Easton and Miss C. Filion.

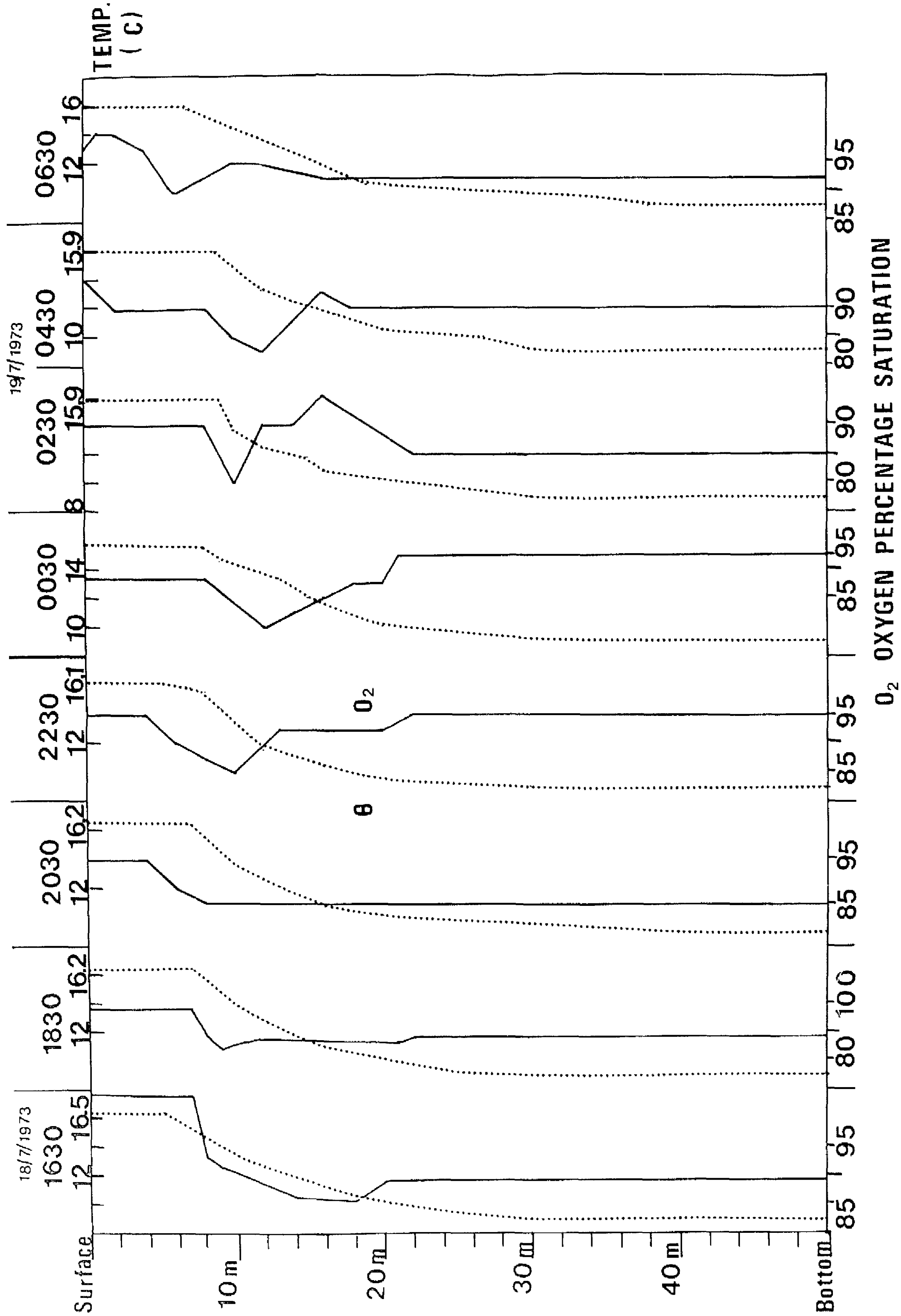
Results and discussion

The four days preceding the 48 hour sampling period were calm and dry with between 3 and 9 hours of bright sunshine per day. However, a sudden change in the weather occurred on the evening of the 17 July, when slight rain and light breezes were noted, the breezes were interrupted by calm periods and occasionally by windy weather, especially so during the second day. The conditions over the period of sampling were generally cloudy and overcast with occasional rain, except during the second day when a short sunny period (1.9 hours) occurred around mid-day. The air temperature on both days, reached a mid-day maximum of 16-17^{o}C falling to around 11-12^{o}C at midnight, while the surface water temperature ranged from 16.6^{o}C to 15.6^{o}C respectively.

The water mass was clearly stratified for the duration of the experiment (Fig. 47a, 47b). The epilimnion generally fluctuated between 5 and 10 metres in depth with a temperature around 16^{o}C while the hypolimnion was initiated between 20 and 30 metres with a temperature reading of about 9^{o}C. Dissolved oxygen was generally steady throughout the epilimnion and hypolimnion while considerable fluctuations were evident in the zone of temperature discontinuity where the oxygen minimum was generally found. This negative heterograde distribution was found on all but three occasions. At 0930 on 18th and 0430 on 19th the oxygen maximum was at the surface, below which it started to decrease rapidly at the beginning of thermocline and suddenly changed and increased, reaching a maximum at the middle of the metalimnion below which a decline in oxygen occurred. The only occasion on which a purely positive heterograde distribution was detected

DIURNAL VARIATION

Fig 47b



was at 0230 on 19th when the oxygen maximum for the whole water column (80%) was also found at this time at the top of the thermocline layer. The only occasions when the oxygen maximum in the epilimnion was found below the surface was at 0630 on both days, when an increase was detected at 1 m depth and at 0830 on the 18th when a maximum was observed at 4 m depth. The levels of saturated oxygen in the epilimnion varied from 104% at 1630 on the 18th to 90% at 0230 on the 19th and in the hypolimnion from 81% at 0030 on the 18th to 95% at 2230 on the same day.

Silicate (Fig. 49, Table 21) shows an inverse clinograde depth distribution with the bottom concentration (14.4 - 16.3 µg at. Si/l) being up to six-fold higher than the surface value (4.13 to 2.01 µg at. Si/l). Silicate was generally low throughout the epilimnion and displayed a rapid rise at the top of the metalimnion, with a gradual increase below that to the bottom. This pattern of vertical distribution has been described for the North Atlantic ocean (Raymont, 1963) and by Hutchinson (1957) for a Japanese lake where an inverse clinograde distribution of silicate was also recorded.

Nitrate (Fig. 48, Table 19) exhibited a maximum at an intermediate depth of 30 metres, where values fluctuated between 12.4 to 15.4 µg at. N/l. Surface concentration of nitrate decreased from 11.8 µg at. N/l at the beginning of sampling to around 5.0 at the completion of sampling programme. While values ranged from 13.4 to 10.9 µg at. N/l at the bottom. The phenomenon of a mid-depth maximum of nitrate under stratified conditions was described by Hutchinson (1957) for a lake in Wisconsin and by Sagi (1970) in the North Pacific ocean. The vertical distribution of nitrite in the present study (Fig. 48, Table 20) is also in accord with Hutchinson (1957) who shows that an increase in nitrite would be expected wherever a direct clinograde nitrate curve is found (that is below the nitrate maximum). This is in fact the case, with a nitrite maximum being in evidence at a depth of 40 metres. The overall variation in nitrite was erratic with values varying from almost undetectable to 0.09 µg at. N/l.

Dissolved phosphate (Fig. 49, Table 22) displayed an inverse clinograde distribution with low concentration at the surface (0.01 to 0.08 µg at. P/l) and high levels at the bottom (0.33 to 0.9 µg at. P/l). This pattern of vertical distribution of phosphate with depth in stratified lakes was in accordance with that described by Hutchinson (1957). He explained that most rapid increase in phosphate levels takes place at the lower part of the hypolimnion, a feature which was evident from the present study.

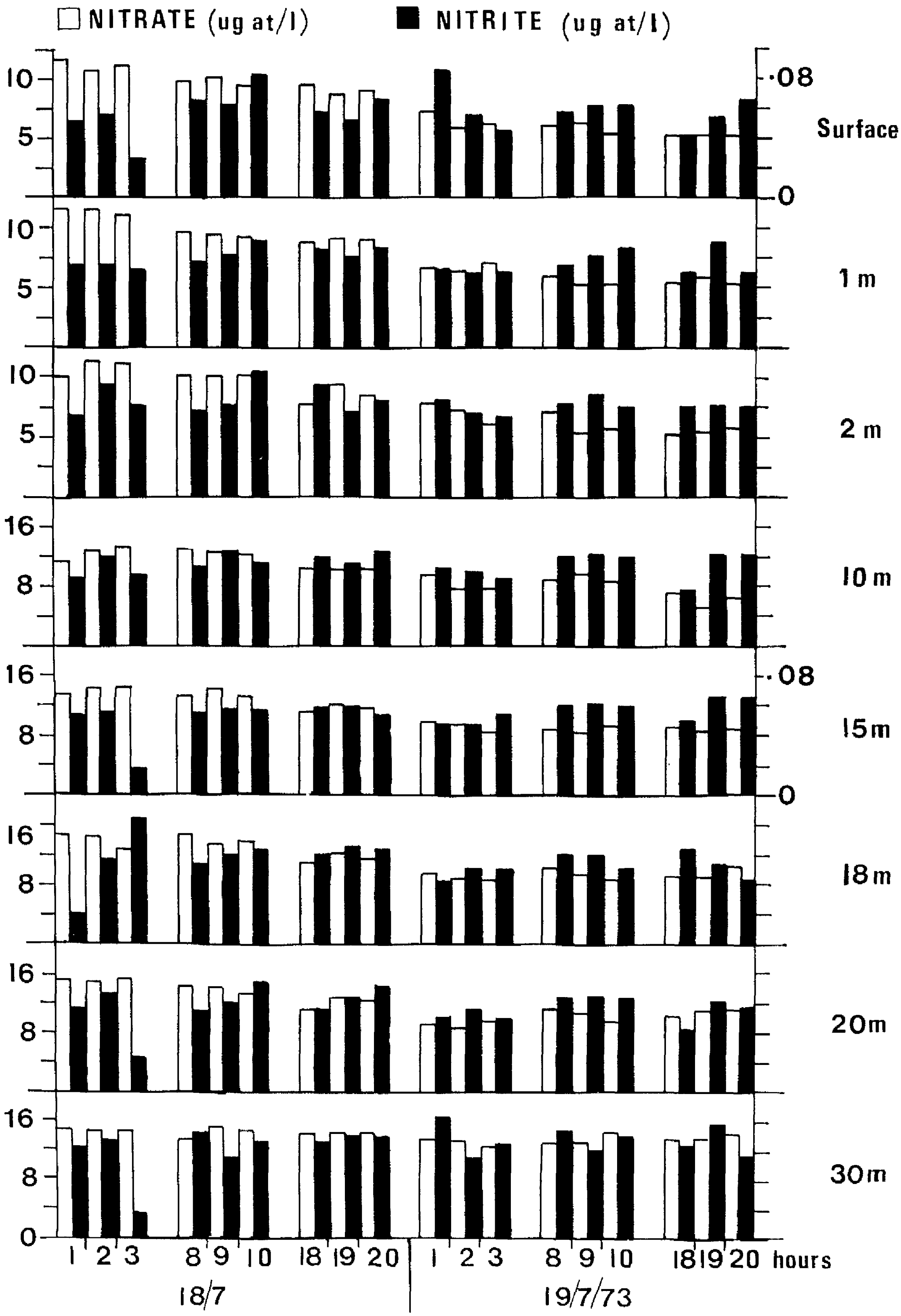
The variation in the vertical distribution of nutrients during the two 24 hour periods can be partially understood in terms of fluctuation in the position of thermocline and partly by nutrient uptake by actively multiplying phytoplankton. Figures 47a, b, show that the boundary between the epilimnion and thermocline showed regular oscillation in its location below the surface. From 0000 hours (on 18th) to 0400 hours the boundary remained at 10 m depth, following which it gradually moved nearer the surface to lie at a depth of 5 m at 1030 hours on the 18th. During the day it fluctuated marginally, and then fell from 5 m at 2230 to around 10 m after midnight. This pattern was repeated on the following day.

The effect of these fluctuations on the vertical distribution of silicate was clear. This nutrient generally showed a much higher concentration at the top of the thermocline than in the overlying water (epilimnion), Consequently as the boundary between the two layers moved closer to the surface a rise in silicate was evident at 10 m depth (which was then included in the thermocline). In fact silicate at 10 m depth increased from 7.77 at 0330 to 8.94 µg at. Si/l at 1030 on the 18th July while silicate in overlying waters fell by more than 1.5 µg at Si/l. This phenomenon was also clear for nitrate which showed the largest discrepancy between 2 m and 10 m concentration when the boundary between the epilimnion and thermocline lay at 5 m depth. Consequently the nitrate utilization of about 1.2 µg at. N/l found in upper 2 m between 0330 and 0830 on 18 July was absent at 10 m depth. Phosphate concentration also displayed an increase at 10 m at this time.

The sinking of the thermocline (to around 10 m depth) after midnight

DIURNAL VARIATION

Fig 48



accompanied by some turbulent mixing from winds may have been responsible for the increase in silicate observed at this time (2.21 to 2.97μg at. Si/l at the surface). An increase in phosphate concentration was not observed at the surface, till 0830 hours, whereas nitrate concentration showed a continual decline.

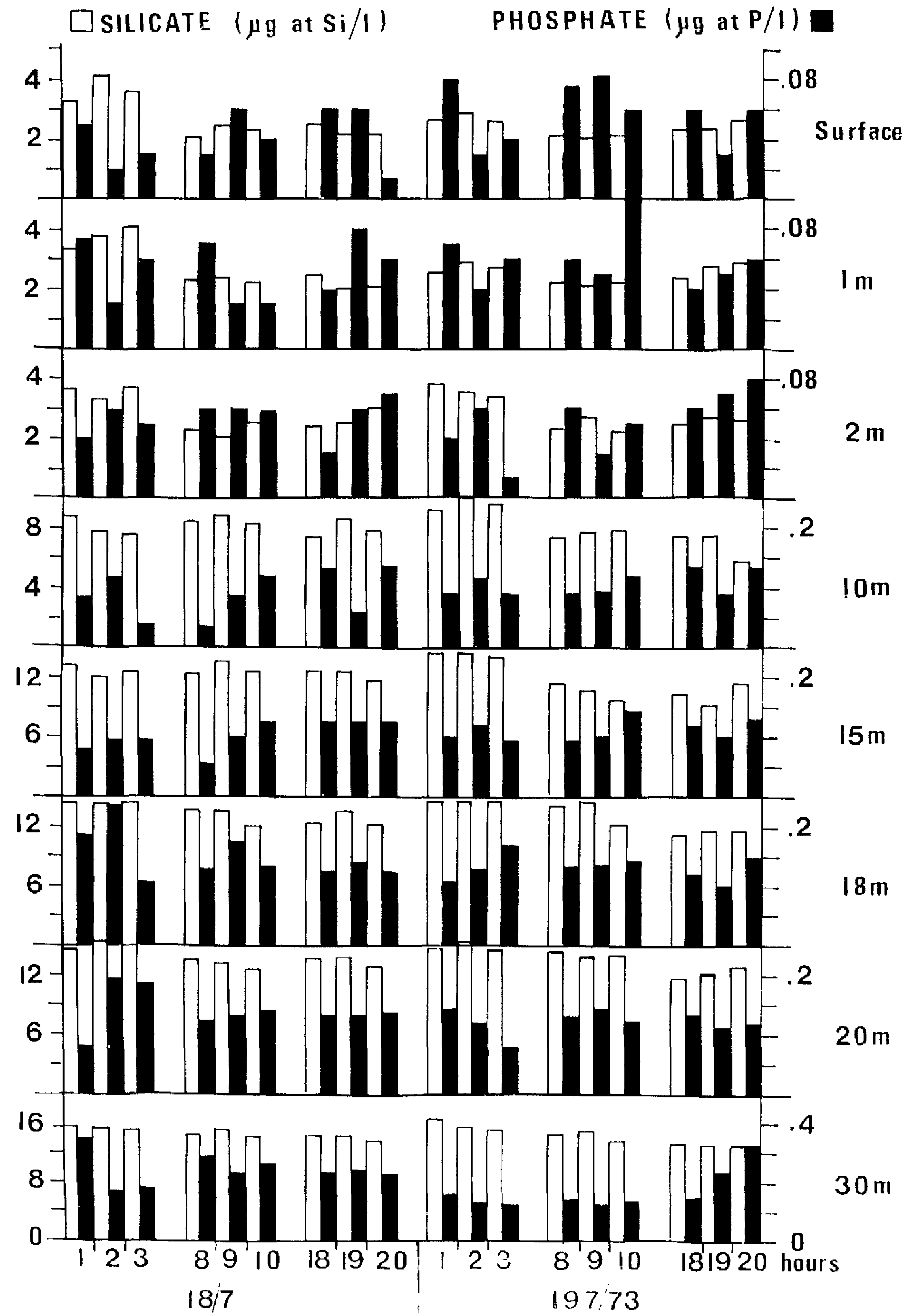
During the period of the experiment both silicate and nitrate showed a considerable net decrease throughout the upper 10 m of the water column, whereas phosphate showed marked fluctuation but no overall change. The silicate curves show a large decline in concentrations in the epilimnion between 0330 and 0930 on both days of the survey and an increase between 2030 and 0130 on the 19th. The latter increase has already been explained on a purely physical basis whereas the decline in silicate can be attributed to the activity of diatoms particularly the dominant form <u>Tabellaria fenestrata</u>.

This species shows its maximum abundance in surface waters, and showed a distinct diurnal variation in cell numbers reaching a maximum at 0130 hours of up tp 610000 cells/l on both days. It is a well established fact that the division of diatoms entails the uptake of a considerable quantity of silicate from the water (Macan 1970; Lund 1965), in this case 2 μg at. Si/l were utilized between 0230 to 0830 at the surface on 18th and 1 μg at. Si/l from 0230 to 0930 on the 19th. Thus the maximum utilization of silicate occurs after the maximum number of diatoms have been reached. This is in agreement with Lund (1965) who states that in relation to the rate of multiplication (in <u>Melosira</u>) silicification may not be completed till after the separation of the two daughter cells.

The curves of nitrate in the upper ten metres displayed a progressive decline throughout the 48 hours with no evidence of a period of upwelling or replenishment. The overall uptake of nitrate at the surface during 48 hours was 6.4 μg at. N/l (11.8 to 5.4 μg at. N/l) while the uptake at 10 m depth was 5.4 μg at. N/l. The nitrate decline at the bottom was only marginal - 1 μg at. N/l. The period of most rapid uptake occurred between 2030 hours and 0230 hours and corresponded with multiplication

DIURNAL VARIATION

Fig 49

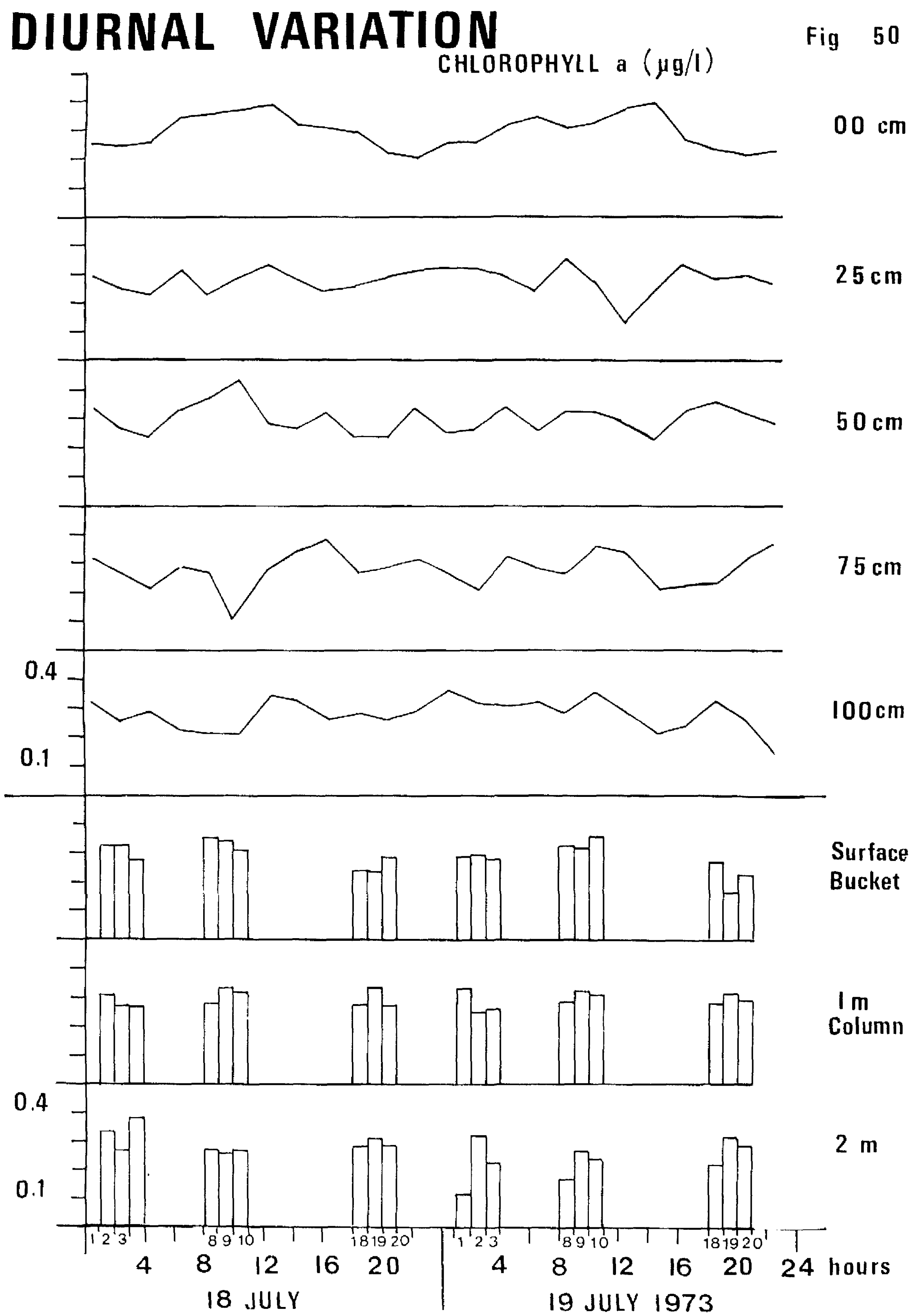


period of Tabellaria. A utilization of about 3 μg at. N/l was recorded at the surface (8.9 to 5.96 μg at. N/l), this process being completed before any uptake of silicate was evident.

The variation of phosphate during the sampling period showed a less regular pattern. A surface minimum of 0.014 μg at. P/l was recorded at 2030 hours on 18 July, during the period of diatom multiplication, otherwise phosphate levels fluctuated irregularly reaching a surface maximum of 0.08 μg at. P/l. Any reduction in phosphate concentration was transient, indicating that there is a continual supply of the nutrient to the surface, probably by upwelling. The maximum recorded phosphate concentration at 1 m depth was 0.1 μg at. P/l while at 10 m this nutrient reached 0.137 μg at. P/l. The only period when phosphate persisted at high levels (0.06 to 0.081 μg at. P/l) at the surface was from 0830 to 1830 on 19 July.

Like phosphate, nitrite displayed considerable fluctuations although a period of lower concentration was evident from midnight to 0330 on both days. During this time a minimal value of 0.026 was recorded on the 18th and 0.045 μg at. N/l on the 19th. The highest concentration of nitrite in the upper 15 m (0.083 μg at. N/l) occurred at the surface, and was observed during a period of rain. Precipitation, as a source of nitrogen containing compounds has been described by many authors throughout the world. For the British Isles (Allen et al., 1968) the annual input of nitrogen from rainfall has been estimated as 8.7 to 19 kg/hectares/annum.

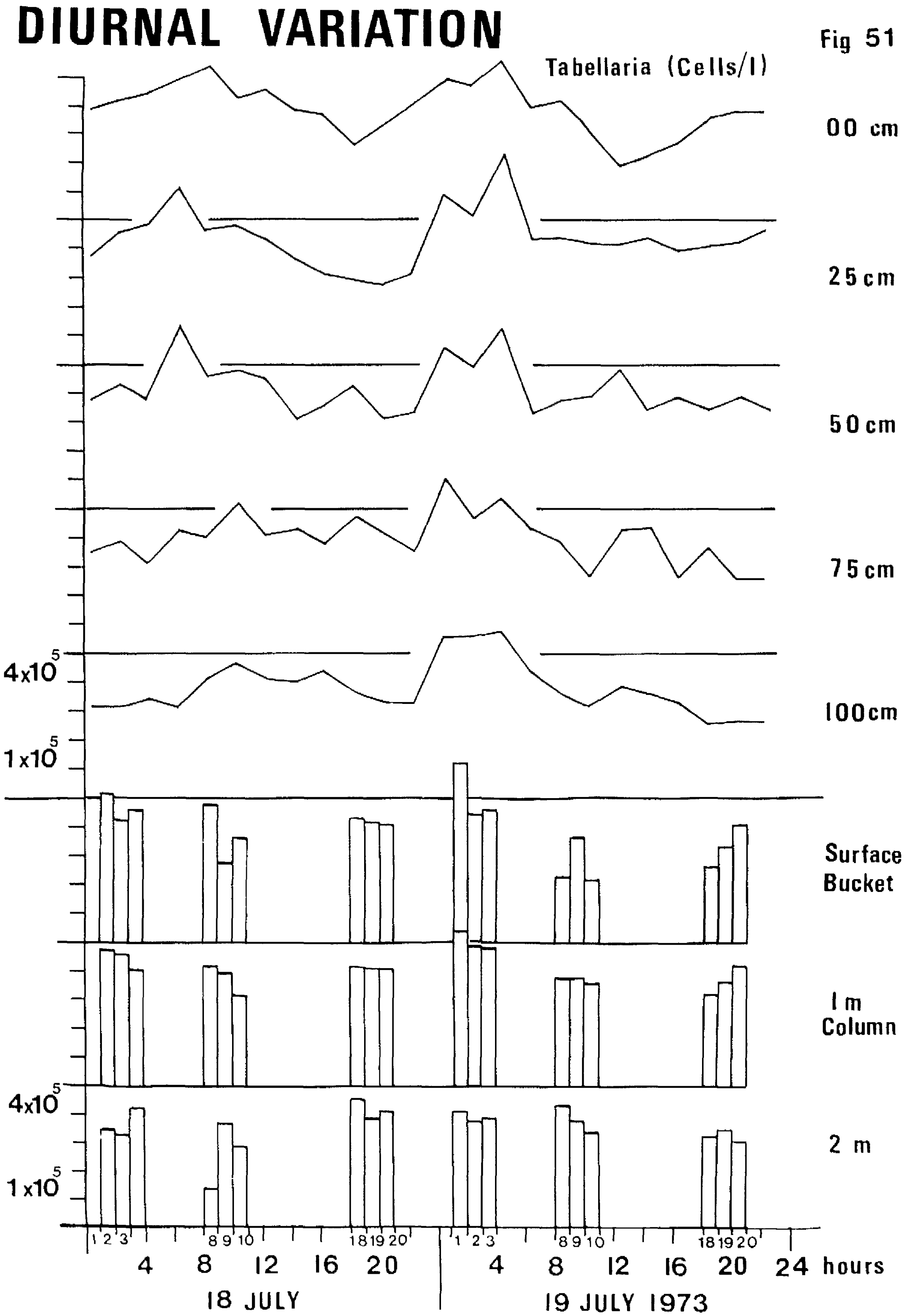
From Fig. 51 and Tables 25 and 25 a persistent diurnal variation of Tabellaria fenestrata throughout the 48 hour period is clear, with a maximum on both days at midnight (from bucket and Van Dorn samples) and slightly later from the samples taken at discrete 25 cm intervals. This periodicity might be explained as a function of several independent interacting factors. The three-fold increase in cell numbers coincided with a decrease in nitrate and was followed by a fall in silicate. This suggests a period of diatom multiplication. A period of increased reproduction activity at the onset of darkness has been remarked on by


DIURNAL VARIATION
Fig 50
CHLOROPHYLL a (µg/l)
00 cm
25 cm
50 cm
75 cm
0.4
0.1
100cm
Surface
Bucket
1 m
Column
0.4
0.1
2 m
1 2 3
8 9 10
18 19 20
1 2 3
8 9 10
18 19 20
4
8
12
16
20
4
8
12
16
20
24 hours
18 JULY
19 JULY 1973

several authors (Doty and Ogari, 1957; Lund, 1965). The continuous decrease in the numbers of Tabellaria, following the maximum, may be a function of grazing, sinking or the water flow rate. The activity of grazing animals in reducing phytoplankton numbers has been invoked by many authors (Wood et al., 1966); this would have its greatest effect at night time. Fogg (1965) considers the movement of water as a possible factor in the loss of phytoplankton. A further factor of great importance is the rate of sinking of cells. Hutchinson (1967) gave the sinking rate of Tabellaria (flocculosa) as 2 - 4.3 x 10^{-3} cm. sec^{-1} although dead or unhealthy cells would tend to sink faster (Lund, 1965). The sinking of T. fenestrata can be clearly followed in Fig. 51, which shows a peak of Tabellaria from midnight to 0300 in the top metre column whereas a peak at 2 m is not apparent until 1800 hours on 18th. A persistent increase at 10 m and 15 m Table 25) was not evident till 0930 on the second day. An investigation of the accuracy of the chlorophyll a estimation showed that, within 30 random samples taken simultaneously from the loch the standard error was $\pm$ 0.02 μg/l.

The most detailed picture of the diurnal variation of Tabellaria was obtained from the sampling carried out at a shorter (2 hours) time interval, taking 25 cm intervals throughout the top metres. From the curves (Fig. 51) it is clear that the actual peak of Tabellaria abundance came between 4 and 6 hours after midnight (a period when no surface bucket samples were taken). At surface, 25 cm and 50 cm this diel periodicity was clear while at 75 cm and 100 cm it was less distinct. The picture was complicated at the latter two depths by the sinking of cells from the surface. This phenomenon was clearest on the second day when large peak was evident at all depths in the early morning followed by a secondary peak (at 50 cm and below). The cause of the smaller peak can probably be attributed to the sinking of cells from the surface or, more unlikely, to a further period of reproduction. This is clearest at 75 cm when numbers almost doubled (250000 cells/l to 420000)between 1030 and 1230 of the second day.

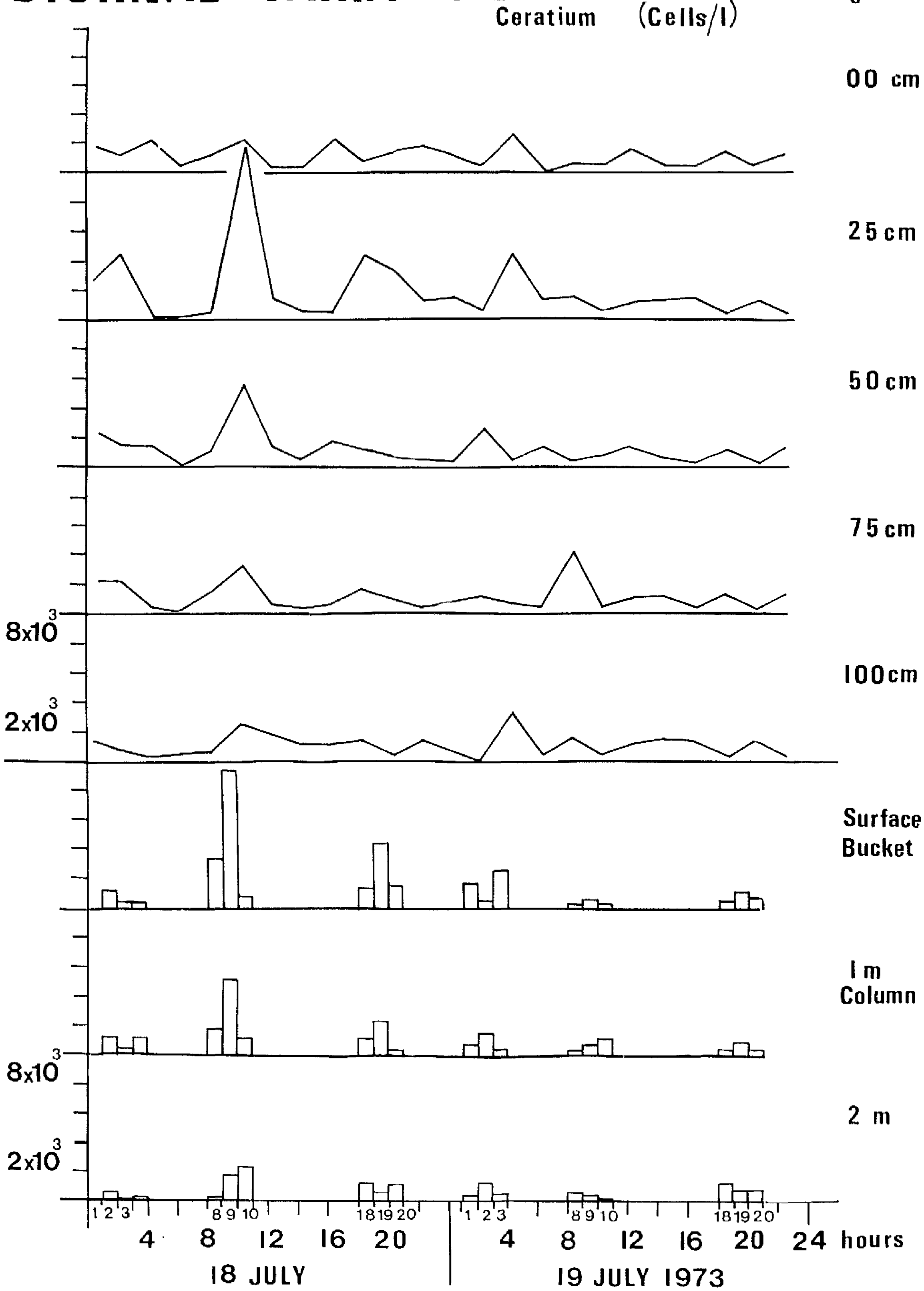
The abundance of chlorophyll a (Fig. 50, Table 23) in surface water



DIURNAL VARIATION
Fig 51
Tabellaria (Cells/l)
00 cm
25 cm
50 cm
75 cm
100cm
4x10^5
1x10^5
Surface Bucket
1 m Column
4x10^5
1x10^5
2 m
1 2 3
8 9 10
18 19 20
1 2 3
8 9 10
18 19 20
4 8 12 16 20
4 8 12 16 20 24 hours
18 JULY
19 JULY 1973

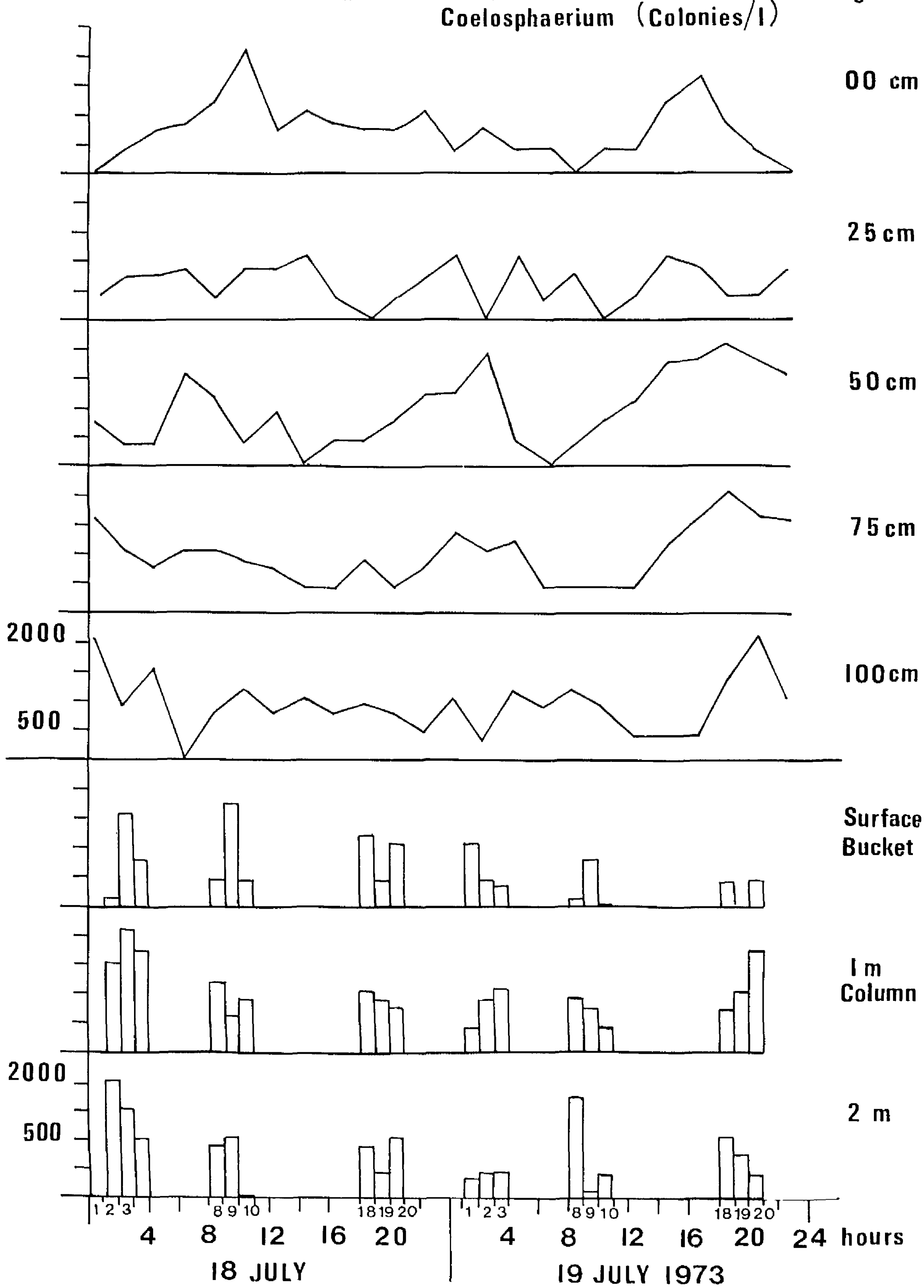
DIURNAL VARIATION

Fig 52



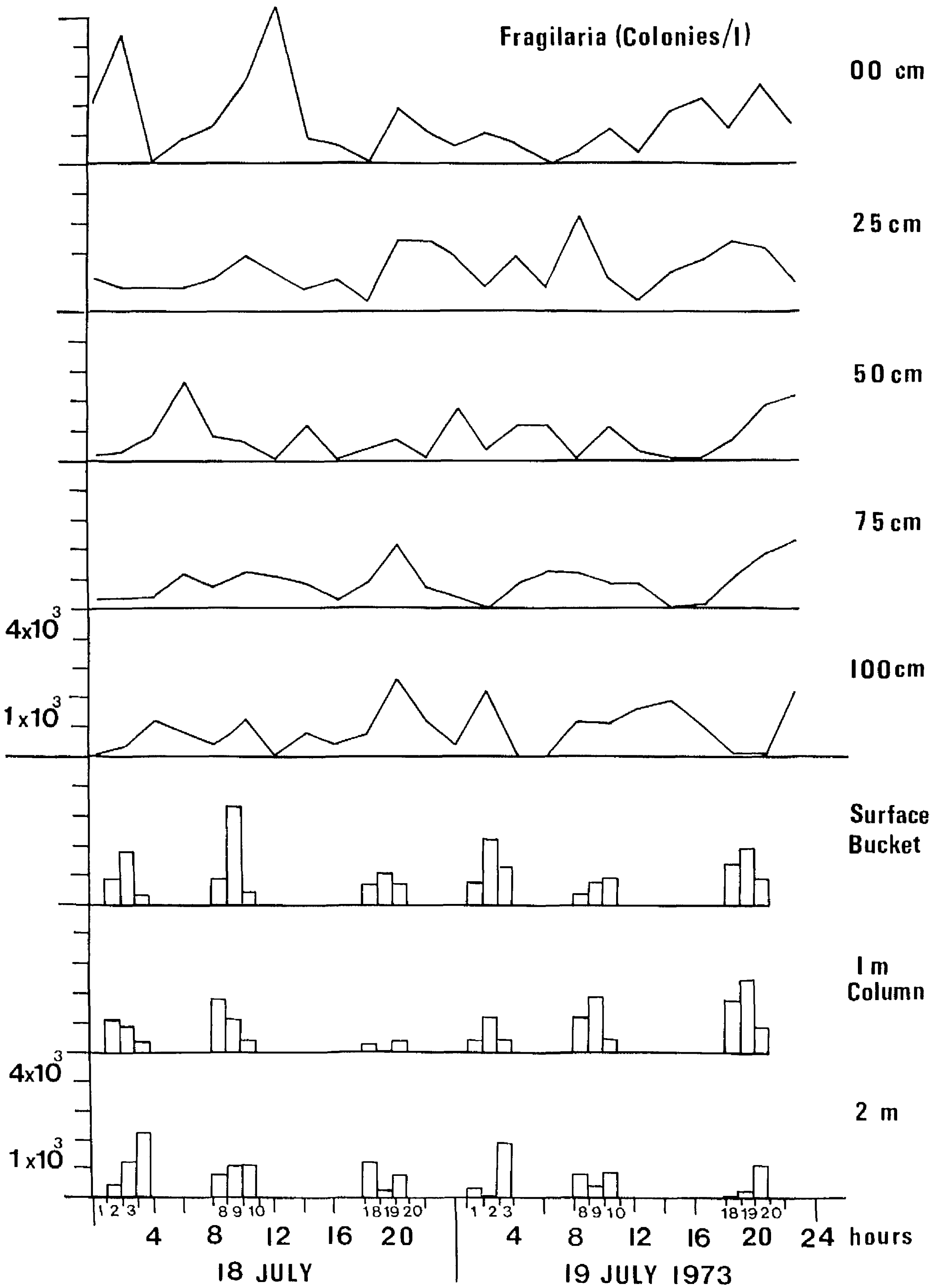
DIURNAL VARIATION

Fig 53



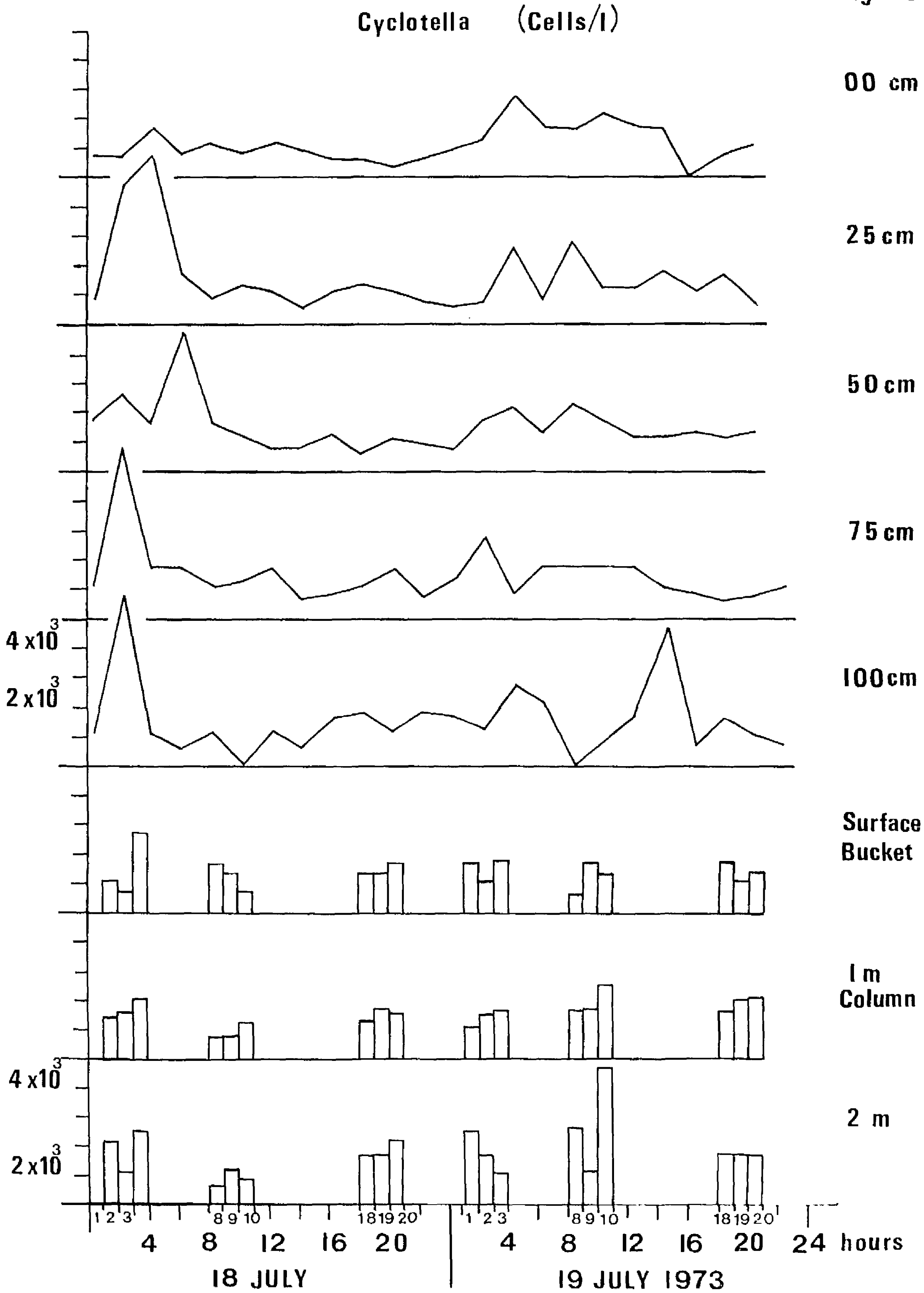
DIURNAL VARIATION

Fig 54



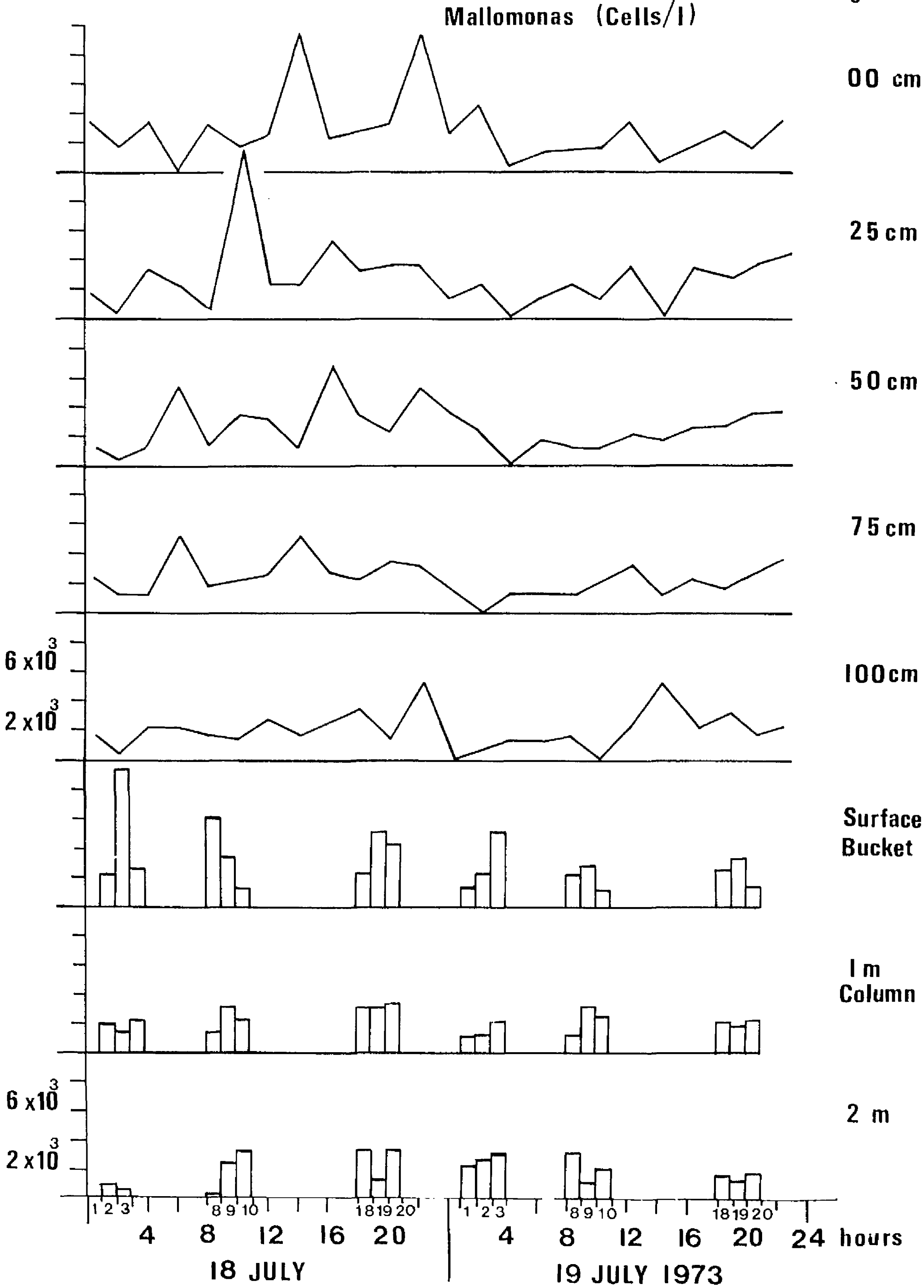
DIURNAL VARIATION

Fig 55



DIURNAL VARIATION

Fig 56



showed a regular pattern of daily variation with a single clear peak during each 24 hour period. Samples taken at surface and at discrete 25 cm intervals show a surface chlorophyll peak at mid-day (0.4 μg /l) and a minimum (0.2 μg/l) at midnight. This is in agreement with Vijayaraghavan (1971) and Lorenzen (1963). However, from bucket and Van Dorn samples a maximum (0.35 μg/l) is reached between 0830 and 1030 on both days (no samples were taken at mid-day). Thus from both series of samples the highest recorded chlorophyll value came after the peak of the dominant phytoplankton. This is in accordance with the findings of Kramer et al. (1970) who found that the predominant organism reached its maximum abundance about 6 hours before the chlorophyll peak.

The clear diurnal variation of chlorophyll in the upper 50 cm of the water column was not evident in the underlying water. Integrated samples of the upper metre showed no clear periodicity whereas bucket samples showed a clear diurnal variation. This indicates that the bucket samples do not represent water below 50 cm, while the Van Dorn samples represent a mixture of top metre of the water column. The greatest abundance of chlorophyll a was generally found in the surface samples with a maximum of 0.38 μg/l on both days. At 25 cm depth the chlorophyll reading did not exceed 0.35 μg/l. Samples taken from surface by bucket showed a maximum of 0.35 μg/l on both days whereas the top 1 m column sample (Van Dorn) did not exceed 0.33 μg/l. At 2 m depth chlorophyll shoed little distinct pattern of variation, fluctuating between 0.389 to 0.115 μg/l. At 10 m and 15 m depth chlorophyll values generally diminished falling to 0.060 μg/l at 15 m. The range of chlorophyll at 10 m depth was from 0.13 to 0.34 μg/l.

Apart from Tabellaria fenestrata the other diatoms represented in figures are Cyclotella and Fragilaria. C. comta (Fig. 55) exhibited a large peak on the first day of the investigation between 0230 and 0430 hours and attained its maximum density below the surface. At 25 cm, 75 cm and 100 cm a maximum density of 11753 cells/l was observed while at the surface numbers never exceeded 3435 cells/l. The pulse of Cyclotella which occurred at the time was found in surface (bucket), 1 m and 2 m depth samples at 0330 with a maximum of 5500 cells/l. A peak at 10 m and 15 m became apparent by 0830 hours. Following the pulse, numbers fell rapidly throughout the water column and generally fluctuated till the completion of sampling. However at 2 m depth a clear pulse (9313 cells/l) occurred on the second day at 1030 followed by a peak of the same magnitude at 100 cm depth four hours later.

Fragilaria crotonensis (Tables 26, 27 and Fig. 54) generally displayed its greatest abundance at the surface both from bottle samples and bucket samples. No diurnal periodicity was evident although on the first day a distinct pulse was observed at the surface around mid-day. From the samples taken at discrete depths a pulse of 5018 colonies/l was recorded at the surface at 1230 hours although no change was detected in the underlying 100 cm. The other series of samples showed a pulse of 2165 colonies/l at 2 m depth at 0330 followed by a peak at 2000 colonies/l at 1 m depth at 0830 with highest numbers 3435 colonies/l at the surface at 1030. At a depth of 10 m the numbers of colonies were considerably reduced whereas at 15 m depth Fragilaria was only recorded on a few occasions. No clear pattern was evident on the second day.

The colonial blue-green algae, Coelosphaerium (Fig. 53, Tables 26 and 27) showed an irregular distribution throughout the upper metres of the water column reaching a maximum of 2000 colonies/l at most levels. Two clear pulses were evident at the surface, from bottle samples, reaching peaks at 1030 on the first day and 1630 on the second day. From the second series of samples a pulse was evident at 2 m depth at 0130, at 1 m depth at 1230 and finally at the surface at 1030 on the first day. On day two a pulse of 1065 colonies/l were recorded at 10 m, 2 m and 1 m depth at 1030, 1830 and 1930 hours respectively (no rise occurred at the surface). There was a general reduction in colony numbers at 10 m depth and very few at 15 m depth were recorded on the second day.

Ceratium hirundinella (Fig. 52 and Tables 28 and 29) was generally confined to the upper part of the water column, rarely found at 10 or 15 m depth. Within the upper metre the maximum abundance was recorded at 25 cm. Here a pulse of 11753 cells/l was recorded at 1030 on the first day of sampling at 50, 75 and 100 cm depth; the magnitude of the pulse decreased to 5533, 3128 and 2610 cells/l respectively. Although no peak was observed at 00 cm the surface bucket samples showed a large pulse (9313 cells/l); thus the bucket sample does not truly represent the surface water only. The Ceratium increase was reflected in the integrated 1 m sample (5018) and at 2 m depth (2165). For the rest of sampling period Ceratium showed erratic variation with fairly low numbers.

Mallomonas (Fig. 56, Tables 28, 29) like Ceratium, reached its maximum numbers below the surface on the first day of sampling although the distribution was generally erratic. At 25 cm depth a pulse reaching 11753 cells/l occurred at 1030 on the 18th while maximum at 00cm (9313 cells/l) occurred 4 hours later. The highest number of Mallomonas from surface bucket samples (9313 cells/l) was recorded at 0230 hours on 18 July. Fairly high densities were found at 10 m and 15 M depth at 1130 on the first day where respective values of 3128 and 1753 cells/l were recorded, both higher than the number of Mallomonas at surface water.

The following points may be inferred from the continuous sampling study:-

(1) There is considerable variation in the number of phytoplankton and chlorophyll a values at 25 cm intervals in the upper one metre of the water column.

(2) Large variations in phytoplankton numbers and chlorophyll values can be expected within a time period of 2 hours at the top one metre column of the water.

(3) Large variations in phytoplankton numbers, chlorophyll a values and key chemical parameters (phosphate, silicate, nitrate and nitrite) can be found at one hour intervals at the same station.

(4) The variation in dissolved oxygen levels in the water column is greater at night than during the day.

Table 25. Continuous sampling data 0000 hours 18.7.73 to 0000 hours 20.7.73.

		Tabellaria fenestrata. No. of cells/l.					Cyclotella comta. No. of cells/l.				
Date	Hours	Surface	1 m	2 m	10 m	15 m	Surface	1 m	2 m	10 m	15 m
18.7.73	01.30	537972	468760	348262	297396	132432	2165	2500	4123	2165	1203
	02.30	411040	451824	336808	255696	189712	1545	3128	2165	2610	2165
	03.30	454116	400044	422496	297396	189252	5533	4123	5018	2853	1753
	08.30	488024	408752	144804	431204	406000	3435	1753	1203	11753	9313
	10.30	206206	391336	366132	249740	91188	2853	1753	2610	6150	1203
	11.30	372548	323060	295564	265780	132432	1545	2610	1958	3128	1203
	18.30	432120	418832	451368	402792	146636	2853	2853	3435	7780	2165
	19.30	418832	406460	394544	291900	66904	2853	3435	3435	2165	480
	20.30	404624	410124	414708	146636	132432	3435	3124	4535	1958	480
19.7.73	01.00	612208	542096	419288	354676	225456	8435	2165	5018	2165	5018
	02.00	447244	496732	373464	266236	196128	2165	3128	3435	2165	1753
	03.00	453656	492304	396376	273568	124184	3760	3435	2165	755	1065
	08.30	233704	384920	426164	371176	123724	1203	3435	5533	3435	2165
	09.30	371176	384920	371176	357428	371176	3435	3435	2165	3435	5533
	10.30	216288	371176	343680	338180	333600	2853	5018	9313	3128	2165
	18.30	265773	335888	339096	453656	333600	3435	3208	3435	2165	1065
	19.30	335888	348264	348264	338180	373464	2165	4123	3435	1065	2165
	20.30	403252	428456	335888	343680	216288	2853	4123	3435	1753	1958

Table 26. Continuous Sampling Data 0000 hours 18.7.73 to 0000 hours 20.7.73

		Coelosphaerium spp. No. of colonies/l.					Fragilaria. No. of colonies/l.				
		Surface	25 cm	50 cm	75 cm	100 cm	Surface	25 cm	50 cm	75 cm	100 cm
18.7.73	00.30	-	480	755	1550	2165	2165	1065	103	343	-
	02.30	480	755	480	1065	893	4535	893	343	343	343
	04.30	755	755	480	755	1545	-	893	755	480	1203
	06.30	893	893	1545	1065	-	893	893	2610	1203	893
	08.30	1203	480	1203	1065	755	1203	1065	893	755	480
	10.30	2165	893	480	893	1203	2853	1958	755	1203	1203
	12.30	755	893	893	755	755	5018	1203	-	1065	-
	14.30	1065	1065	-	480	1065	893	893	1203	893	893
	16.30	893	430	480	480	755	755	1065	-	480	480
	18.30	755	-	480	893	893	-	480	480	893	755
	20.30	755	480	755	480	755	1958	2370	755	2165	2610
	22.30	1065	755	1203	755	480	1065	2370	-	755	1203
19.7.73	00.30	480	1065	1203	1373	1065	618	1958	1753	480	480
	02.30	755	-	1958	1065	343	1065	893	480	-	2165
	04.30	480	1065	480	1203	1203	755	1958	1203	893	-
	06.30	480	343	-	480	893	-	480	1203	1203	-
	08.30	-	755	343	480	1203	480	3128	-	1203	1065
	10.30	480	-	755	480	893	1065	1065	1065	893	1065
	12.30	480	480	1065	480	480	480	480	480	893	1545
	14.30	1203	1065	1753	1203	480	1753	1203	-	-	1958
	16.30	1500	895	1755	1545	480	2203	1750	-	-	1065
	18.30	755	480	2123	2123	1350	1250	2203	750	1065	-
	20.30	480	480	1753	1550	2123	2600	2123	1950	1950	-
	22.30	-	755	1550	1550	1065	1350	1065	2230	2230	2065

Table 27. Continuous Sampling Data 0000 hours 18.7.73 to 0000 hours 20.7.73

		Coelosphaerium spp. No. of colonies/l.					Fragilaria. No. of colonies/l.				
Date	Hours	Surface	1 m	2 m	10 m	15 m	Surface	1 m	2 m	10 m	15 m
18.7.73	01.30	103	1550	2065	-	755	893	1065	343	343	-
	02.30	1545	2165	1545	755	343	1753	893	1203	755	343
	03.30	755	1753	1065	480	755	343	480	2165	480	-
	08.30	480	1203	893	343	755	893	1958	755	343	240
	10.30	1753	618	1065	343	343	3435	1065	1065	1065	-
	11.30	480	893	-	480	-	480	-	1065	1203	-
	18.30	1203	1065	893	-	480	755	343	1203	1065	480
	19.30	480	893	480	480	343	1065	-	343	755	-
	20.30	1065	755	1065	-	-	755	480	755	-	-
19.7.73	01.00	1065	480	343	755	103	755	480	343	-	240
	02.00	480	893	480	343	240	2165	1203	-	480	-
	03.00	343	1065	480	343	480	1203	480	1958	343	-
	08.30	103	893	1753	343	480	480	1203	755	343	-
	09.30	755	755	103	-	-	755	1958	480	1065	1203
	10.30	-	480	480	1065	-	893	480	755	1203	-
	18.30	480	755	1065	755	103	1400	1750	-	1203	-
	19.30	-	1065	755	103	-	1950	2500	343	-	-
	20.30	480	1755	480	343	-	893	893	1065	343	1203

Table 28. Continuous Sampling Data 0000 hours 18.7.73 to 0000 hours 20.7.73

		Mallamonas spp. No. of cells/l.					Ceratium spp. No. of cells/l.				
		Surface	25 cm	50 cm	75 cm	100 cm	Surface	25 cm	50 cm	75 cm	100 cm
18.7.73	00.30	3328	1800	1203	2100	1950	1753	2610	2165	2165	1203
	02.30	1753	343	480	1065	480	1203	4123	1545	2165	755
	04.30	3780	3128	1065	1065	2165	2165	-	1545	755	240
	06.30	-	2165	5533	5018	2165	343	-	-	240	480
	08.30	3128	893	1203	1958	1958	1065	343	1065	1753	480
	10.30	1958	11753	3735	2165	1753	2165	11753	5533	3128	2610
	12.30	2165	2165	3128	2610	2853	343	1065	1203	755	1958
	14.30	9313	2165	1065	5018	1958	343	480	480	480	1065
	16.30	2165	5018	6943	2610	2610	2165	480	1753	755	1065
	18.30	2610	3128	3435	2165	3435	893	4123	1203	1958	1545
	20.30	3128	3435	2165	3435	1543	1203	3128	893	1203	343
	22.30	9313	3435	5018	3128	5018	1958	1065	755	480	1545
19.7.73	00.30	2610	1065	3780	1958	-	1203	1203	480	755	755
	02.30	4535	2165	2165	-	755	480	893	2853	1203	-
	04.30	480	-	-	1203	1203	2610	4123	480	755	3435
	06.30	1065	1065	1958	1203	1203	-	1065	1203	240	480
	08.30	1203	2165	1065	1065	1753	480	1545	755	4123	1958
	10.30	1203	1203	1065	2165	-	343	480	893	343	618
	12.30	3435	3435	2165	3128	2165	1753	1065	1203	1203	1065
	14.30	893	-	1958	1065	5533	480	1203	618	1203	1545
	16.30	1800	3200	2800	2300	2165	480	1545	343	480	1203
	18.30	2800	2800	2800	1900	3200	1203	480	1207	1203	480
	20.30	1600	3800	3400	2300	1950	480	1203	408	480	1203
	22.30	3300	4200	3800	3800	2200	1203	408	1203	1203	480

Table 29. Continuous Sampling Data 0000 hours 18.7.73 to 0000 hours 20.7.73

		Mallamonas spp. No. of cells/l.					Ceratium spp. No. of cells/l.				
Date	Hours	Surface	1 m	2 m	10 m	15 m	Surface	1 m	2 m	10 m	15 m
18.7.73	01.30	2100	2000	1065	1065	-	1203	1203	755	343	-
	02.30	9313	1545	755	-	-	343	480	-	-	343
	03.30	2610	2165	-	1065	343	343	1665	343	-	-
	08.30	6150	1545	480	343	240	3435	1958	343	-	-
	09.30	3435	3128	2610	480	-	9313	5018	1958	343	-
	11.30	1203	2370	3128	3128	1753	893	1065	2165	-	-
	18.30	2165	3128	3435	2165	480	1545	1065	1203	343	-
	19.30	5018	3128	1203	1545	-	4535	2165	893	-	-
	20.30	4123	3435	3435	-	-	1753	480	1065	-	-
19.7.73	01.00	1203	1203	2165	480	103	1958	755	480	-	-
	02.00	2165	1203	2853	-	-	755	1753	1065	-	-
	03.00	5018	2165	3128	-	480	2610	480	480	240	-
	08.30	2165	1203	3128	-	-	343	240	755	480	-
	09.30	2853	3435	1065	-	-	893	755	480	-	755
	10.30	1065	2853	2165	1203	1065	343	1065	-	240	-
	18.30	2600	2370	1950	755	-	5000	300	1203	-	343
	19.30	3200	1950	1025	-	755	1201	900	755	-	-
	20.30	1200	2190	1950	1203	480	343	300	755	343	-

Table 24. Continuous sampling data 0000 hours 18.7.73 to 0000 hours 20.7.73.

		Tabellaria fenestrata. No. of cells/l.					Cyclotella comta. No. of cells/l.				
Date	Hours	Surface	25 cm	50 cm	75 cm	100 cm	Surface	25 cm	50 cm	75 cm	100 cm
18.7.73	00.30	389504	370716	387672	350096	311604	1753	1958	3435	2165	2165
	02.30	413791	451368	425248	385380	312520	1545	9313	5018	11753	11753
	04.30	448791	477244	387672	311604	343220	3435	11753	3435	3435	2165
	06.30	492000	605792	637872	437620	329016	1753	3435	9313	3435	1065
	08.30	537972	451136	454646	402336	403252	2165	1958	3128	2165	2165
	10.30	428456	471528	477244	510020	455492	2165	2610	2165	2640	-
	12.30	451368	434412	450448	402336	411956	1753	2165	1753	3435	2610
	14.30	389504	355596	311144	438076	400044	2165	1065	1753	1203	1203
	16.30	370716	301008	367508	398668	440368	1958	2165	1753	1958	3128
	18.30	265780	265780	418372	471072	379424	1203	2610	2610	2165	3435
	20.30	335888	265780	309772	415624	347804	1203	2165	1065	3435	2165
	22.30	403252	307020	342764	350096	348720	893	1753	2165	1545	3435
19.7.73	00.30	496732	596172	560884	600752	559512	1065	1203	1958	2610	3128
	02.30	468760	519184	491692	472444	557428	1545	1545	1545	5533	2165
	04.30	551720	729520	618164	547140	572340	2370	5018	3435	1958	5533
	06.30	398668	422956	333600	429828	438536	5533	1753	4123	3435	4123
	08.30	409208	429372	385380	393168	364300	3435	5533	2610	3435	-
	10.30	339096	408292	398668	253408	329939	3435	2165	4535	3435	1958
	12.30	192460	415624	482528	421124	382632	4123	2165	3435	3435	3435
	14.30	212000	443576	347344	432580	364300	3780	2165	2165	2165	9313
	16.30	265773	389504	398668	253408	335888	3435	3780	2165	1958	1958
	18.30	348264	415624	348264	370716	253408	-	2165	2610	1203	3435
	20.30	370716	422956	398668	253408	265780	1958	3435	2165	1753	2165
	22.30	370716	471528	335888	253408	253408	2165	1753	2610	2165	1753

Table 23. Loch Lomond. Continuous Sampling Data 0000 hours 18.7.73 to 0000 hours 20.7.73

Chlorophyll (a) (μg. atom/l.)

Date	Hours	Surface	25 cm	50 cm	75 cm	100 cm	Hours	Surface	1 m	2 m	10 m	15 m
18.7.73	00.30	0.25	0.29	0.32	0.307	0.32	01.30	0.32	0.307	0.33	0.34	0.138
	02.30	0.243	0.255	0.272	0.273	0.258	02.30	0.32	0.27	0.268	0.23	0.216
	04.30	0.264	0.23	0.242	0.227	0.295	03.30	0.273	0.276	0.389	0.254	0.108
	06.30	0.344	0.318	0.33	0.299	0.23						
	08.30	0.35	0.239	0.359	0.277	0.21	08.30	0.35	0.28	0.27	0.141	0.08
	10.30	0.36	0.29	0.43	0.103	0.20	10.30	0.34	0.33	0.26	0.206	0.13
	12.30	0.38	0.32	0.289	0.286	0.34	11.30	0.31	0.32	0.277	0.24	0.16
	14.30	0.314	0.289	0.27	0.347	0.32						
	16.30	0.38	0.242	0.31	0.37	0.26	18.30	0.24	0.27	0.28	0.25	0.18
	18.30	0.285	0.264	0.245	0.26	0.28	19.30	0.242	0.33	0.31	0.183	0.104
	20.30	0.23	0.28	0.24	0.28	0.26	20.30	0.288	0.27	0.28	0.19	0.14
	22.30	0.206	0.31	0.33	0.31	0.28						
19.7.73	00.30	0.26	0.32	0.25	0.266	0.36	01.00	0.288	0.33	0.115	0.19	0.13
	02.30	0.256	0.32	0.26	0.20	0.316	02.00	0.295	0.25	0.32	0.181	0.092
	04.30	0.322	0.28	0.34	0.313	0.302	03.00	0.277	0.256	0.23	0.2	0.06
	06.30	0.344	0.24	0.269	0.28	0.32						
	08.30	0.304	0.35	0.32	0.269	0.28	08.30	0.32	0.29	0.16	0.13	0.12
	10.30	0.32	0.27	0.32	0.35	0.351	09.30	0.31	0.32	0.27	0.202	0.06
	12.30	0.37	0.139	0.28	0.34	0.278	10.30	0.35	0.31	0.24	0.24	0.13
	14.30	0.38	0.248	0.212	0.215	0.207						
	16.30	0.251	0.32	0.32	0.22	0.241	18.30	0.27	0.27	0.22	0.23	0.155
	18.30	0.232	0.28	0.35	0.23	0.32	19.30	0.153	0.31	0.31	0.189	0.138
	20.30	0.22	0.29	0.301	0.32	0.26	20.30	0.234	0.28	0.28	0.23	0.115
	22.30	0.23	0.27	0.28	0.36	0.142						

Table 22. Loch Lomond. Continuous Sampling Data 0000 hours 18.7.73 to 0000 hours 20.7.73.

Phosphate (μg. atom P/l.).

Date	Hours	Surface	1 m	2 m	10 m	15 m	18 m	20 m	30 m	40 m	47 m
18.7.73	01.30	0.05	0.072	0.04	0.08	0.078	0.183	0.078	0.35	0.43	0.42
	02.30	0.02	0.03	0.06	0.12	0.09	0.23	0.196	0.157	0.43	0.43
	03.30	0.03	0.06	0.05	0.03	0.09	0.117	0.18	0.17	0.63	0.63
	08.30	0.03	0.07	0.06	0.03	0.062	0.127	0.12	0.28	0.53	0.63
	10.30	0.06	0.03	0.06	0.08	0.1	0.175	0.13	0.23	0.34	0.63
	11.30	0.04	0.03	0.06	0.12	0.125	0.137	0.14	0.26	0.63	0.63
	18.30	0.06	0.04	0.03	0.13	0.125	0.125	0.13	0.23	0.2	0.52
	19.30	0.06	0.08	0.06	0.062	0.125	0.137	0.13	0.24	0.23	0.42
	20.30	0.014	0.06	0.07	0.137	0.125	0.125	0.13	0.23	0.23	0.35
19.7.73	01.00	0.08	0.07	0.04	0.087	0.10	0.106	0.14	0.16	0.3	0.43
	02.00	0.03	0.04	0.06	0.112	0.12	0.13	0.12	0.13	0.34	0.33
	03.00	0.04	0.06	0.013	0.087	0.09	0.17	0.08	0.13	0.33	0.53
	08.30	0.075	0.06	0.06	0.087	0.9	0.13	0.13	0.14	0.4	0.42
	09.30	0.081	0.05	0.03	0.09	0.1	0.13	0.14	0.12	0.3	0.9
	10.30	0.06	0.1	0.05	0.12	0.14	0.14	0.12	0.13	0.32	0.53
	18.30	0.06	0.04	0.06	0.13	0.12	0.12	0.13	0.15	0.62	0.62
	19.30	0.03	0.05	0.07	0.08	0.10	0.10	0.11	0.23	0.7	0.35
	20.30	0.06	0.06	0.08	0.13	0.13	0.15	0.12	0.32	0.3	0.48

Table 21. Loch Lomond. Continuous sampling data 0000 hours 18.7.73 to 0000 hours 20.7.73.

Silicate (µg. atom/l.)

Date	Hours	Surface	1 m	2 m	10 m	15 m	18 m	20 m	30 m	40 m	47 m
18.7.73	01.30	3.30	3.38	3.62	8.84	13.1	14.59	14.48	15.54	16.82	16.82
	02.30	4.13	3.77	3.34	7.94	12.00	14.4	15.23	15.54	16.55	16.50
	03.30	3.55	4.06	3.70	7.77	12.86	14.69	15.01	15.44	15.86	16.29
	08.30	2.11	2.24	2.3	8.67	12.65	13.72	13.68	14.74	15.80	16.20
	10.30	2.55	2.49	2.04	8.94	13.6	13.6	13.48	15.46	15.30	16.50
	11.30	2.38	2.20	2.59	8.21	12.75	12.46	12.96	14.04	14.39	16.20
	18.30	2.53	2.51	2.45	7.46	12.69	12.75	13.58	14.2	12.08	16.42
	19.30	2.20	2.04	2.53	8.69	12.69	13.66	13.62	14.22	12.75	16.72
	20.30	2.21	2.03	3.09	7.57	11.79	12.40	13.04	13.87	14.47	16.59
19.7.73	01.00	2.74	2.51	3.86	9.14	14.40	14.40	14.86	16.96	16.46	16.69
	02.00	2.97	2.97	3.54	10.06	14.40	14.40	15.32	15.54	16.23	16.46
	03.00	2.74	2.74	3.31	9.6	14.06	14.40	14.4	15.54	16.46	16.23
	08.30	2.17	2.24	2.3	7.24	11.44	14.06	14.33	14.91	15.76	15.87
	09.30	2.01	2.11	2.79	7.69	10.69	14.16	13.82	15.02	15.42	15.7
	10.30	2.10	2.24	2.30	7.83	10.12	12.42	13.95	13.85	14.7	16.19
	18.30	2.39	2.49	2.55	7.53	10.59	11.21	11.81	13.8	13.97	14.38
	19.30	2.4	2.74	2.7	7.55	9.28	11.91	12.49	13.7	14.27	14.93
	20.30	2.68	2.97	2.61	5.98	11.43	11.97	13.1	13.3	14.44	15.4

Table 20. Loch Lomond. Continuous Sampling Data 0000 hours 18.7.73 to 0000 hours 20.7.73.

Nitrite - nitrogen (µg. atom/l.).

Date	Hours	Surface	1 m	2 m	10 m	15 m	18 m	20 m	30 m	40 m	47 m
18.7.73	01.30	0.051	0.055	0.053	0.045	0.053	0.02	0.056	0.061	0.07	0.08
	02.30	0.055	0.056	0.075	0.06	0.056	0.058	0.066	0.066	0.03	0.026
	03.30	0.026	0.051	0.061	0.048	0.018	0.083	0.023	0.016	0.07	0.02
	08.30	0.063	0.058	0.058	0.053	0.055	0.053	0.053	0.071	0.07	0.062
	10.30	0.061	0.061	0.061	0.063	0.058	0.06	0.06	0.055	0.07	0.072
	11.30	0.081	0.071	0.083	0.056	0.058	0.067	0.075	0.066	0.073	0.07
	18.30	0.058	0.063	0.075	0.06	0.059	0.06	0.056	0.066	0.083	0.068
	19.30	0.051	0.06	0.058	0.055	0.06	0.066	0.063	0.07	0.083	0.085
	20.30	0.066	0.066	0.065	0.063	0.053	0.063	0.071	0.07	0.078	0.078
19.7.73	01.00	0.083	0.051	0.063	0.051	0.048	0.041	0.05	0.083	0.066	0.07
	02.00	0.055	0.05	0.056	0.05	0.048	0.051	0.055	0.053	0.07	0.066
	03.00	0.045	0.05	0.053	0.046	0.053	0.05	0.05	0.066	0.071	0.07
	08.30	0.058	0.055	0.061	0.06	0.06	0.06	0.063	0.073	0.076	0.08
	09.30	0.061	0.061	0.068	0.061	0.061	0.06	0.063	0.06	0.083	0.078
	10.30	0.061	0.066	0.06	0.06	0.06	0.05	0.063	0.07	0.076	0.073
	18.30	0.041	0.05	0.061	0.038	0.05	0.063	0.041	0.063	0.078	0.063
	19.30	0.053	0.07	0.061	0.061	0.066	0.053	0.061	0.078	0.068	0.081
	20.30	0.066	0.05	0.06	0.061	0.066	0.043	0.058	0.058	0.053	0.078

Table 19. Loch Lomond. Continuous sampling data 0000 hours 18.7.73 to 0000 hours 20.7.73.

Nitrate + Nitrite (µg. atom - N/l).

Date	Hours	Surface	1 m	2 m	10 m	15 m	18 m	20 m	30 m	40 m	47 m
18.7.73	01.30	11.8	11.6	10.1	11.69	13.62	14.69	15.08	15.08	13.6	13.4
	02.30	10.9	11.6	11.49	12.9	14.18	14.49	14.85	15.04	13.2	13.4
	03.30	11.2	11.0	11.3	13.23	14.96	12.56	15.2	15.0	13.1	13.3
	08.30	9.95	9.83	10.46	13.28	13.27	14.61	14.02	13.74	12.3	12.6
	10.30	10.3	9.62	10.46	12.82	14.22	13.43	14.02	15.4	13.4	12.8
	11.30	9.08	9.28	10.3	12.3	13.69	13.69	13.69	14.53	13.5	12.9
	18.30	9.48	8.96	7.7	10.27	11.65	10.56	11.45	14.02	12.24	12.24
	19.30	8.67	9.28	9.16	10.11	12.04	12.04	12.6	14.3	12.83	12.04
	20.30	8.9	9.08	8.07	10.46	11.85	11.45	12.24	14.2	11.77	12.64
19.7.73	01.00	7.3	6.79	7.74	9.83	9.91	9.2	9.0	13.2	12.4	13.03
	02.00	5.96	6.35	7.26	7.89	8.96	8.69	8.69	13.3	12.64	12.83
	03.00	6.3	6.95	6.04	7.9	8.29	8.49	9.67	12.4	13.66	10.9
	08.30	6.1	6.1	7.1	8.8	8.6	10.2	11.2	13.4	14.3	11.3
	09.30	6.3	5.8	5.4	9.3	8.3	9.3	10.8	13.5	12.3	12.2
	10.30	5.9	5.6	5.8	8.2	9.2	8.6	9.7	14.2	12.2	13.1
	18.30	5.2	5.6	5.3	7.2	9.3	9.2	10.6	13.8	12.3	12.9
	19.30	5.3	6.1	5.4	5.8	8.8	9.3	11.2	13.9	12.5	12.3
	20.30	5.4	5.3	5.6	6.3	9.1	10.2	11.3	14.1	12.8	12.4

(5) The maximum abundance of chlorophyll a (on both days) was found between 1000 and 1400 hours.

(6) The decrease of nitrate coincided with the increase in phytoplankton numbers whereas the decrease of silicate came after the period of increase.

(7) The thermocline moved upwards during the day and downwards at night.

(8) The hypolimnion and thermocline act as a source of nutrient to the epilimnion in Loch Lomond.

(9) Oxygen saturation never fell below 80% throughout the water column with the minimum value usually being found in the metalimnion.

(10) The multiplication of *T. fenestrata* took place at night.

(11) The greatest abundance of *Fragilaria* was at the surface.

(12) Bucket samples did not represent only surface water.

(13) Twenty-four hours sampling does not give a true feature of diurnal variation neither for phytoplankton, chlorophyll nor chemical parameters, a longer period is necessary.

CHAPTER 5

DISCUSSION

The five fresh water lochs investigated in this survey can be classified according to their circulation type as "Halomictic" (Peschalski, 1964) since they possess one, two or more than two periods of circulation during the year. Hutchinson (1957) concluded from the early studies on some Scottish fresh water lochs (Loch Lomond amongst them) by Jardine (1812) Buchan (1871, Buchannan (1887) that most are warm monomictic in nature. Slack (1957) clearly showed the presence of one circulation period in all three regions of Loch Lomond but did not classify them according to circulation type. However Hunter (1970) described Loch Lomond as a typical warm monomictic lake, although in severe winters it may become dimictic.

The results of the present investigation clearly demonstrate that the North and Middle regions of Loch Lomond (Tarbet and Luss basins) are of a warm monomictic type. Both regions have a single circulation period and are clearly stratified for more than half the year (May to October at Middle and April to December at the North station). For the remainder of the year the water mass is completely mixed. According to Welch (1952) and Hutchinson (1957) such bodies of water can be classified as tropic lakes of the second order since they have a single circulation period in the winter with a water temperature always remaining above 4°C.

At the North Station, in the Tarbet basin, the thermocline was initiated at 5 m depth in late spring and early summer whereas by the beginning of December it could just be detected at 75 m. The epilimnion temperature ranged from about 7°C at the commencement of stratification to about 16°C at the end of July. The variation in the hypolimnion temperature was extremely small, being only 1.4°C. These data are closely in accordance with the views of Slack (1957) and Hunter (1970). At the Middle Station in the Luss basin where the water is much shallower (50 m) and the loch is wider the water remains completely mixed for a longer period. Stable layering of the water continued from May to October with an epilimnion temperature ranging from 7.8 to 18.5°C. During this period the metalimnion was initiated at 10-15 m for much of the summer extending to a maximum depth of 22 m in October. Both the annual range of temperature at the surface (13.5°C) and in the hypolimnion (6.5°C) were greater than at the North Station (as indicated by Slack (1957)) but there is still one period of circulation.

At the South Station in the fault basin the water temperature fell below 4°C only in February 1972 when 3.8°C was recorded at the bottom (20 m). However a reverse thermocline was not recorded although this can happen in a severe winter, e.g. as in 1963 when the loch surface became frozen over with, presumably, the formation of a reverse thermal gradient. This region can therefore be classified as generally warm monomíctic with the possibility of becoming dimictic in severe weather. This is in agreement with Hunter (1970). The circulation period at this station from September to May was longer than the other two main stations and the annual range of temperature (14°C) was greater. The maximum surface (18.5°C) and bottom (14°C) temperatures were only exceeded by those at the South Balmaha station.

The distinctive thermal characters of the three regions could be explained by topography of the surrounding areas, morphology of the basin and the ratio of the surface area to volume. The lower loch has the largest surface area to volume ratio and consequently receives more radiant energy than the upper loch which has a small surface area and large volume. The greater wind exposure of the shallow southern part of Loch Lomond allows mixing at almost any time of the year. This was particularly evident in May 1973 when stable layering was a transient phenomenon, being replaced by isothermal conditions later in the same month. The rapid response of water temperature to environmental changes at the South Station can be contrasted with the North Station where the greater depth and volume of water results in a smaller annual temperature range.

The oxygen distribution in the water column in Loch Lomond with concentration never falling to low levels is typical of oligotrophic areas according to Hunter (1970). In the present survey the lowest recorded value was 72% although Slack (1957) recorded a minimum percentage saturation of 62%. Both values were obtained in the hypolimnion of North Station (Tarbet basin).

At the Middle and South Stations the persistence of high oxygen levels throughout the year is a consequence of the long period of circulation and the relatively short period of stratification combined with greater exposure to the wind. The absence of stagnation at the North Station which is stratified for about three quarters of the year is attributed by Slack (1957) to the very large volume of hypolimnion making any significant degree of deoxygenation difficult. McColl (1972) gave a similar explanation for the lack of deoxygenation in the deep lakes in New Zealand. In addition the factor responsible for clinograde oxygen distribution (e.g. decomposition of organic matter) operates at a lower rate at the low temperature found in the hypolimnion in the upper loch. Animal respiration is also of less importance here since the number of animals per square metre of mud surface is less than that in the South Station (Weerekoon, 1956).

The vertical distribution of oxygen at all regions of Loch Lomond tends to be generally clinograde during the summer and orthograde in winter. During stratification a marked oxygen minimum was often observed in the metalimnion producing a negative heterograde (Hutchinson, 1957) distribution although positive heterograde curves have also been recorded on occasions.

Lake of Menteith was completely isothermal for most of the year. The range of temperature in this body of water was from 3.2°C to 20°C. Although it was not possible to take oxygen-temperature profiles at the deepest point in the lake. Data for 1969 and 1970(supplied by Mr B. Morrison - private communication) from the deepest region show that the lake may be classified according to Hutchinson (1957) as warm monomictic. The frequent freezing of this shallow lake indicates that dimictic circulation could be expected, although ice cover was not evident during the present survey.

The vertical distribution of oxygen was generally clinograde with the oxygen minimum at the bottom . Here the lowest recorded oxygen content was 77% in May 1973 coinciding with the end of the spring outburst of Melosira whereas a maximum of 124% saturation was found at the surface in January. Oxygen super saturation of the surface water coincided with a bloom of Coelosphaerium, accompanied by Anabaena. The clinograde curve is a consequence of the decomposition of large quantities of phytoplankton (Hutchinson 1957) on the lake floor; however, the oxygen deficit would have been greater had it not been for the continual wind circulation of the water mass.

Loch Rusky is situated at higher altitude than Lake of Menteith and very often freezes over during the winter (Dr. Weir - private communication). However in 1973 the temperature of the water did not fall below 2°C and ice cover was not observed. The period of stratification lasted from July to October and the surface temperature ranged from 2-19°C making Loch Rusky monomictic.

Oxygen showed a significant clinograde distribution for most of the year in Loch Rusky with greatest percentage saturation at the surface between November and January. During the period of steepest gradient (110%at the surface to 70% at the bottom) was found on 24 January, 1973. A negative heterograde distribution was found in July, when saturation in the metalimnion fell to 78% while 88% and 84% were recorded at surface and bottom respectively.

Loch Achray and Loch Ard are typical warm monomictic lakes, both being stratified from May till November. The surface temperature range in Loch Achray was from 4 to 18.7°C and in Loch Ard from 4.4 to 18.6°C. Both lochs were sampled in a water depth of 20 m, of which the hypolimnion constituted almost half (or slightly more in Loch Achray). The temperature range in the hypolimnion was very similar in both bodies of water. The distribution of oxygen was mainly clinograde although an orthograde distribution was found during the winter. The lowest recorded value of oxygen saturation in any of the five lochs (68%) was found in Loch Ard while the minimum in Loch Achray was 76%. A negative heterograde distribution of oxygen was found on a single occasion in Loch Ard with the oxygen minimum at the bottom of metalimnion.

A clinograde distribution of oxygen in the water column coincides with the end of phytoplankton peaks in all five lochs and the concomitant increase in the biological oxidation of dead organic matter (in the lower part of the water column) and result in reduction in oxygen content of the water (Hutchinson, 1957). A positive heterograde distribution of oxygen with maximum in the metalimnion resulted from the photosynthetic activity of phytoplankton retarded in their descent by water of increased density. This stable layer would not be able to lose oxygen by turbulence. A negative heterograde distribution of oxygen with a minimum in the metalimnion results from the decay of accumulated organic particles sinking from the epilimnion into the less turbulent thermocline.

The South Station of Loch Lomond and Lake of Menteith could also be defined as polymictic according to the classification of Paschalski (1969); this applies to lakes in which the water mass may be mixed several times in one summer, with only short periods of stratification.

The pattern of seasonal nutrient variation in Loch Lomond and the other four lochs with the maximum abundance of phosphate, nitrate and silicate occurring in the winter and the lowest concentration in the summer is in accordance with the general pattern described for many bodies of water (e.g. Heron, 1961; Duthie, 1965; Stewart, 1974). In Loch Lomond nitrate and silicate were always present and never fell to undetectable levels even during the summer periods. The lowest recorded surface nitrate value was 4.1 μg at. N/l at the North Falloch station while silicate reached its lowest concentration at the South Station where 2.2 μg at. Si/l was recorded. Dissolved phosphate only rose above 0.2 μg at. P/l at the South Balmaha Station fal-ing to trace levels throughout the loch during the summer. The highest winter levels of nitrate (23.1 μg at. N/l) were found at South Balmaha while at the northern end of the loch the maximum of only 14.2 was recorded. Silicate, at its winter peak range from 25.3 μg at. Si/l at the southern end of the loch to 16 μg at. Si/l throughout the upper loch. Nitrite was generally low only varying between 0.01

and 0.12 µg at. N/l.

The earliest maximum was that of nitrate which reached its peak concentration between January and February at all stations closely followed by phosphate and silicate which attained maxima between February and March. The vertical distribution of nutrients in the upper 10 m was generally in accordance with that at the surface except that the minimum was generally greater at depth.

The seasonal distribution of nutrients in lake water can be ascribed to many different factors both internal and external to the body of water. Within the loch itself the winter rise in all nutrients is associated with the annual mixing cycle (Hutchinson 1957). The contribution made to nutrient supply by the hypolimnion became evident in Loch Lomond during the continuous 48 hours sampling programme. Nevertheless nutrient release to the overlying water from the sediment is negligible because of the high oxygen saturation (Mortimer 1971). The phosphate distribution in natural waters is determined by behaviour of other substances (Reid 1961) such as iron which has been shown to occur in the sediment of Loch Lomond (Slack 1957). Nitrate results from the process of nitrification (Martin and Goff, 1972). External sources of supply are also of considerable importance both from natural and artificial sources. Each year large quantities of dissolved inorganic nitrogen compounds are supplied in the rainfall (Allen *et al.* 1968) whereas the most important natural source of silicate and phosphate is from the erosion of rock mineral (Golterman 1973). In Loch Lomond the winter maximum of silicate is closely related to the rise in the silicate content of the inflowing streams. Natural terrestrial ecosystems also supply nutrients which reach the loch via the run off water (Allen *et al.*, 1968; Martin and Goff, 1972; Golterman, 1973) while the input of nitrogen and phosphorus compounds from agriculture and urbanization is of increasing importance in many areas (Stewart, 1968). The summer depletion of dissolved nutrients is a function of assimilation by phytoplankton and bacteria (Stewart, 1974). Consequently the lower loch which generally has a higher standing crop of phytoplankton shows a greater summer nutrient depletion than do stations in the upper loch.

This general pattern of events has been described for many bodies of water and is generally applicable to Loch Lomond although a few peculiar features need further attention and explanation. Firstly, in 1972 a rise in the levels of nitrate, phosphate and silicate took place throughout the loch in late spring while in 1973 a similar increase occurred slightly earlier. In both years the increase coincided with an unusual pattern of rainfall. In 1972 April, May and June were unusually wet and had a greater total amount of rainfall than January, February and March. In 1973 April, May and June became increasingly wet. The nutrient data for the inflows in 1973 show high nutrient content in the first half of March and again towards the end of April. The increase in phosphate and silicate in the lower loch towards the end of April coincided with the high content of these nutrients in most of the inflows. Another factor in the vernal rise in nutrient is the decline and decomposition of the early spring phytoplankton outburst with subsequent release of nutrient to the water (Heron 1961 and Macan 1970) and their subsequent distribution throughout the circulated water mass.

Secondly, in September 1972 phosphate showed a sudden and striking increase rapidly rising from almost undetectable levels to more than 0.1 µg at. P/l at all stations. The greatest abundance of this nutrient was detected at both extremities of the loch, with South Balmaha reaching 0.29 and North Falloch rising to 0.22 µg at. P/l. It is unlikely that this increase had an internal origin for several reasons. First, the strong stratification at the North and Middle Stations at this time would prevent the recirculation of such large quantities of nutrient (Hutchinson 1957). Second, the oxygen content of the water column (more than 2 mg/l) is sufficient to prevent any release of phosphate from the sediment (Mortimer, 1971). Third, if phosphate originated biologically a simultaneous rise in other nutrients might be expected (Stumm 1973). However, this was not apparent. Unless we ascribe the increase to unknown sources within the loch, it is more likely that the source is from outside the loch. This will be either directly from rainfall (Kramer 1973) or from the inflows to the loch. It is unlikely that the source was from rainfall since September was the driest month during the two years of the survey. However, water analysis of all major inflows shows high levels of phosphate during August and the first half of September. The Endrick, Fruin and Falloch all attain their highest annual levels of phosphate during this period, while Finlas, Luss, Douglas and most other inflows showed increases. This is evidently the cause of the increased levels of phosphate observed in the loch at this period.

In the Endrick and Fruin which flow through fertile arable land the increase of phosphate was accompanied by high nitrate levels. However, in the Falloch, Finlas and Douglas the phosphate rise was accompanied by an increase in silicate indicating (according to Golterman 1973) a geological origin of these nutrients. An additional source of phosphate in the upper loch is from run-off water from peat which may contain more than 1 mg/l phosphate (Golterman 1973).

The seasonal variation of nitrite in Loch Lomond was variable with maximum at all stations in August; this coincided with the nitrate minimum. Reid (1961) showed the similar situation and stated that the reason for this was unknown. However in Loch Lomond the nitrite maximum was clearly influenced by the high nitrite content of the rivers and burns during the summer.

The annual range of pH in Loch Lomond is small in all regions. This is in accordance with the small range exhibited by most large lakes (Welch 1958). The minimum pH values were found in all cases in winter and could be related to the high rainfall which effectively reduces the pH (Welch 1952). There is also a relationship with overturn period (Welch 1952) which leads to a reduction in pH. The increase in pH observed throughout the loch in summer could, to a certain extent, be related to the phytoplankton (Prescott 1969). However the influence of the inflows is also a major factor particularly in determining the high pH values in the lower loch and the lower overall values in the upper loch.

Alkalinity likewise, showed a small annual range generally being high in spring and summer and low in winter. According to Lund (1965) the pH reflects either high concentration of bicarbonate or caronate (alkalinity) or low alkalinity, which indicates that there is little carbon dioxide in solution. The influence of the inflows in determining alkalinity in the upper and lower loch is clear. The higher alkalinity in the lower loch is a consequence of the main inflows, especially the Endrick which has a range of alkalinity from 41.1 to 96.5 mg/l $CaCO_3$. In the north the River Falloch has a generally low range of alkalinity, never exceeding 11 mg/l $CaCO_3$.

Nutrient variation in Loch Lomond can be contrasted with that in other bodies of water in Britain. In Lake Windermere a productive lake, Macan (1970) showed from a data of Heron (1961) that although phosphate was some times completely exhausted in surface waters nitrate did not fall below 1 µg at. N/l; this is similar to the situation in Loch Lomond. However, silicate fell to undetectable levels in Windermere in summer, a situation never encountered in Loch Lomond. The range of pH values in Lake Windermere (6.8 - 7.5) approximates to that of the South Station of Loch Lomond whereas the range of alkalinity (6 - 7.5 mg $CaCO_3$/l) is smaller.

Llyn Ogwen (Duthie 1965), a small oligotrophic lake, showed a wider range of silicate variation compared with Loch Lomond with a peak value of 36 µg at. Si/l and a minimum of less than 1 µg at. Si/l. Phosphate was generally very low whereas nitrate never reached the highest value found in Loch Lomond and never fell below the minimum value. The pH of Llyn Ogwen (around 6) was lower than any region of Loch Lomond, as was the alkalinity which never exceeded 3.5 mg $CaCO_3$/l.

In Lough Neigh, an area which has become eutrophic (Wood and Gibson, 1973) both nitrate and phosphate reached much higher values than the recorded maximum for Loch Lomond. Nitrate ranged from 64 - 3 µg at. N/l while phosphate had a peak of 2 µg at. P/l falling to undetectable levels in summer. In a highly eutrophic area in Scotland such as Loch Leven

(Bailey-Watts and Lund, 1973) very high nutrient levels were recorded with nitrate reaching 32 μg at. N/1, silicate reaching 350 μg at. Si/1, while phosphate only reached 0.5 μg at. P/1 during three months of study (August, September and October). Both silicate and phosphate were reduced to very low levels. pH in Loch Leven always exceeded 7 and reached a maximum of around 10 (I.B.P. Project report 1970-71).

Of the other four lochs studied it is possible to compare the nutrient status of Lake of Menteith and Loch Rusky (both lowland lochs) with the South and South Balmaha Stations of Loch Lomond and that of Loch Achray and Loch Ard with North of Loch Lomond.

In Lake of Menteith phosphate and silicate values showed a larger range than in South Station, Loch Lomond. Phosphate content varied from 0.27 to 0.03 μg at. P/1 while silicate attained its maximum of 85 μg at. Si/1 in the winter, falling to a transient minimum (0.5 μg at. Si/1) below the corresponding minimum for Loch Lomond. Nitrate only reached 15 μg at. N/1 compared with 25.3 μg at. N/1 in Loch Lomond and fell to considerably lower levels (0.78 μg at. N/1). The phosphate minimum in Lake of Menteith was very short-lived while the values generally exceeded 0.2 μg at. P/1 for at least half the year (August - February). Generally Lake of Menteith was characterized by higher phosphate and silicate levels than Loch Lomond was in nitrate content.

The phosphate and silicate peaks of Lake of Menteith at the end of February occurred simultaneously and were of a similar magnitude to the levels of these nutrients in the main inflows. The nitrate content of the inflowing water however only reached half the maximum recorded for the lake itself. Generally changes in the nutrient status of the inflowing burn were rapidly reflected in nutrient changes in the lake. However the increased silicate content of the inflow in June occurred at the same time as values in the loch reached a minimum. This can be ascribed to the rapid utilization of the supply of silicate by large crops of diatoms present at the time (Cheng and Tyler, 1973).

The seasonal pattern of nitrite in Lake of Menteith is quite different from the seasonal distribution in Loch Lomond. In Lake of Menteith nitrite reaches its highest value during the winter and closely followed the nitrate variation. This appears to be a consequence of the rise in nitrite in the burn.

The pH range of Lake of Menteith corresponds to the range of the most southerly station of Loch Lomond and followed the similar seasonal pattern. The pH of the main inflow showed a similar range (7.2 - 7.9). The alkalinity on the other hand was higher than Loch Lomond. Again the inflowing water with high alkalinity (10 -18 mg $CaCO_3$/l) has a considerable effect on the alkalinity of the Lake itself.

In Loch Rusky the silicate maximum (93 µg at. Si/l) is higher than that recorded for any of the other four lochs studied. It is only slightly higher than the maximum in Lake of Menteith, Nitrate never fell to undetectable levels but remained below 3 µg at. N/l from August to September. As in Lake of Menteith and in contrast to Loch Lomond the decline of silicate and nitrate was continuous; however the phosphate levels remained high with an irregular seasonal distribution. The increase of phosphate in July and sudden peak in August (at surface only) which exceeded the winter maximum, resulted from the periodic artificial enrichment of the loch (Dr. Weir, private communication). The only nutrient which fell to almost undetectable levels in Loch Rusky was silicate at the end of May.

The second variation of pH in Loch Rusky was small as found in other lochs although low levels in winter and higher levels in summer and spring were evident. This could be related to the rainfall and phytoplankton. The range of alkalinity was the highest of any of the five lochs studied and was clearly influenced by artificial addition of lime to the burn, which was reflected in the periodic increase in the alkalinity in the inflow examined).

Loch Achray and Loch Ard show a generally similar seasonal pattern of nutrient variation to the North Station of Loch Lomond. The highest concentration of phosphate and silicate were found in Loch Achray while nitrate reaches its highest levels in Loch Ard. All three bodies of water were characterized by nitrate level never falling below 4.0 µg at. N/l even at the summer minimum. The highest recorded phosphate value in Loch Achray (0.25 µg at. P/l) was more than twice the maximum of the other two lochs, and silicate concentration reached 34.4 µg at. Si/l which was much greater than Loch Ard or North Loch Lomond.

In Loch Achray, apart from the period of May to August when nutrients were clearly affected by phytoplankton, the general pattern of nutrient variation was extremely irregular and must have been influenced by other factors. The sudden pulses of phosphate in February and the beginning of May could possibly be related to the excretion activity of zooplankton (Lund 1965 snd Rigler 1961) which was clearly present (in net samples) in very high numbers in this loch. The lack of co-ordination between phosphate and nitrate changes may be a consequence of excretion of nitrogen in forms other than nitrate (Martin and Goff, 1972). Nitrogen containing compounds may also be released to the environment by fungi and bacteria (Martin and Goff, 1972). Another important factor influencing the peculiar nutrient variation may be the presence of Macrophytes in large numbers in the wide littoral zone of Loch Achray and the flooding of the loch over nearby land during February. De-nitrification may remove up to 11% of the total nitrogen input to the loch (Brezonik and Lee, 1968). A further factor affecting the nutrient variation may be the rapid rate of water flow through Loch Achray (Brook 1956) which was probably greater than the other four lochs studied. There was no close relationship between the phosphate and silicate content of the main inflow and the concentration of these nutrients in the loch. Thus the peculiar seasonal distribution of nutrient in Loch Achray needs to be the subject of a further detailed study.

The seasonal pattern of nutrient distribution in Loch Ard followed the general pattern being high in winter and low in summer. The rise in nutrients at the beginning of winter coincided with the complete mixing of the water column and the increase in rainfall. In Loch Ard there was no close relationship between the nitrate and silicate content of the inflows and that of the loch while phosphate showed a close parallel between the increase in the burns and that in the loch.

Seasonal patterns of nitrite variation showed higher values in winter. This is in agreement with Hutchinson (1957) who, however, found no explanation for this rise. In contrast the rise in nitrite occurred during the summer in Loch Lomond with lower concentrations than Loch Achray (0.09 μg at. N/1) and Loch Ard (0.14 μg at. N/1). The pH values in both Loch Achray and Loch Ard were lower than those found in the upper part of Loch Lomond. Neither reached neutrality and Loch Achray fell to slightly lower values (6.1) than Loch Ard (6.3). The low pH values were a direct consequence of the low pH of the inflowing water. Generally both lochs showed the same pattern found in North Station of Loch Lomond being low in winter and high in summer.

The values of alkalinity were low in both lochs with levels being generally less than North Loch Lomond. The influence of the main inflows was clear in both cases although occasionally high values of alkalinity were found in the inflows to Loch Ard.

The seasonal succession of phytoplankton in Loch Lomond exhibited a classic pattern being dominated by diatoms in spring followed by Dinobryon in June in addition to Dinoflagellates, Chlorophyta and Blue-green algae in summer and finally being dominated by diatoms again in the autumn. This pattern of seasonal distribution of phytoplankton has been found in many lakes in the north temperate zone, among them Windermere (Macan 1970) and Gull Lake (Moss 1972).

Within the bounds of the general picture the seasonal succession of the individual species of phytoplankton may differ from one body of water to another or even at different locations in the same body of water. In

Loch Lomond Asterionella formosa displayed two annual pulses in spring and autumn 1972 and in spring and summer 1973. The first appearance of this species in the spring (1972) occurred at the North Station simultaneously with Melosira and preceding T. fenestrata and Fragilaria. This pattern of succession for A. formosa has been described in Windermere (Lund 1949; Heron 1961; Macan 1970) and in many other areas (Hutchinson 1967). This succession of species, as has been explained (Macan 1970) is due to the more rapid rate of division of Asterionella compared with Tabellaria and the larger initial cell population of Asterionella than Fragilaria. Thus under the favourable conditions in spring it will be expected that A. formosa would reach a peak before the other two species. Due to the spring peak of Asterionella and Melosira, the concentrations of silicate and phosphate were reduced. This coincided with the increase of T. fenestrata and Fragilaria which have been shown to have lower requirement for these nutrients (Macan 1970). The disappearance of Asterionella coincided with the establishment of stratification and the consequent sinking of cells beneath the limit of the photic zone. The absence of turbulence within the water column would prevent re-circulation of Asterionella (Reynolds 1973).

At the South and Middle Stations (Spring 1972) A. formosa reached a peak later than at the north station and followed the pulses of T. fenestrata and Fragilaria. This is in disagreement with Lund (1949) who stated that Asterionella is almost always the winner in what must be a race for the available nutrient. This peculiar succession was also observed in Esthwaite Water in 1949 (Macan 1970). The only explanation is that the circumstances were unfavourable for the growth of Asterionella as suggested for Esthwaite Water.

The formation of a second pulse of A. formosa at the South Station occurred concurrently with the period of overturn at the end of September. This pulse reached greater magnitude than the spring peak, but disappeared rapidly during October when silicate concentration fell below 9 µg at. Si/l (0.5 mg/l). At the North Station the second pulse occurred from July to

August rapidly diminished at the beginning of September when silicate fell below 9 μg at. Si/l. It has been shown that below this concentration (0.5 mg/l silicate become limiting for the growth of Asterionella formosa (Lund 1949, Lund 1965, Fogg 1965).

In 1973 the spring peak of Asterionella was earliest at the South Station (March - April) and came before T. fenestrata and Fragilaria. At the Middle Station the pulse continued from March to the end of June, possibly because of continuing turbulence maintaining it in the euphotic zone. At the North Station a single pulse of Asterionella appeared during April and May with no evidence of second peak till September. This may be the result of the deeper and stronger thermal discontinuity at this station with turbulence being insufficient to bring cells up from the thermocline.

T. fenestrata produced two clear pulses in 1972 at South Loch Lomond, one in May to June and one in autumn. It continued to increase in September even when silicate fell below 9 μg at. Si/l and was not reduced till December when declining light and temperature made conditions unfavourable for further growth (Hutchinson 1967). In 1973 a single relatively large peak of Tabellaria occurred in July at all stations following the second pulse of Asterionella. Apparently silicate level was the only factor limiting the further increase of Asterionella and although it has been suggested that 0.5 mg/l is also limiting the further increase of Tabellaria (Hutchinson, 1957). This was found to be untrue in the present case when T. fenestrata and Fragilaria continued to increase even when silicate fell to less than 0.2 mg SiO_2/l (2.3 μg at. Si/l). This shows that Tabellaria and Fragilaria have the ability to utilize silicate at much lower levels in nature than has been previously proposed. This has been indicated by Macan (1970) who stated that T. fenestrata and Fragilaria are able to take up phosphate and silicate at much lower concentration than A. formosa. Alkalinity in the loch never fell below 2.1 mg $CaCO_3$/l, the critical level for growth of T. fenestrata (Knudson 1954). The relatively large peak of T. fenestrata recorded at the North Station indicates that even in this part of the loch large pulses may occur if physical factors are favourable.

Fragilaria crotonensis formed two pulses at the South and Middle Stations in 1972, the first peak in May to June followed Melosira while the second occurred during September - November following Asterionella. The ending of the late spring pulse could be related to the establishment of stratification and absence of turbulence while the further growth of the autumn peak would have been prevented by adverse physical conditions. In 1973 a spring pulse at the South and Middle Stations was evident during March and a larger one during June and July. At the NOrth Station a single pulse was evident in July in both years. The occurrence of pulses of Fragilaria at most times of the year in Loch Lomond indicates that this species has a greater tolerance to light and temperature than suggested by Reynolds (1973).

Cyclotella comta and C. glomerata exhibited two annual peaks at the South Station in 1972 coinciding with Melosira in the spring and preceding the Asterionella, Tabellaria, Fragilaria pulses in spring and summer. One pulse was formed during isothermal conditions and one when the loch was stratified. According to Hutchinson (1967) temperature alone cannot be used to determine the time of the maximum of the species of Cyclotella. C. glomerata showed the same pattern in 1973 although C. comta showed no clear spring pulse. At the Middle Station only the autumn pulse of C. comta and C. glomerata was evident (in 1972) while an increase was evident in August 1973. At the North Station a single pulse occurred in both years. The wide range of physical and chemical conditions under which Cyclotella was found in Loch Lomond indicate the wide tolerance of the two species to the various parameters studied.

Melosira italica subarctica showed the peculiar feature of possessing only a single clear pulse throughout Loch Lomond during early spring in both 1972 and 1973. Its increase coincided with high silicate levels (Kilham 1971) increasing daily solar radiation and isothermal conditions which are necessary for its growth according to Lund (1954). Melosira has a faster rate of increase (Macan 1970) than other phytoplankton and consequently formed the first pulse of the year during spring. The presence of autumn pulse of Melosira in many other areas (Lund 1954) and its absence in Loch Lomond was shown more than 50 years ago by West (1912). Lund (1954) in describing this peculiarity related it to the nature of the loch itself which he referred to as morphometric oligotrophy.

Isothermal water conditions are an essential factor for the re-suspension and growth of this meroplanktonic organism (Fogg 1965). At the North Station Melosira does not appear in any number till water circulation takes place at the end of December, bringing up Melosira spores from the basin. A similar situation occurred at the Middle Station in November but in both cases, light was evidently insufficient for any further increase to take place.

The presence of complete circulation of the water mass, sufficient turbulence and satisfactory physical conditions at the South and South Balmaha stations during September and the absence of Melosira is a puzzling feature. There are three possible explanations for this peculiarity:-

(1) The location of South and South Balmaha stations nearer to the outflow of Loch Lomond (R. Leven) increases the possibility of the loss of phytoplankton in the outflowing water. Any Melosira lost in this way would not be replaced from the Middle and North Stations both of which are still strongly stratified.

(2) The largest accumulation of Melosira spores was found at the bottom of the Luss basin and not at the South basin (Slack 1965). This suggests that the source of Melosira in Loch Lomond is mainly from Luss basin. Here isothermal conditions did not occur in 1972 till the end of November when physical factors were not favourable (Lund 1954) for the growth of Melosira.

(3) The levels of silicate at the South and South Balmaha stations during September and October were less than 9 μg at. Si/l which is insufficient to support the increase of this organism.

0.8 mg/l (13.36 μg at. Si/l) has been shown to be limiting for the growth of Melosira italica subarctica (Hutchinson 1957)½

Dinobryon formed a single pulse at all stations in Loch Lomond in both years with largest number at the North Station. The peak was usually reached between July and August and generally coincided with lowest level of phosphate as indicated by Provasoli (1969), Lund (1965), Hutchinson (1957, 1967). At the North and Middle Stations phosphate was almost undetectable while at the South Station, where the smallest pulse was observed, this nutrient was comparatively high.

The single annual pulse of Mallomonas observed in both 1972 and 1973 occurred during summer or autumn in agreement with the general pattern described by Osmund (1959) and Hutchinson (1967). The dinoflagellates, Ceratium and Peridinium, produced a single pulse at all stations between July and September in both years. Hutchinson (1967) indicated that these are warm water organisms and occur when the water temperature is between 12 and 19°C as was the case in Loch Lomond.

The occurrence of Botryococcus colonies in large numbers at the surface at all stations could be related to the presence of large amounts of lipid which may be up to 30 - 40% of dry wet (Fogg 1965). In both years a single pulse of Botryococcus occurred between July and August as found in other areas (Hutchinson 1967). In 1973 the number of Botryococcus colonies per litre at the Middle Station was twice the South Station total whereas the nutrients were generally higher at the South Station. Rawson (1956), Hutchinson (1967) indicated that this organism is characteristic of oligotrophic areas.

Anabaena circinales displayed a single pulse in summer 1972 and 1973 with the maximum abundance at the South Station. This is the first recorded occurrence of Anabaena in Loch Lomond and may be an indication of the onset of eutriphication (Wood and Gibson, 1973). Tabellaria flocculosa on the other hand, a species which is typical of oligotrophic areas (Teiling, 1955; Rawson, 1956) was almost entirely confined to the North Station of Loch

Lomond. Here it formed a single pulse between February and April in both years coinciding with high nutrient and cold weather (Macan 1970).

The phytoplankton of the two lowland lochs, Lake of Menteith and Loch Rusky, could be compared with the South and South Balmaha Stations of Loch Lomond. During the late autumn of 1972 Fragilaria, Asterionella, and Melosira were found in Lake of Menteith while they were absent from Loch Lomond and Loch Rusky. A pulse of Melosira occurred in spring in all three lochs, with that of Loch Rusky being the greatest. Before the increase of Melosira the levels of silicate were much higher than in Loch Lomond, exceeding 80 μg at. Si/l in both lochs. Consequently the magnitude of the successive peaks of Melosira, Asterionella and Fragilaria was much greater than that of Loch Lomond. In Lake of Menteith and Loch Rusky the disappearance of Melosira and Asterionella can be related to the reduction in the concentration of silicate which reached limiting levels (Fogg 1965) in both cases. In Lake of Menteith at the beginning of June phosphate was sufficient for the further increase of Asterionella being greater than 0.03 μg at. P/l (Fogg 1973). Nitrate and Nitrite concentration at this time fell below what is considered to be a limiting level (less than 10 μg/l (0.7 g at. N/l) (Lund 1965)). The ration of nitrogen (from nitrate and nitrite) to phosphorus, less than 5:1, also suggests the possibility of nitrate limitation (Lund, 1965; Kramer et al., 1973). However considerable increase in diatoms continued indicating the presence of a source of nitrogen other than nitrate and nitrite. This may have been a consequence of a fixation of nitrogen and its liberation as ammonia by Anabaena flos-aquae or A. circinales which were present in large quantities. During the latter half of July a decline of most diatoms was evident which may be related to the low levels of silicate and nitrate and the absence of blooms of Anabaena. On the other hand concentrations of nitrate and silicate at the South and South Balmaha Stations of Loch Lomond never fell to such low levels and the N/P ratio always exceeded 50:1.

A second pulse of Tabellaria coinciding with an increase in Fragilaria occurred in Loch Rusky during August when silicate levels were below 9 μg at. Si/l. However as the nutrients increased during the autumn the second pulses of Asterionella, Melosira, Cyclotella, Tabellaria and Fragilaria were evident in Lake of Menteith. The absence of the first three diatoms in the autumn increase in Loch Rusky may be explained by the low silicate levels during this period (less than 9 μg at. Si/l). Another factor may be that Loch Rusky was still stratified at this time, preventing the recirculation of diatoms into the surface waters. Of the blue-green algae, Anabaena circinales formed a peak in spring in Lake of Menteith and in summer in Loch Lomond but was not observed in Loch Rusky. A. flos-aque on the other hand was present in Loch Rusky and Lake of Menteith and absent in Loch Lomond. The occurrence of this species may be related to high pH and alkalinity (McCombie 1952), conditions not present in Loch Lomond. Massive numbers of this organism, exceeding 16 million cells per litre, were found in Loch Rusky while in Lake of Menteith two pulses occurred both reaching around one million cells per litre. The only other species of Anabaena observed, A. spiroides, which is believed to be nitrogen fixing (Lund 1965), was found in Lake of Menteith only. This organism reached a maximum of more than 3 million cells/l.

Dinobryon, which formed a single annual pulse in Loch Lomond, was not recorded in Lake of Menteith or Loch Rusky while Microcystis formed a peak in Lake of Menteith only. Mallomonas and Peridinium were absent from Lake of Menteith while they produced pulses in summer or autumn in Loch Rusky and Loch Lomond.

The phytoplankton of the two highland lochs, Loch Achray and Loch Ard, are comparable with the North and Middle Stations of Loch Lomond. In Loch Ard the seasonal pattern of succession generally followed that of Loch Lomond. Throughout the period of circulation in Loch Ard (December to June), the numbers of Melosira were high, reaching maximum abundance in June. In Loch Achray numbers of diatoms remained extremely low throughout the winter and spring, with no increase being apparent till May. A simultaneous and rapid increase took place during this month involving Melosira, Asterionella, Tabellaria fenestrata, T. flocculosa and Cyclotella comta. This peculiar pattern with no indication of diatom succession in spring, was not found in any other lochs studied. The delay in the formation of the vernal diatom outburst in Loch Achray when physical and chemical conditions, compared with other lochs, appeared to be satisfactory, would seem to be related to the absence of some essential but unmeasured factor or factors.

In Loch Ard a summer or early autumn peak of Fragilaria was followed by Tabellaria while in Loch Achray only Cyclotella comta formed a clear peak in early autumn. C. comta however showed no clear peak during the sampling period in Loch Ard. This could be contrasted with Loch Lomond, where most diatoms formed two clear annual peaks, including C. glomerata which was absent from Loch Ard and only observed on two occasions in Loch Achray. Fragilaria, on the other hand, produced clear pulses in Loch Ard and Loch Lomond but was found only twice in Loch Achray. The absence of a second peak of Melosira and Asterionella in Loch Ard could be ascribed to low silicate levels and the lack of turbulence during stratification. The same reasons may apply to Loch Achray. Of the other phytoplankton, A. circinales was common in all three lochs during a short period in the summer. Larger numbers of Anabaena were recorded in Loch Ard and Loch Achray than in Loch Lomond. Ceratium and Peridinium were absent in Loch Achray but formed pulses in summer in Loch Ard and Loch Lomond. Coelosphaerium reached greater abundance in Loch Lomond and Loch Ard but was generally scarce in Loch Achray. Kephyrion, on the other hand, was only found in abundance in Loch Achray while it was only occasionally recorded from north of Loch Lomond and Loch Ard. All three bodies of water showed clear peaks of Dinobryon when phosphate concentration was low.

Brock (1964) stated that most oligotrophic lochs lie to the north of the Highland Boundary Fault and most eutrophic lochs in Scotland lie to the south. Loch Achray was among the lochs which were classified as oligotrophic (Brock 1959). Using Nygaard's compound phytoplankton quotient applied to net samples, Loch Lomond and Loch Ard gave quotients of 0.9 and 1.2 respectively, making them both mesotrophic. However, Slack (1954, 1957, 1965) defined Loch Lomond as generally oligotrophic with the south being more productive than the north. From the nature of the catchment area Shafi and Maitland (1971) described the upper loch as oligotrophic and the southern region as mesotrophic.

From the chlorophyll levels and total number of phytoplankton in Loch Lomond it is certainly true that the South Station of the loch is more productive than the Middle Station while the North Station has the lowest productivity. The highest recorded number of phytoplankton in spring at the South Station exceeded 900,000 units/l in 1972 and 400,000 units/l in 1973. At the Middle Station numbers did not exceed 250,000 units/l while at the North Station the maximum recorded number of phytoplankton was less than 150,000 units/l. This progressive reduction from South to North was repeated in the autumn but with relatively smaller numbers of phytoplankton. Peak chlorophyll a values at the South Station exceeded 0.35 μg/l, the Middle Station never exceeded 0.96 μg/l, while the North Station lay below 0.25 μg/l.

From the study of individual species as trophic indicators, it is evident that Tabellaria flocculosa, a species which is found to be characteristic of oligotrophic areas (Teiling 1955, Rawson 1956) was almost entirely restricted to the North Station. Dinobryon divergens, another oligotrophic species (Provasoli 1969) was found in greater abundance in the upper loch. On the other hand Anabaena, which reaches ten-fold higher numbers at the South Station than the North, is regarded by Prescott (1969) as being typical of eutrophic areas.

From the nutrient study of the loch it was clear that the winter maximum was less than that of the Middle and North Station. This is also another indicator for the South being more productive (richer in nutrient) than North (poor in nutrient) (Hutchinson 1967; Hunter 1970). The water chemistry of the catchment area shows that the river and burns supply a greater load of nutrients to the South than those inflows which drain poor peaty areas to the north. The Endrick for example which flows into the south contains an average of 40 times as much phosphate, 15 times as much nitrate and 4 times as much silicate as the River Falloch which flows into the north. The Endrick and Fruin, which drain rich agricultural land, clearly have an effect on the enrichment of the lower loch which may be the cause of the recent appearance of Anabaena in this area.

The shape of the basin which has been used by Odum (1953), Prescott (1969) and Hunter (1970) as a guide to the trophic state, is a typical eutrophic saucer shape in the south and a deep v-shaped valley (oligotrophic) type in the north. The oligotrophic character of the north is also indicated by the short (or absent) littoral zone while the large shallow areas in the south are eutrophic in character (Welch 1952). In all three basins of Loch Lomond oxygen saturation never fell to low values even at the bottom; Ruttner (1952) suggests that this is a feature of an oligotrophic lake.

Another indication of the oligotrophic nature of the upper loch is the large depth and volume of the hypolimnion in comparison with the epilimnion (Welch 1952) while at the south the hypolimnion when it exists is relatively short. The open and exposed nature of the southern basin with its continual exposure to wind action may be the main factor preventing deoxygenation. This process, combined with the continuous dilution of the richer water inflowing to the south by the nutrient poor water from the north, are possibly the main factors preventing eutrophication in the lower loch. In the upper loch with its vast hypolimnion deoxugenation will be more difficult and it will consequently be more resistant to eutrophication (McColl 1972).

Slack (1957) showed that there is an accumulation of mainly allochthonous material in the sediment of the upper loch while in the lower loch autochthonous material predominates. This indicates the more productive nature of the southern basin of the loch. The higher alkalinity of the lower loch is also a pointer to greater productivity while in the upper loch the pH which remains below 7.4 -s a character of oligotrophic areas (Prescott 1969).

A physical factor which may have a considerable effect on the productivity of the loch is the relative amount of solar radiation received by each region. In the upper loch the incident daily radiation is reduced by the mountainous topography of the surrounding land, the small surface area of the narrow upper region and the greater amount of cloud cover compared with the lower loch. The reduction in the daily incident solar radiation in the north has been practically confirmed by Dr R. Tippett (private communication). The souther region is wide and open with a larger surface area and consequently receives markedly more light energy per unit volume of water than the north (Hunter 1970).

From the total phytoplankton, chlorophyll and all other factors considered it is clear that South Station of Loch Lomond is more productive than the North and Middle. However, on the general eutrophic, oligotrophic scale, even the southern part of Loch Lomond is poor in nutrient and low in chlorophyll and might be classified as oligotrophic.

In Loch Achray the total phytoplankton reached around one million per litre in May while chlorophyll values did not exceed 0.25 g/l. During July to August Kephyrion, an indicator of oligotrophic areas (Hutchinson 1967) made a considerable contribution to the total population. Generally this loch showed a lower phytoplankton productivity than the north of Loch Lomond and had a lower pH and alkalinity. Although the peak chlorophyll value exceeded that of north Loch Lomond it did not reach the highest value recorded in the south. The low phosphate level could also be regarded as an indication of its low productivity. Compared with north Loch Lomond Loch Achray has a large littoral zone and is much shallower. The hypolimnion of this body of water was found to be constantly oxygenated as in north Loch Lomond. The large flow rate of Loch Achray possibly has a great effect on reducing its productivity.

The total phytoplankton in Loch Ard in spring never exceeded 300,000 units/l while in the summer it almost reached 600,000 units/l and chlorophyll had a maximum abundance of 0.34 μg/l. This loch could be regarded as being more productive than north Loch Lomond and almost as productive as the south region of Loch Lomond. Brook (1964) regarded it as being mesotrophic. It posses lower phosphate and higher nitrate and silicate levels than north Loch Lomond although it has a lower pH and alkalinity. The composition of phytoplankton, which is mainly diatom in nature, with larger amount of Dinobryon than in Loch Lomond, indicates its oligotrophic character. Like Loch Achray and Loch Lomond the hypolimnion when it exists shows no signs of deoxygenation. In regard to nutrient level and population composition and size, chlorophyll values and the other factors considered both Loch Achray and Loch Ard could be considered to be oligotrophic.

Of the two lowland lochs Lake of Menteith possesses a population composed mainly of diatoms and blue-green algae which is typical of eutrophic areas (Prescott 1969). The total phytoplankton population reaches more than 3.5 million per litre, more than four-fold greater than the maximum in the south part of Loch Lomond. Chlorophyll reached 3 μg/l during January while in spring the values were five-fold higher than south of Loch Lomond. Such chlorophyll values are in accordance with the reading for mesotrophic lakes in New Zealand, Rotokakahi and Ikareka (McColl 1972) and some Japanese lakes (Sakamoto 1966). The nutrient levels with much higher phosphate and silicate and less nitrate and higher pH and alkalinity than Loch Lomond indicate its greater potential for productivity. This is borne out by the very large population of Melosira and Asterionella both of which exceed one million cells/l almost reaching the level of Lake Windermere, a eutrophic area.

The greater productivity of this area is also demonstrated by the presence of successive pulses of blue-green algae which are eutrophic indicators and the absence of oligotrophic species such as *T. flocculosa* (Teiling 1955), *Dinobryon* and *Mallomonas* (Hutchinson 1967). The shallow nature of the lake basin and the large littoral zone are also characteristic of eutrophic areas. The great exposure to wind mixing might be the only reason that deoxygenation does not occur. However Mr B. Morrison, (private communication) has recorded summer deoxygenation at its deepest part. From the above considerations it would appear that Lake of Menteith might be eutrophic; nevertheless from chlorophyll values and nutrient status Lake of Menteith falls into the mesotrophic category.

Loch Rusky on the other hand, cannot be regarded as a natural loch because of the artificial fertilization of the water by the angling society (Dr. Weir, private communication). In comparison with the South Station of Loch Lomond and Lake of Menteith, the levels of phosphate and silicate are greater with the phosphate level being generally more than twice that of Loch Lomond South Station. Like Lake of Menteith Loch Rusky possesses large littoral zone, and is generally shallow throughout but never deoxygenated at any depth.

The production of a pulse of more than 2 million cells of *Asterionella* per litre, and a similar pulse of *Melosira* which exceeded that of Lake of Menteith, is an indication of high productivity. *Anabaena* produced the single largest bloom recorded, reaching sixteen million cells/l. The highest chlorophyll levels in any of the five lochs were found in Loch Rusky where a peak of 3.2 μg/l was recorded. This is ten-fold higher than that of South of Loch Lomond and exceeded the peak of chlorophyll in Lake of Menteith. From the above considerations Loch Rusky can be regarded as being eutrophic as far as levels of phosphate and nitrate are concerned (compared with data given by Thomas (1969) and McColl (1972)), and mesotrophic as far as chlorophyll concentrations are concerned (McColl 1972). Owing to the continual process of artificial nutrient enrichment it is evident that Loch Rusky is moving towards a state of eutrophication.

All lochs investigated are in areas of high amenity value and have not, till now, come under much environmental pressure. If they are to maintain this role, future development of tourism, industry and water resources should be closely controlled. This is particularly true in the Loch Lomond area where any stress, especially in the upper region, might put considerable pressure on the capacity of the loch to resist eutrophication. This study should provide a base line for monitoring any future changes which may take place.

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APPENDIX 1

Determination of Orthophosphate (Strickland & Parsons, 1968)

The analysis of samples were commenced not more than 4 hours after completion of sampling. Zooplankton and large pieces of debris being removed by filtration through a fine (25) nylon mesh.

The samples were not preserved in any way.

The following special reagents were required for the analysis and were prepared as follows:

(1) Ammonium molybdate solution:

15.0 gm of finely crystallin, analytical reagent quality (A.R.) ammonium paramolybdate $(NH_4)_6 Mo_7O_{24}.4H_2O$ were dissolved in 500 ml of distilled water. This solution was made up freshly before each analysis.

(2) Sulphuric acid solution:

140 ml of concentrated A.R. sulphuric acid (Spgr. 1.82) was added cautiously to 900 ml of distilled water. After cooling this solution could be stored indefinitely in a polythene container.

(3) Ascorbic acid:

27 gm of good quality ascorbic acid was dissolved in 500 ml distilled water. The solution was stored in the frozen condition in a plastic bottle. It was thawed when required for use and then refrozen immediately. Ascorbic acid stored in this fashion is stable for long periods but was never kept for more than 1 month.

(4) Potassium antimonyl-tartrate solution:

0.34 gm of good quality potassium antimonyl-tartrate were dissolved in 250 ml of distilled water. This solution is stable for many months where stored in a polythene container.

(5) Mixed reagent:

One litre of mixed reagent (enough for 100 samples) can be prepared by mixing 200 ml ammonium molybdate, 500 ml sulphuric acid, 200 ml ascorbic acid and 100 ml potassium antimonyl-tartrate. This reagent always prepared for immediate use.

100 ml aliquots of each sample were measured into 2 or 3 replicate 250 ml narrow-neck polythene bottles, which had previously been washed twice with the water to be analysed. These bottles were transferred to a water bath maintained between 20-25°C and left to equilibrate for 30 minutes. After this period 10 $\mp$ 0.5 ml of freshly-prepared mixed reagent was added to each 100 ml aliquot from a dispenser, and thoroughly mixed. The bottles were then returned to the water bath, the extinction of the solution being measured after one hour in a Unicam 4 cm glass cell at a wavelength of 885 m using red filter. The same Unicam SP600 spectrophotometer was used on all occasions, distilled water being used in the reference cell. Cell to cell blanks were determined by filling all 4 cm cells with distilled water, the deviations from the reference cell being noted. A turbidity blank was found to be unnecessary.

The reagent blank was estimated for each set of determination, 3 100 ml aliquots of distilled water being used instead of sample. All the extinctions were connected for the reagent blank and the cell to cell blank.

The procedure was calibrated using a standard phosphate solution of potassium dihydrogen phosphate:

0.408 gm of A.R. anhydrous potassium dihydrogen phosphate (KH_2PO_4) was dissolved in 1000 ml of distilled water; 1 ml of this solution contains 3 μg at. P. This standard was stored frozen solid in a plastic bottle and thawed before use. 1 ml of this concentrated solution was diluted to 1000 ml with distilled water to give a final concentration of 3 μg at. P/l. 3 or 4 100 ml aliquots of this standard solution were carried through the phosphate determination with the samples and blanks.

The calibrated factor (F) was calculated from the following expression:

$$F = \frac{3.00}{E_{standard} - E_{blank}}$$

where $E_{standard}$ is the mean extinction of 3 or 4 standard and E_{blank} is the mean extinction of 3 blanks.

The phosphate-phosphorus concentration of any sample in µg at. P/l can then be determined by multiplying the factor F by the corrected mean extinction of the two aliquots from each sample. This factor is fairly constant around 13 for a 4 cm cell.

After completion of the analysis the 250 ml polythene bottles were washed well and stored filled with distilled water, the spectrophotometer cells being kept in a beaker of ethanol.

The minimum level of detection is 0.03 µg at.P/l. The accuracy of the method is $\pm$ 1%.

APPENDIX 2

Determination of Silicate (after Strickland & Parsons 1968)

Analysis of samples was commenced not more than three hours after the completion of sampling, the samples being returned to the laboratory in polythene containers.

The following special reagents were required for the analysis:-

(1) Molybdate reagent:

4.0 gm of analytical reagent quality ammonium panamolybdate $(NH_4)_6Mo_7O_{24}.4H_2O$ (finely crystalline) was dissolved in 300 ml distilled water. After the addition of 12 ml of concentrated Hydrochloric acid (Sp. gr. 1.18) the solution was mixed and made up to 500 ml with distilled water. This reagent was freshly prepared each week.

(2) Metol-sulphite solution:

6 gm of anhydrous sodium sulphite Na_2SO_3 A.R. was dissolved in 500 ml distilled water followed by the addition of 10.0 gm of metol (p-methylaminophenol sulphate) when the metol has dissolved the solution was then filtered through No. 1 Whatman filter paper and stored in tightly stoppered polythene bottles. This solution tended to deteriorate rapidly and was freshly prepare each week.

(3) Oxalic acid solution:

50 gm of A.R. oxalic acid dihydrate $(COOH)_2.2H_2O$ were shaken with 500 ml of distilled water. This produces a saturated solution which was decanted from the crystals before use. This solution is stable indefinitely and was prepared in large quantities every 3 months.

(4) Sulphuric acid solution:

A 50% v/v solution was prepared by adding 250 ml concentrated (Sp. gr. 1.82) A.R. sulphuric acid cautiously to 250 ml of distilled water. This was cooled to room temperature and the volume made up to 500 mls with distilled water. This solution was prepared in quantities of 5 litres.

(5) Reducing reagent:

100 ml of metol-sulphite solution were mixed with 60 ml of oxalic acid solution, 60 mls of 50% sulphuric acid were then added slowly with mixing and the volume was made up to 300 ml with distilled water. The reagent was used immediately after preparation.

25 ml aliquots of each sample were dispensed into 2 or 3 replicate narrow-neck polythene bottles, which had previously been washed twice with the sample to be analysed. The sample solutions were then transferred to a thermostatically controlled water bath, maintained between 18 and 25°C and left to reach a constant temperature for 30 minutes.

10 ml of molybdate solution was then added to each sample and mixed thoroughly. The mixture was allowed to stand for 10 minutes. 15 ml of reducing agent was then added rapidly and the solution was immediately mixed. To allow complete reduction of the silicomolybdate complex, the solution was allowed to stand for 2-3 hours, the extinction being measured in a 4 cm Unicam glass cell against distilled water. A Unicam SP 600 spectrophotometer was used with a red filter at a wavelength of 810 m. Cell to cell blanks were determined by filling all 4 cm cells with distilled water and measuring the deviations from zero (reference cell). All extinctions were corrected for cell to cell blanks and reagent blanks, a turbidity blank was found to be unnecessary.

Reagent blanks accompanied each set of determination, three 25 ml aliquots of silicate-free distilled water being carried through the analysis procedure. Calibration standards were also included with each week's analysis.

Standard silicate solution: Dried A.R. sodium silicofluoride Na_2SiF_6 forms a convenient standard (Strickland & Parsons, 1968). 0.960 gm of fine powder were dissolved in 100 ml distilled water in a plastic beaker. The solution was then transferred to 1000 ml volumetric flask and made up to the mark with distilled water; this solution was rapidly transferred to a polythene bottle for storage, as it rapidly picks up silica from glass. The solution is easy to prepare and is stable indefinitely, which is an advantage over most standards consisting of sodium silicate.

1 ml of this solution contins 5 μg at. Si. This concentrated standard was diluted to 4 μg at. Si/1 with silicate-free distilled water. Three 25 ml aliquots of this standard silicate solution were carried through the experimental procedure with the samples and blanks.

The calibration factor, F, was calculated using the following expression:-

$$F = \frac{4.00}{E_{standard} - E_{blank}}$$

where $E_{standard}$ is the mean extinction of 3 or 4 standards and E_{blank} is the mean extinction of three blanks.

The silicate silicon concentration in μg at. Si/1 of any sample can then be determined by multiplying the factor, F, by the corrected mean extinction of two aliquots from each sample. The factor generally lies around a value of 23.0 for a 4 cm cell.

After completion of the analysis, the polythene bottles are washed and stored in silicate-free distilled water, the spectrophotometric cells being cleaned in acetone and kept in a beaker of ethanol.

The minimum level of detection is 0.1 μg at. Si/1.

APPENDIX 3

Determination of Nitrate (Wood, Armstrong & Richards, 1967)

Samples to be analysed were filtered through a fine nylon mesh and returned to the laboratory within three hours of completion of sampling. Analysis was then commenced immediately. The following apparatus and special reagents were required:-

Apparatus:

The reducing column [redacted], was similar to the one described by Morris and Riley (1963) and has the discharge tip at the same height as the top of the cadmium filings, which prevents the column from running dry. This precaution was essential since exposure to air rapidly reduces the efficiency of the column. Wood, Armstrong and Richards (1967) suggested a 15 cm column of copperized cadmium with an 8 mm bore for use with fresh water samples.

Special reagents:

(1) Sulphanilamide solution (see Appendix for nitrite).

(2) N-(1-naphthyl)-ethylenediamine dihydrochloride solution (see Appendix for nitrite).

(3) Copper sulphate (0.08 M) : 20 gm $CaSO_4.5H_2O$ was dissolved in water and made up to 1 litre.

(4) EDTA solution (0.1 M). 38 gm of tetra sodium salt of ethylenediamine tetra-acetic acid was dissolved in 500 ml and diluted to 1 litre.

(5) HCl (2N) 85 ml of 12N HCl was diluted to 500 ml with distilled water.

(6) HCl (0.0015N) 0.125 ml of 12N HCl was diluted to 1 lit-e with distilled water.

(7) HNO_3 (0.3N) 10 ml of 15.4N HNO_3 was diluted to 500 ml with distilled water.

(8) Column wash solution: 1 ml tetra sodium EDTA solution was added to 50 ml of 0.0015 HCl.

Preparation of reducing column:

(1) Coarse cadmium filings were produced from a stick of cadmium and sifted to obtain the fraction which passed through a 2 mm screen

but were retained by a 0.5 mm screen. Iron contamination was removed by drawing a magnet through the filings.

(2) 40 gm of filings per column were washed with 2N HCl in a separating funnel and rinsed thoroughly with distilled water. This was followed by washing with 0.3N HNO_3 to pit the cadmium, a distilled water rinse and then washing with 2N HCl to remove the nitrate ions.

(3) After a thorough rinse with distilled water the cadmium was treated with 100 ml $CaSO_4$ solution per 40 gm of filings in a special wash bottle (Fig. 2), then filings were well shaken and then flushed with distilled water, preventing any exposure to air.

(4) A small plug of glass wool was placed at the bottom of the column which was then filled with distilled water. The copperized cadmium was introduced slowly by inverting the special wash bottle into the column reservoir and tapping the column to settle the cadmium.

(5) The copper and fine cadmium which settled out on top of the cadmium column was removed by suction. A small plug of glass wool was placed on top of the cadmium to act as a filter.

(6) 50 ml of wash solution was used to wash the column, which was allowed to stand for 24 hours before use with 2 or 3 changes of wash solution.

(7) A freshly prepared column of copperized-cadmium only reduces 15% nitrate to nitrite. 3-4 litres of water containing 60 g at. N/l + 20 ml EDTA were passed through a new column to condition sufficiently to give a uniform 98% reduction to nitrite.

Procedure

One ml of EDTA solution was added to a 50 ml aliquot of sample in a 50 ml graduated cylinder and shaken. Replicate of each sample were ; taken. Any excess sample or column wash was removed from the column reservoir to about 0.5 cm above the cadmium and a 3-4 ml portion of sample was added to rinse out the previous sample. The remainder of the sample was then added and the graduated cylinder was placed under the discharge tap. The flow rate is controlled to between 10 and 12 ml/minute , 20 ml of sample being passed through the column and used to rinse the cylinder. The next 15 ml of reduced sample was collected and diluted to 30 ml with distilled water. The sample was then treated as a nitrite sample. For full description of the method see Appendix for nitrite determination.

Extinctions were determined within 1 hour using 1 cm Unicam glass cell at a wavelength of 543 m using blue filter. A Unicam Sp 600 spectrophotometer was used throughout the investigation.

The distilled water blanks and three standard accompanied each series of determination. A nitrate standard was prepared by dissolving 0.1264 gm of A.R. potassium nitrate (dried for 1 hour at 110°C) in 250 ml of water with 2 drops of chloroform added as a preservation. 1 ml of this solution contains 5 μg at. A standard solution for calibration purposes is prepare by diluting 1 ml of the concentrated standard to 900 ml with distilled water, giving a final concentration of 20 μg at. N/l. 1 ml EDTA solution was added to 50 ml aliquots of standard and blank which were carried through the complete procedure. The calibration factor, F, was determined by calculation of the expression:-

$$F = \frac{20}{E_{standard} - E_{blank}}$$

The concentration of nitrate-nitrogen + nitrite-nitrogen in any sample in μg at. N/l can be determined by multiplying the corrected mean extinction of the sample by the calibration factor F. In general the value of F for 1 cm cell lies around 48.

After completion of analysis the column was filled with column wash solution, and the graduated cylinders were washed and filled with distilled water. The 1 cm cells were cleaned with acetone and kept in a beaker of ethanol.

APPENDIX 4

Determination of Nitrite

Samples for nitrite analysis were diltered through a 25 nylon mesh and returned to the laboratory within three hours of completion of sampling. Analysis was commenced immediately.

The following special reagent was required for the analysis:-

(1). Sulphanilamide solution

50 gm of sulphanilamide was dissolved in 300 ml of distilled water and 50 ml of concentrated hydrochloric acid (1.18 s.g.) was added. The final volume was made up to 500 ml with distilled water. The solution is stable for many months and was made up in quantities sufficient for 3 months analyses.

(2) N-(l-napthyl)-ethylenediamine dihydrochloride solution

0.5 gm of the dihydrochloride was dissolved in 500 ml of distilled water. The solution was stored in dark bottles and was made afresh each month.

Procedure

A 50 ml aliquot of each sample was measured into a 50 ml graduated culinder which had previously been rinsed twice with sample. 1.0 ml of sulphanilamide was added from an automatic pipette to each sample, followed by mixing. After 2-8 minutes 1.0 ml of naphthylene ethylene diamine solution was added and mixed immediately. Between 10 minutes and 2 hours afterward the extinction of the solution was measured in a 4 cm Unicam glass cell against distilled water at a wavelength of 543 m . A Unicam SP 600 spectrophotometer was used with the blue filter in place. The extinction was corrected by subtracting the mean distilled water reagent blank (E_{blank}) which was run in duplicate. A turbidity blank was found to be unnecessary.

The nitrite-nitrogen concentration in μg at. N/1 can be calculated by multiplying the calibration factor, F, by the corrected extinction for each sample.

A standard solution of nitrite was prepared by dissolving 0.345 gm analytical reagent quality sodium nitrite dried at 110^{o}C for 1 hour in 1 litre of distilled water (1 ml = 5 μg at.N). Stored in the dark, bottles with 1 ml of chloroform preservative, the solution was stable for many months. For use the same day the standard solution was diluted to give a final concentration of 2.0 μg at. N/l. Three 50 ml aliquots of this standard were carried through the analysis procedure, and the mean extinction (E standard) was found. The calibration factor for the determination was calculated from the expression:-

$$F = \frac{2}{E_{standard} - E_{blank}}$$

The glass cylinders used in the analysis were washed after the completion of each set of determination and stored filled with distilled water. The 4 cm cells were cleaned with acetone and kept in ethanol when not in use.

APPENDIX 5

pH determination

Immediately on completion of sampling, polythene bottles filled to the brim with sample were returned to the laboratory for pH determination. Sample aliquots were allowed to warm to room temperature and the pH was determined using a Pye model 292 pH meter.

A glass electrode in combination with a saturated calomel electrode was used, producing an electrical charge of 59.1 mv at 25°C for a change of one pH unit. The glass electrode consists of a small thin glass bulb 0.05 mm thick which is filled with an electrolyte, the potential of this electrode depends on the external hydrogen ion concentration. The calomel reference electrode consists of mercury in a slurry of mercurie chloride; this was connected to the indicator electrode by a saturated potassium chloride bridge.

The electrode was standardized using commercially available pH buffer tablets having a pH near to that of the sample. The buffer solution used here has a pH of 6.99 at 20°C, since the potential of the electrode combination is temperature dependent, the temperature compensator must be set at the buffer temperature. Samples allowed to warm to within 3°C of the buffer temperature before determinations were made, the temperature compensator being reset to the exact sample temperature.

The electrode were washed with water and dried with a tissue before immersion in any sample. 3 to 5 minutes was allowed for equilibration once the electrode were immersed in the sample. The pH was then read directly to an accuracy of $\mp$ 0.02 units.

APPENDIX 6

Determination of Alkalinity (Mackereth 1963)

Determination were made on samples immediately on return to the laboratory; the following special reagents were required:-

(1) 0.01 N Hydrochloric acid: This was prepared by diluting 10N HCl followed by standardization against freshly prepared standard sodium carbonate solution.

(2) Standard sodium carbonate 0.02N: Pure anhydrous Na_2CO_3 was dried overnight at $110^{o}C$, 1.059 gm was dissolved in distilled water and diluted to 1 litre. This solution rapidly -picks up carbon dioxide and was stored in a stoppered polythene bottle.

(3) INdicator: B.D.H. 4.5 indicator was used.

To facilitate recognition of the end-point a standard end point colour was prepared by adding 5 drops of indicator to 100 ml of a buffer solution at pH 4.5 (50 ml N sodium acetate + 50 ml N acetic acid) this was kept in a stoppered conical flask.

A 100 ml aliquot of sample was pipetted into a conical flask and 5 drops of indicator solution was added. Standard acid was run-in from a 10 ml burette with continuous mixing from a magnetic stirring bar. The titration was completed when the colour of the sample matched that of the standard end-point. Duplicate aliquots were run for each sample.

Each ml of 0.01 N acid contain 0.01 meg of acid. Thus each ml of standard acid used in the titration corresponds to 0.01 meg of bicarbonate in 100 ml of sample or 0.1 meg/l, therefore if v ml of acid is used in the titration, the bicarbonate concentration in the sample is 0.1 x v meg/l.

The alkalinity of natural water is generally expressed in terms of dissolved calcium carbonate (though it has no basis in reality). This figure is found by multiplying the value found for meg HCO_3/l by the equivalent weight of $CaCO_3$ (50) the total alkalinity is therefore expressed as mg $CaCO_3$/l.

APPENDIX 7

Saturated Oxygen and Temperature Measurement

All readings of saturated oxygen and temperature was made with the dissolved oxygen meter and improved galvanic cell described by Mackereth 1964.

The oxygen electrode has an electrical output of 200 A when immersed in water saturated with oxygen at 15^{O}C and atmospheric pressure. The sensitivity at this temperature is 22 A per p.p.m. oxygen. The electrode and thermister were calibrated together, the probe being immersed in five litres of water through which air was continuously bubbled from a sintered glass distributor. The water temperature was measured from the mean temperature of three accurate thermometers. Ice was added to lower the temperature to that at which calibration starts (2^{O}C) and the temperature was allowed to rise slowly. A 1^{O}C rise in 15 minutes allows the oxygen saturation in the water to remain in equilibrium with the atmosphere. At each 1^{O}C interval the thermister bridge was balanced and the potentiometer reading was noted. The oxygen concentration was then set to 100% saturation on the saturated oxygen scale by adjusting the sensitivity control, the sensitivity reacing was noted. Calibration tables were prepared showing potentiometer readings and sensitivity settings for each 0.2^{O}C over the temperature range expected.

To measure oxygen percentage saturation and temperature in situ the probe was connected to the meter, and immersed in the water for sufficient time for equilibration to take place. The thermister bridge was then balanced and the potentiometer setting noted. By reference to the calibration table the temperature and corresponding sensitivity can be found. The sensitivity is then dialled on the sensitivity control and the oxygen percentage saturation is read directly on the meter scale.

Determination of Chlorophyll a (after Richards & Thompson (1952) with modification described by Strickland & Parsons (1968) using trichomactic equations of Parsons & Strickland (1963))

Samples for pigment determination were returned to the laboratory in subduced light, immediately after completion of sampling.

Apparatus

(1) Millipore filtration apparatus designed to hold 47 mm diameter filters with a large volume reservoir.

(2) Stoppered graduated glass centrifuge tubes of 15 ml capacity.

(3) Tissue grinder.

Special reagents

(1) 90% acetone: 100 ml of distilled water was pipetted into 1 litre volumetric flask and made up to the mark with analytical reagent grade acetone.

(2) Magnesium carbonate suspension: 1 gm of finely powdered (light weight) A.R. $MgCO_3$ was added to 100 ml of distilled water and shaken. This solution was dispensed from a plastic wash bottle.

A polythene bottle containing a suitable volume of sample (1 or 2 litres) was inverted into the reservoir of the filtration apparatus fitted with a 4.5 cm Whatman GF/C glass fibre filter. 1 ml of magnesium carbonate suspension was then added to the sample. Filtration was allowed to proceed at atmospheric pressure in the dark at about $1^{\circ}C$, several hours were necessary for completion. The filter was then removed from the apparatus and the excess glass fibre paper with a clean pair of scissors. Filters were then either stored at $-20^{\circ}C$ or extracted without delay.

The filter was placed in a grinding tube with 2 ml 90% acetone and macerated with a tissue grinder at 500 r.p.m. This procedure was carried out in ice cold acetone and subduced light. When the glass fibres were thoroughly dispersed the contents of the grinding tube were transferred quantitatively to a stoppered 15 ml centrifuge tube, 90% acetone being used to rinse the grinding tube. The stoppered centrifuge tubes were then placed in a refrigerator in complete darkness for 24 hours to allow the pigment to extract.

After this period the tubes were removed from the refrigerator and made up to exactly 12.0 ml with 90% acetone, the contents of the tubes were then centrifuged for 10 minutes between 3000 and 4000 r.p.m., the clear supernatant liquid was decanted into a Unicam glass 1 cm spectrophotometer cell fitted with a glass stopper. The extinction of the solution was measured without delay against a cell containing 90% acetone at 750, 665, 645, 630 and 430 m . All readings were corrected for cell to cell blanks, measured for all cells at the five wavelengths used.

Before the concentration of chlorophyll a was calculated the extinction coefficients were normalized to the value expected from 10 ml of acetone extract, by multiplying the observed value by 1.2.

All readings were corrected for turbidity blank by subtracting the extinction at 750 m . The concentration of chlorophyll a in the water sample was then calculated from the expression:-

$$g \text{ chlorophyll } \underline{a}/1 = \frac{c}{v}$$

where v was the volume of sample filtered in litres and c was a value estimated from the equation $C = 11.6E_{665} - 1.51E_{645} - 0.14E_{630}$ where E was the corrected extinction value at the wavelength indicated by the subscript.

The corrected extinction measured at 430 m may be used in conjunction with the extinction at 665 m to obtain the ratio E430:E665. This is referred to pigment ratio.

Enumeration of phytoplankton

The enumeration technique used in the present study was a modification of the membrane filtration technique of McNabb (1960). Immediately on return to the laboratory the sample (without formalin fixation) is thoroughly agigated and a suitable aliquot is withdrawn for filtration. The size of this aliquot is such that the organisms are not too crowded to make visual separation difficult not too widely spaced to make counting tedious. 250 ml of sample were generally filtered though 100 ml was used when phytoplankton numbers were high. The aliquot was measured into the reservoir of a millipore filtration unit, which had been previously cleaned with two washes of distilled water. 25 mm diameter millipore HA filters with 0.45 μ pore size were used on all occasions. The filter flask (Buchner flask) was connected to a vacuum pump and the filtration was continued till the last trace of liquid just disappeared; this process takes roughly ten minutes. The vacuum pump was then disconnected leaving the planktonic organisms as a film on the filter.

The filter disk was carefully removed from the filtration unit and after trimming was placed, filtering-surface up, on a clean microscope slide. 3 drops of Uvinert immersion oil were added to the upper surface of the filter and the slide was placed in a dark incubator at room temperature for 24 hours. The cleared filter was then covered with a clean coverglass, the excess oil was removed with a tissue and the mount was sealed with clear nail varnish. Slides prepared in this manner have shown no signs of deterioration after 24 months when kept in the dark.

The enumeration was commenced by placing the slide on the mechanical stage which was moved so that 30 random fields were viewed. According to McNabb (1960) it is not necessary to count numbers of individuals but only to record whether a certain species is present or absent in each field. However, the procedure only gives an estimate of the actual density of phytoplankton and was not employed in this investigation. Instead the actual number of each species was recorded in every field. The number of algae per litre can then be found for any species knowing the total count (D) in 30 fields, the area of the filter, the area of the field and the number of litres filtered from the following equation:-

$$\text{Number of algae per litre} = \frac{D \times \text{area of filter}}{\text{area of 30 fields} \times \text{number of litres filtered}}$$

The enumeration of organisms on the filter is subject to the same statistical requirements as the scanning of sedimented organisms with Utermöhl's inverted microscope technique (Margalef 1971). If the planktonic organisms are randomly distributed on the filter and a sufficiently large number of random fields (30) are enumerated, then the total count can be given 95% confidence limits (Legendre & Watt, 1972).

To determine whether the distribution is random, the the chi squared ((χ^2)) test should be applied to several series of 30 counts from the same slide. χ^2 values of 14.2 to 18.1 were found in the present investigation for five replicate series of counts. These values indicate that the distribution of organisms on the filter is random (probability better than 0.02). The distribution of organisms in fields is described by the Poisson distribution which has the following 95% confidence limits (Lund etaal., 1958):-

$$\text{Upper limit} = \chi + 2.42 + 1.96\sqrt{x + 1.5}$$

$$\text{Lower limit} - \chi + 1.42 - 1.96\sqrt{x + 0.5}$$

If any count lies within the confidence limits of another there is no significant difference between them; if the confidence limits do not overlap the counts are significantly different (see Biometrical Statistical Tables Vol. 1, 1954).

Table 1. Loch Lomond - South Basin

Phosphate (μg. atom/1).

Date	Surface	3 m	5 m	10 m	Date	Surface	3 m	5 m	10 m
7. 4.72	0.07	0.06	0.09	0.08	25.10.72	0.08	0.08	0.07	0.08
14. 4.72	0.08	0.08	0.08	0.07	2.11.72	-	-	-	-
20. 4.72	0.075	0.08	0.08	0.07	23.11.72	0.1	0.08	0.08	0.1
27. 4.72	0.07	0.07	0.08	0.07	7.12.72	0.12	0.1	0.09	0.12
4. 5.72	0.05	0.06	0.06	0.05	21.12.72	0.13	0.12	0.12	0.12
17. 5.72	0.06	0.06	0.06	0.06	4. 1.73	0.16	0.13	0.13	0.12
29. 5.72	0.07	0.08	0.07	0.075	17. 1.73	0.15	0.16	0.15	0.118
5. 6.72	0.08	0.08	0.07	0.08	1. 2.73	0.19	0.18	0.18	0.12
12. 6.72	0.04	0.06	0.06	0.06	15. 2.73	0.2	0.2	0.18	0.16
19. 6.72	0.04	0.04	0.06	0.07	1. 3.73	0.175	0.2	0.165	0.14
27. 6.72	0.05	0.04	0.04	0.05	15. 3.73	0.15	0.13	0.14	0.1
4. 7.72	0.03	0.04	0.03	0.05	28. 3.73	0.08	0.08	0.1	0.1
10. 7.72	0.02	0.04	0.03	0.05	12. 4.73	0.1	0.09	0.095	0.09
18. 7.72	0.03	0.03	0.04	0.05	26. 4.73	0.09	0.09	0.095	0.085
26. 7.72	0.02	0.03	0.03	0.05	2. 5.73	0.07	0.07	0.08	0.08
1. 8.72	0.03	0.04	0.04	0.04	10. 5.73	0.07	0.06	0.06	0.075
8. 8.72	0.04	0.04	0.06	0.04	24. 5.73	0.07	0.06	0.06	0.075
15. 8.72	0.03	0.03	0.05	0.04	7. 6.73	0.06	0.06	0.05	0.07
22. 8.72	0.02	0.05	0.06	0.03	24. 6.73	0.07	0.07	0.06	0.06
29. 8.72	0.06	0.06	0.06	0.03	6. 7.73	0.02	0.03	0.03	0.04
6. 9.72	0.08	0.07	0.07	0.08	24. 7.73	0.025	0.02	0.03	0.04
12. 9.72	0.12	0.1	0.1	0.1	2. 8.73	0.05	0.03	0.04	0.04
27. 9.72	0.1	0.06	0.1	0.12	17. 8.73	0.06	0.06	0.05	0.06
11.10.72	0.08	0.07	0.07	0.08	4. 9.73	-	-	-	-

Table 2. Loch Lomond - Middle Basin

Phosphate (µg. atom/l.)

	Surface	3 m	5 m	10 m		Surface	3 m	5 m	10 m
7. 4.72	0.075	0.07	0.085	0.085	25.10.72	0.07	0.07	0.065	0.08
14. 4.72	0.08	0.085	0.085	0.08	2.11.72	-	-	-	-
20. 4.72	0.07	0.07	0.08	0.075	23.11.72	0.08	0.085	0.075	0.085
27. 4.72	0.04	0.05	0.065	0.065	7.12.72	0.08	0.095	0.08	0.1
4. 5.72	0.04	0.04	0.055	0.065	21.12.72	0.09	0.095	0.08	0.1
17. 5.72	0.05	0.05	0.06	0.08	4. 1.73	0.11	0.12	0.09	0.11
29. 5.72	0.075	0.07	0.07	0.08	17. 1.73	0.13	0.13	0.095	0.12
5. 6.72	0.08	0.075	0.08	0.07	1. 2.73	0.12	0.13	0.105	0.115
12. 6.72	0.075	0.07	0.08	0.08	15. 2.73	0.16	0.13	0.115	0.115
19. 6.72	0.08	0.075	0.075	0.085	1. 3.73	0.14	0.14	0.105	0.1
27. 6.72	0.075	0.075	0.075	0.08	15. 3.73	0.075	0.1	0.08	0.075
4. 7.72	0.075	0.08	0.065	0.07	28. 3.73	0.065	0.07	0.085	0.08
10. 7.72	0.065	0.065	0.06	0.065	12. 4.73	0.08	0.07	0.09	0.08
18. 7.72	0.055	0.06	0.055	0.06	26. 4.73	0.09	0.09	0.09	0.085
26. 7.72	0.04	0.04	0.04	0.06	2. 5.73	0.07	0.09	0.08	0.08
1. 8.72	0.04	0.05	0.04	0.05	10. 5.73	0.07	0.08	0.075	0.08
8. 8.72	0.055	0.05	0.04	0.04	24. 5.73	0.05	0.07	0.075	0.08
15. 8.72	0.05	0.04	0.04	0.04	7. 6.73	0.06	0.055	0.05	0.065
22. 8.72	0.04	0.04	0.045	0.04	24..6.73	0.04	0.05	0.05	0.05
29. 8.72	0.04	0.04	0.045	0.045	6. 7.73	0.04	0.04	0.03	0.04
6. 9.72	0.04	0.04	0.045	0.055	24. 7.73	0.02	0.04	0.04	0.04
12. 9.72	0.11	0.1	0.1	0.095	2. 8.73	0.02	0.02	0.05	0.045
27. 9.72	0.085	0.1	0.075	0.085	17. 8.73	0.04	0.05	0.065	0.065
11.10.72	0.075	0.08	0.07	0.08	20. 9.73	-	-	-	-

Table 3. Loch Lomond - North Basin

Phosphate (µg. atom./1.)

Date	Surface	3 m	5 m	10 m	Date	Surface	3 m	5 m	10 m
7. 4.72	0.035	0.035	0.04	0.04	25.10.72	0.03	0.05	0.04	0.04
14. 4.72	0.03	0.03	0.035	0.035	2.11.72	-	-	-	-
20. 4.72	0.035	0.03	0.035	0.035	23.11.72	0.045	0.075	0.04	0.04
27. 4.72	0.03	0.04	0.05	0.035	7.12.72	0.035	0.075	0.045	0.05
4. 5.72	0.05	0.065	0.05	0.05	21.12.72	0.05	0.08	0.06	0.06
17. 5.72	0.06	0.06	0.045	0.05	4. 1.73	0.075	0.075	0.06	0.075
29. 5.72	0.06	0.07	0.05	0.045	17. 1.73	0.07	0.08	0.075	0.08
5. 6.72	0.065	0.07	0.06	0.05	1. 2.73	0.1	0.1	0.085	0.085
12. 6.72	0.06	0.06	0.06	0.06	15. 2.73	0.085	0.1	0.1	0.08
19. 6.72	0.065	0.05	0.055	0.05	1. 3.73	0.095	0.095	0.1	0.08
27. 6.72	0.065	0.06	0.05	0.06	15. 3.73	0.075	0.075	0.075	0.075
4. 7.72	0.06	0.05	0.045	0.06	28. 3.73	-	-	-	-
10. 7.72	0.04	0.04	0.03	0.05	12. 4.73	0.035	0.05	0.045	0.055
18. 7.72	0.045	0.04	0.03	0.035	26. 4.73	0.04	0.055	0.045	0.03
26. 7.72	0.04	0.025	0.02	0.035	10. 5.73	0.05	0.05	0.055	0.04
1. 8.72	0.025	0.02	0.03	0.03	24. 5.73	0.055	0.075	0.06	0.055
8. 8.72	0.025	0.03	0.03	0.03	7. 6.73	0.05	0.07	0.06	0.06
15. 8.72	0.02	0.02	0.035	0.025	24. 6.73	0.03	0.07	0.05	0.05
22. 8.72	0.025	0.03	0.04	0.025	6. 7.73	0.03	0.05	0.04	0.025
29. 8.72	0.025	0.04	0.045	0.025	24. 7.73	0.02	0.025	0.02	0.025
6. 9.72	0.03	0.06	0.045	0.035	2. 8.73	0.02	0.025	0.03	0.03
12. 9.72	0.125	0.115	0.1	0.08	17. 8.73	0.045	0.05	0.04	0.04
27. 9.72	0.1	0.08	0.065	0.075	20. 9.73	-	-	-	-
11.10.72	0.05	0.06	0.05	0.06					

Table 4. Phosphate (μg. atom/l.)

	Lake of Menteith		Loch Rusky		Loch Achray		Loch Ard	
Date	Surface	3 m	Surface	5 m	Surface	5 m	Surface	5 m
18.10.72	0.19	0.19	0.171	0.237	0.152	0.108	0.025	0.03
1.11.72	0.093	0.15	0.162	0.112	0.043	0.037	0.0125	0.0125
15.11.72	0.131	0.137	0.144	0.171	0.081	0.094	0.03	0.03
29.11.72	0.117	0.13	0.21	0.16	0.085	0.104	0.026	0.04
13.12.72	0.158	0.233	0.261	0.364	0.075	0.088	0.055	0.06
27.12.72	0.16	0.238	0.27	0.38	0.126	0.125	0.025	0.07
10. 1.73	0.17	0.245	0.28	0.39	0.15	0.135	0.05	0.05
24. 1.73	0.148	0.242	0.29	0.41	0.112	0.14	0.08	0.07
7. 2.73	0.155	0.274	0.39	0.41	0.239	0.25	0.085	0.08
21. 2.73	0.163	0.26	0.29	-	0.175	0.12	0.125	0.09
8. 3.73	0.200	0.254	0.32	0.34	0.0798	0.133	0.085	0.075
26. 3.73	0.18	0.23	0.26	0.29	0.10	0.08	0.07	0.05
8. 4.73	0.162	0.24	-	-	-	-	-	-
20. 4.73	0.152	0.253	0.32	0.31	0.121	0.108	0.06	0.06
3. 5.73	0.1995	0.252	0.32	0.26	0.142	0.166	0.04	0.05
17. 5.73	0.174	0.137	0.12	0.16	0.071	0.124	0.045	0.035
1. 6.73	0.145	0.126	0.115	0.18	0.075	-	0.027	0.05
14. 6.73	0.065	0.078	0.105	0.13	0.045	0.032	0.04	0.05
28. 6.73	0.03	0.05	0.22	0.25	0.03	0.03	0.035	0.035
11. 7.73	0.053	0.053	0.12	0.17	0.026	0.026	0.0125	0.025
26. 7.73	0.133	0.159	0.11	0.16	0.053	0.039	0.015	0.025
8. 8.73	0.107	0.100	0.22	0.16	0.094	0.067	0.025	0.03
23. 8.73	0.151	0.151	0.59	0.22	0.151	0.137	0.03	0.025
20. 9.73	0.163	0.186	0.14	0.22	0.101	0.09	0.035	0.035

Table 5. Loch Lomond - South Basin

Silicate (µg. atom/l).

Date	Surface	3 m	5 m	10 m	Date	Surface	3 m	5 m	10 m
7. 4.72	18.21	18.14	17.86	18.57	25.10.72	6.19	6.19	6.19	6.29
14. 4.72	12.3	12.3	15.1	14.5	2.11.72	-	-	-	-
20. 4.72	13.4	12.54	12.6	12.04	23.11.72	11.43	11.71	10.95	10.95
27. 4.72	12.7	11.6	12.6	13.3	7. 2.72	13.63	13.69	13.8	13.97
4. 5.72	14.35	13.7	14.4	15.34	21.12.72	15.22	15.54	15.33	16.1
17. 5.72	15.18	15.23	15.07	14.96	4. 1.73	17.5	17.5	17.5	17.5
29. 5.72	14.22	14.44	14.89	14.78	17. 1.73	19.5	19.5	19.6	19.7
5. 6.72	14.93	14.93	14.93	14.00	1. 2.73	18.84	18.85	19.79	19.04
12. 6.72	14.9	14.9	14.9	14.0	15. 2.73	21.93	22.15	21.57	21.3
19. 6.72	14.87	13.8	14.55	13.23	1. 3.73	20.98	21.3	20.98	21.3
27. 6.72	13.55	14.27	13.05	13.87	15. 3.73	19.9	19.8	20.98	20.44
4. 7.72	14.3	14.09	14.04	13.62	28. 3.73	17.35	17.67	18.1	18.00
10.77.72	12.8	13.45	13.6	12.9	12. 4.73	15.97	15.76	15.97	15.97
18. 7.72	12.9	13.33	13.86	13.93	26. 4.73	16.59	16.8	16.8	16.59
26. 7.72	12.00	12.10	12.5	12.5	2. 5.73	16.53	16.8	16.8	16.59
1. 8.72	10.15	10.39	11.02	12.07	10. 5.73	16.53	16.67	16.44	16.76
8. 8.72	8.94	8.98	9.5	9.61	24. 5.73	12.39	13.31	13.61	13.7
15. 8.72	9.32	9.53	9.64	9.71	7. 6.73	12.32	13.31	13.61	13.7
22. 8.72	9.43	9.07	9.53	8.97	24. 6.73	5.9	5.96	5.64	5.53
29. 8.72	8.36	8.46	8.46	7.88	6. 7.73	4.04	4.15	4.7	5.00
6. 9.72	7.89	7.99	8.01	8.54	24. 7.73	2.27	2.15	2.5	3.66
12. 9.72	9.28	9.71	9.35	9.35	2. 8.73	2.36	2.17	2.21	3.66
27. 9.72	8.77	8.79	8.81	8.88	17. 8.73	5.13	5.02	4.77	5.3
11.10.72	6.05	5.76	5.78	6.05	4. 9.73	-	-	-	-

Table 6. Loch Lomond - Middle Basin

Silicate (μg. atom/l.)

Date	Surface	3 m	5 m	10 m	Date	Surface	3 m	5 m	10 m
7. 4.72	18.45	18.2	18.26	19.65	25.10.72	11.16	11.16	11.16	10.8
14. 4.72	17.1	15.5	15.3	17.4	2.11.72	-	-	-	-
20. 4.72	15.76	15.72	16.6	15.44	23.11.72	13.9	14.23	13.9	13.46
27. 4.72	16.3	16.00	16.00	15.7	7.12.72	13.58	13.58	13.52	13.58
4. 5.72	13.66	15.34	16.13	15.57	21.12.72	14.07	14.17	13.86	14.00
17. 5.72	15.34	16.2	16.24	15.9	4. 1.73	14.74	15.04	14.94	14.94
29. 5.72	15.45	15.68	15.79	16.02	17. 1.73	15.33	15.33	15.33	15.44
5. 6.72	15.28	15.23	14.81	15.93	1. 2.73	15.08	15.6	17.08	16.00
12. 6.72	14.06	13.83	14.19	14.00	15. 2.73	17.35	17.46	17.9	17.78
19. 6.72	14.23	14.45	13.83	13.706	1. 3.73	17.89	17.14	18.04	17.89
27. 6.72	14.23	13.27	13.44	12.23	15. 3.73	17.78	18.38	18.31	17.78
4. 7.72	14.04	13.85	13.81	14.04	28. 3.73	-	-	-	-
10. 7.72	12.7	13.1	13.6	12.9	12. 4.73	15.4	15.33	15.86	15.76
18. 7.72	12.24	12.31	12.67	13.84	26. 4.73	15.73	15.73	15.73	16.16
26. 7.72	-	-	-	-	2. 5.73	15.0	15.0	15.5	15.5
1. 8.72	9.206	9.206	10.00	10.115	10. 5.73	-	-	-	-
8. 8.72	8.82	8.94	9.72	11.417	24. 5.73	15.99	16.67	16.22	16.25
15. 8.72	9.1	9.16	9.53	10.11	7. 6.73	13.31	13.73	13.58	13.73
22. 8.72	9.02	8.74	9.03	8.83	24. 6.73	5.64	5.87	5.95	5.9
29. 8.72	7.98	7.78	7.88	8.07	6. 7.73	5.15	5.85	5.2	5.4
6. 9.72	7.42	7.58	7.68	9.43	24. 7.73	2.83	2.4	3.0	5.1
12. 9.72	7.6	7.78	7.78	7.87	2. 8.73	2.47	3.77	3.94	6.92
27. 9.72	8.68	8.64	8.86	8.77	17. 8.73	5.32	5.32	4.81	7.5
11.10.72	8.83	8.65	8.2	8.63	4. 9.73	-	-	-	-

Table 7. Loch Lomond - North Basin

Silicate (µg. atom/1.).

Date	Surface	3 m	5 m	10 m	Date	Surface	3 m	5 m	10 m
7. 4.72	13.2	13.22	16.45	15.28	25.10.72	-	-	-	-
14. 4.72	13.4	14.2	15.00	15.00	2.11.72	-	-	-	-
20. 4.72	14.94	14.5	14.31	14.21	23.11.72	13.46	13.84	13.79	13.57
27. 4.72	14.8	15.2	15.2	15.2	7.12.72	13.26	13.55	13.8	13.8
4. 5.72	16.02	15.57	16.36	15.5	21.12.72	14.28	14.33	14.38	14.28
17. 5.72	15.88	15.52	15.63	15.12	4. 1.73	14.73	14.56	14.75	14.94
29. 5.72	14.55	13.88	14.89	14.78	17. 1.73	14.9	14.59	14.48	14.69
5. 6.72	14.7	15.3	14.88	14.88	1. 2.73	13.09	13.3	12.77	12.88
12. 6.72	13.72	13.61	13.43	13.54	15. 2.73	14.48	15.12	15.12	15.97
19. 6.72	13.27	14.45	13.54	14.34	1. 3.73	14.69	14.69	15.1	14.86
27. 6.72	13.44	13.16	12.18	13.48	15. 3.73	14.69	15.61	15.22	15.27
4. 7.72	13.04	13.51	13.62	13.81	28. 3.73	-	-	-	-
10. 7.72	13.3	12.9	12.9	13.1	12. 4.73	13.73	13.73	12.88	12.46
18. 7.72	11.7	11.8	12.67	13.04	26. 4.73	14.67	14.88	14.67	14.67
26. 7.72	10.5	11.0	11.5	12.5	10. 5.73	16.00	15.00	15.00	15.00
1. 8.72	9.37	9.79	9.96	12.52	24. 5.73	16.08	15.99	15.76	15.76
8. 8.72	10.06	10.22	10.06	9.99	7. 6.73	12.78	13.09	12.88	12.26
15. 8.72	9.89	9.59	9.73	9.53	24. 6.73	11.3	11.75	11.75	11.9
22. 8.72	9.53	9.27	9.51	9.195	6. 7.73	8.3	8.5	5.15	5.85
29. 8.72	8.01	7.73	8.14	7.69	24. 7.73	6.92	7.02	5.00	6.4
6. 9.72	7.83	8.05	8.2	9.22	2. 8.73	5.04	5.72	5.79	7.9
12. 9.72	8.05	8.05	8.18	8.37	17. 8.73	6.17	6.68	7.54	8.5
27. 9.72	9.418	9.63	9.68	9.52	4. 9.73	-	-	-	-
11.10.72	9.72	9.7	9.75	9.98					

Table 8. Silicate (μg. atom/l.)

	Lake of Menteith		Loch Rusky		Loch Achray		Loch Ard	
Date	Surface	3 m	Surface	5 m	Surface	5 m	Surface	5 m
18.10.72	54.3	54.3	24.66	24.168	11.33	11.11	12.5	12.0
1.11.72	44.8	42.3	18.52	18.42	14.98	14.93	10.0	11.5
15.11.72	42.3	34.2	18.5	18.4	15.38	14.04	10.0	11.0
29.11.72	32.6	34.2	27.69	27.69	18.7	18.5	11.0	12.5
13.12.72	45.8	45.8	34.5	34.5	22.3	22.3	12.0	12.5
21.12.72	59.6	59.8	38.0	37.0	34.4	25.0	14.0	14.5
10. 1.73	60.1	60.3	46.0	44.0	31.95	26.0	14.0	15.0
24. 1.73	70.3	65.4	50.0	50.0	21.3	25.5	16.0	16.0
7. 2.73	80.1	75.0	53.0	53.0	20.0	28.0	18.0	17.5
21. 2.73	85.0	85.0	85.0	70.0	18.74	-	21.0	20.0
8. 3.73	54.3	54.3	93.0	93.0	19.08	18.86	20.0	18.0
26. 3.73	29.39	29.8	15.0	14.3	19.408	19.32	18.00	15.0
8. 4.73	25.13	26.83	-	-	-	-	-	-
20. 4.73	25.13	26.83	18.2	17.2	17.99	17.99	13.0	12.5
3. 5.73	20.63	25.52	7.1	4.3	15.52	16.22	12.5	10.0
17. 5.73	11.3	13.12	2.1	1.0	8.2	8.2	12.5	11.0
1. 6.73	1.49	2.215	0.4	0.5	7.4	10.1	12.0	11.0
14. 6.73	0.47	0.532	3.1	3.2	7.8	8.2	9.0	11.0
28. 6.73	4.4	4.5	9.2	8.4	14.04	14.0	9.0	9.0
11. 7.73	6.7	6.53	7.1	12.2	11.71	13.41	10.0	10.5
26. 7.73	5.21	5.8	2.3	3.1	10.6	12.7	11.0	10.5
8. 8.73	16.74	17.04	4.3	4.2	10.52	10.6	10.0	10.5
23. 8.73	23.85	22.57	6.2	6.3	10.94	11.37	10.0	10.5
20. 9.73	36.2	36.2	16.1	16.5	11.0	15.0	12.5	12.5

Table 9. Loch Lomond - South Basin

Nitrate + Nitrite (µg. atom/l).

Date	Surface	3 m	5 m	10 m	Date	Surface	3 m	5 m	10 m
7. 4.72	17.95	18.17	18.92	18.88	25.10.72	11.97	11.78	10.91	12.01
14. 4.72	19.25	21.05	21.95	22.66	2.11.72	-	-	-	-
20. 4.72	19.25	19.17	18.92	18.8	23.11.72	14.81	14.39	13.97	13.97
27. 4.72	17.95	18.17	18.95	18.88	7.12.72	16.45	15.74	16.12	16.77
4. 5.72	17.02	16.1	17.5	17.7	21.12.72	18.4	17.3	18.4	18.2
17. 5.72	18.4	17.1	18.04	18.14	4. 1.73	19.32	18.91	20.14	19.22
29. 5.72	18.08	19.85	21.8	18.85	17. 1.73	22.2	22.2	22.7	22.62
5. 6.72	19.0	19.5	21.6	20.9	1. 2.73	21.51	22.23	20.52	21.11
12. 6.72	19.48	18.89	18.07	20.01	15. 2.73	20.08	22.5	22.5	22.9
19. 6.72	14.9	13.99	14.98	15.51	1. 3.73	16.8	18.00	17.9	18.00
27. 6.72	15.08	16.02	16.98	16.94	15. 3.73	19.42	20.47	20.01	20.55
4. 7.72	14.5	16.3	15.34	15.34	28. 3.73	16.96	19.36	18.24	-
10. 7.72	13.5	14.00	14.6	15.0	12. 4.73	17.6	17.6	18.00	17.6
18. 7.72	12.64	12.64	13.77	14.64	26. 4.73	19.94	19.94	21.4	21.42
26. 7.72	11.6	11.7	12.5	14.5	2. 5.73	16.00	17.5	19.5	19.5
1. 8.72	10.12	10.6	11.65	14.19	10. 5.73	16.08	17.5	18.0	19.0
8. 8.72	12.81	12.08	11.6	11.86	24. 5.73	15.8	16.9	15.95	16.6
15. 8.72	12.85	11.63	11.83	11.63	7. 6.73	15.09	15.09	15.01	15.09
22. 8.72	12.22	11.57	11.57	12.00	24. 6.73	15.82	15.51	15.0	15.0
29. 8.72	11.63	12.36	10.52	9.99	6. 7.73	15.09	15.34	15.3	15.3
6. 9.72	11.84	11.35	11.96	12.12	24. 7.73	8.82	8.82	10.00	11.9
12. 9.72	13.68	13.98	14.14	13.68	2. 8.73	7.69	5.04	6.22	7.15
27. 9.72	13.34	13.14	12.94	12.84	17. 8.73	9.4	10.04	10.04	9.5
11.10.72	13.2	12.5	12.4	12.9	4. 9.73	-	-	-	-

Table 10. Loch Lomond - Middle Basin

Nitrate + Nitrite (μg. atom/l.)

	Surface	3 m	5 m	10 m		Surface	3 m	5 m	10 m
7. 4.72	14.21	14.7	15.18	16.5	25.10.72	12.2	12.22	12.22	12.22
14. 4.72	19.45	19.73	18.64	18.08	2.11.72	-	-	-	-
20. 4.72	15.6	14.76	18.7	17.6	23.11.72	13.97	14.39	14.01	13.93
27. 4.72	15.6	14.5	18.7	17.6	7.12.72	14.8	14.96	15.74	15.74
4. 5.72	13.2	15.4	15.3	14.43	21.12.72	15.3	15.5	15.6	15.8
17. 5.72	16.5	15.1	15.4	13.2	4. 1.73	17.99	16.56	17.99	16.1
29. 5.72	15.4	14.96	16.3	16.7	17. 1.73	18.07	19.19	19.06	18.5
5. 6.72	17.5	16.00	16.00	16.00	1. 2.73	18.93	18.0	17.53	18.33
12. 6.72	18.22	17.12	16.89	16.32	15. 2.73	17.2	-8.5	17.5	17.62
19. 6.72	15.0	15.0	15.0	15.0	1. 3.73	12.4	14.68	13.2	14.0
27. 6.72	14.8	14.65	13.5	14.21	13. 3.73	14.77	16.14	15.51	15.1
4. 7.72	15.0	14.08	15.4	14.6	28. 3.73	-	-	-	-
10. 7.72	12.7	13.1	13.6	12.9	12. 4.73	17.6	18.08	16.6	17.0
18. 7.72	12.16	12.36	12.64	13.2	26. 4.73	16.32	17.53	17.16	16.5
26. 7.72	-	-	-	-	2. 5.73	16.0	16.0	16.0	16.0
1. 8.72	10.45	10.13	11.13	13.54	10. 5.73	-	-	-	-
8. 8.72	10.63	12.45	13.13	13.58	24. 5.73	16.0	15.54	16.65	14.32
15. 8.72	11.54	11.52	11.63	11.71	7. 6.73	13.0	13.5	13.5	13.0
22. 8.72	12.0	11.7	11.57	12.1	24. 6.73	13.0	13.0	13.0	13.0
29. 8.72	11.14	10.52	11.55	12.0	6. 7.73	13.7	13.7	13.7	14.7
6. 9.72	10.5	11.39	11.31	11.84	24. 7.73	5.56	5.56	5.4	5.9
12. 9.72	11.40	12.54	12.32	12.77	2. 8.73	4.8	6.45	6.12	5.97
27. 9.72	11.85	12.94	12.94	12.82	17. 8.73	9.21	8.3	8.86	7.5
11.10.72	14.76	13.12	14.35	14.35	4. 9.73	-	-	-	-

Table 11. Loch Lomond - North Basin

Nitrate + Nitrite (μg. atom/l.).

Date	Surface	3 m	5 m	10 m	Date	Surface	3 m	5 m	10 m
7. 4.72	10.25	12.33	10.16	11.44	25.10.72	10.08	12.0	11.8	14.0
14. 4.72	13.36	14.77	-	-	2.11.72	-	-	-	-
20. 4.72	10.25	12.32	10.16	11.44	23.11.72	13.34	13.97	13.55	14.39
27. 4.72	10.8	11.12	11.4	14.5	7.12.72	13.99	13.9	14.0	14.2
4. 5.72	10.9	10.01	11.08	11.08	21.12.72	14.1	13.8	14.1	14.0
17. 5.72	11.34	11.08	11.0	12.32	4. 1.73	14.3	14.3	15.33	15.7
29. 5.72	11.88	14.6	13.6	14.96	17. 1.73	15.08	16.13	15.33	15.7
5. 6.72	13.1	-	-	-	1. 2.73	15.8	16.0	15.5	15.0
12. 6.72	12.69	12.69	13.24	14.04	15. 2.73	15.0	15.1	15.0	14.7
19. 6.72	11.67	12.98	12.96	11.67	1. 3.73	13.1	13.0	13.2	13.4
27. 6.72	11.88	12.75	12.55	12.25	15. 3.73	12.03	12.12	13.26	12.8
4. 7.72	12.58	12.7	12.4	12.1	28. 3.73	-	-	-	-
10. 7.72	12.66	13.2	12.75	13.55	12. 4.73	10.94	11.0	11.9	11.1
18. 7.72	11.9	12.3	12.1	12.16	26. 4.73	9.7	9.52	9.52	9.52
26. 7.72	-	-	-	-	10. 5.73	10.58	10.58	10.58	10.58
1. 8.72	9.34	10.13	10.05	12.74	24. 5.73	10.87	10.69	14.0	12.5
8.88.72	10.3	10.8	10.08	11.54	7. 6.73	10.73	12.42	12.6	11.5
15. 8.72	10.56	10.89	11.28	11.63	24. 6.73	10.44	12.19	11.55	11.00
22. 8.72	11.49	11.14	11.7	11.27	6. 7.73	10.68	10.00	10.00	11.00
29. 8.72	10.32	10.93	10.7	11.34	24. 7.73	7.5	9.5	9.7	10.0
6. 9.72	11.07	11.15	11.03	9.6	2. 8.73	7.0	9.0	8.0	9.0
12. 9.72	10.87	10.95	11.63	10.49	17. 8.73	9.3	9.4	9.8	10.24
27. 9.72	12.74	12.74	12.35	12.15	4. 9.73	-	-	-	-
11.10.72	12.7	13.16	13.12	13.2					

Table 12. Nitrate + Nitrite (µg. atom/1.)

	Lake of Menteith		Loch Rusky		Loch Achray		Loch Ard	
Date	Surface	3 m	Surface	5 m	Surface	5 m	Surface	5 m
18.10.72	5.7	5.9	7.5	9.0	11.33	11.11	10.0	10.0
1.11.72	1.4	1.4	5.2	5.6	8.96	9.0	10.0	10.5
15.11.72	1.95	2.37	5.98	6.1	9.1	9.64	9.1	10.0
29.11.72	2.25	1.48	4.5	6.5	9.8	9.9	10.0	9.5
13.12.72	7.8	7.4	9.40	10.3	10.4	11.2	11.1	11.2
27.12.72	9.32	10.95	10.0	10.9	13.08	12.00	12.1	13.3
10. 1.73	12.08	13.96	11.5	13.8	15.2	14.5	10.1	12.2
24. 1.73	14.07	14.26	16.5	17.8	13.8	13.05	14.1	16.1
7. 2.73	14.11	14.29	16.5	17.1	11.04	11.95	17.5	18.0
21. 2.73	15.28	15.28	16.8	18.2	11.85	-	20.2	20.1
8. 3.73	15.03	16.5	19.2	20.8	14.61	14.2	20.2	21.1
26. 3.73	10.94	11.4	15.2	15.6	11.17	10.94	10.1	17.5
8. 4.73	8.3	9.3	-	-	-	-	-	-
20. 4.73	6.00	7.20	10.0	5.9	11.2	12.0	11.1	14.1
3. 5.73	5.45	5.9	7.5	8.0	11.9	11.9	10.2	12.5
17. 5.73	1.04	1.04	3.3	2.8	6.8	7.7	9.5	12.5
1. 6.73	0.63	0.39	5.8	5.8	10.5	10.5	10.0	12.0
14. 6.73	1.102	1.22	4.5	5.1	9.2	9.4	10.5	10.0
28. 6.73	1.02	0.093	4.5	4.5	7.3	7.5	8.0	11.5
11. 7.73	1.2	1.0	3.8	4.5	6.5	6.4	7.5	10.0
26. 7.73	0.78	1.96	2.5	2.1	4.31	3.52	4.1	7.5
8. 8.73	1.9	1.82	2.0	1.8	6.39	6.22	7.5	9.2
23. 8.73	2.64	2.5	2.4	2.0	6.6	4.6	8.2	11.5
20. 9.73	2.93	2.73	3.3	3.6	6.0	6.0	10.1	12.5

Table 13. Loch Lomond - South Basin

pH

Date	Surface	3 m	5 m	10 m	Date	Surface	3 m	5 m	10 m
23.12.71	6.9	6.9	6.9	6.9	6. 9.72	7.3	7.3	7.1	7.1
7. 1.72	6.8	6.8	6.8	6.8	12.9.72	7.1	7.1	7.1	7.1
20. 1.72	6.8	6.8	6.8	6.8	27. 9.72	7.3	7.3	7.3	7.3
3. 2.72	6.9	6.8	6.8	6.8	11.10.72	7.3	7.3	7.3	7.3
17. 2.72	6.8	6.8	6.8	6.8	25.10.72	7.4	7.2	7.2	7.2
24. 2.72	6.9	6.9	6.9	6.9	2.11.72	-	-	-	-
2. 3.72	7.0	7.1	7.1	7.1	23.11.72	7.1	7.1	7.1	7.1
16. 3.72	7.2	7.1	7.2	7.2	7.12.72	7.0	7.0	7.0	7.0
30. 3.72	7.3	7.3	7.3	7.3	21.12.72	7.1	7.0	7.0	7.0
7. 4.72	7.4	7.4	7.4	7.4	4. 1.73	6.9	6.9	6.9	6.9
14. 4.72	7.4	7.3	7.3	7.2	17. 1.73	6.8	6.8	6.8	6.8
20. 4.72	7.4	7.3	7.4	7.3	1. 2.73	6.7	6.7	6.8	6.8
27. 4.72	7.2	7.2	7.3	7.2	15. 2.73	6.9	6.8	6.9	6.9
4. 5.72	7.2	7.1	7.2	7.2	1. 3.73	6.8	6.8	6.8	6.8
17. 5.72	7.1	7.1	7.1	7.1	15. 3.73	7.0	7.0	7.0	7.0
29. 5.72	7.1	7.1	7.1	7.1	28. 3.73	7.1	7.2	7.2	7.2
5. 6.72	7.2	7.2	7.2	7.2	12. 4.73	7.2	7.2	7.2	7.2
12. 6.72	7.3	7.3	7.2	7.1	26. 4.73	7.0	7.0	7.0	7.0
19. 6.72	7.3	7.3	7.3	7.3	2. 5.73	7.0	7.0	7.0	7.0
27. 6.72	7.3	7.3	7.3	7.3	10. 5.73	6.9	6.9	6.9	6.9
4. 7.72	7.3	7.3	7.3	7.3	24. 5.73	6.9	6.9	6.9	6.9
10. 7.72	7.3	7.4	7.3	7.3	7. 6.73	6.9	6.9	6.9	6.9
18. 7.72	7.5	7.4	7.5	7.4	24. 6.73	7.1	7.1	7.0	7.0
26. 7.72	7.6	7.6	7.5	7.4	6. 7.73	7.2	7.2	7.3	7.2
1. 8.72	7.5	7.3	7.3	7.1	24. 7.73	7.4	7.4	7.4	7.4
8. 8.72	7.5	7.4	7.3	7.3	2. 8.73	7.2	7.2	7.2	7.2
15. 8.72	7.4	7.2	7.2	7.2	17. 8.73	7.2	7.2	7.2	7.2
22. 8.72	7.4	7.3	7.2	7.3	4. 9.73	-	-	-	-
29. 8.72	7.3	7.2	7.2	7.1					

Table 14. Loch Lomond - Middle Basin

pH

	Surface	3 m	5 m	10 m		Surface	3 m	5 m	10 m
23.12.71	6.9	7.0	7.0	6.8	6. 9.72	7.3	7.3	7.3	7.1
7. 1.72	6.8	6.9	6.8	6.8	12. 9.72	7.15	7.1	7.1	7.15
20. 1.72	6.6	6.8	6.7	6.8	27. 9.72	7.1	7.15	7.15	7.15
3. 2.72	6.7	6.8	6.7	6.8	11.10.72	7.05	7.05	7.05	6.9
17. 2.72	6.7	6.7	6.8	6.9	25.10.72	6.9	7.1	7.1	6.9
2. 3.72	6.6	6.7	6.8	6.8	2.11.72	-	-	-	-
16. 3.72	6.9	6.8	6.8	6.8	23.11.72	6.9	6.9	6.9	6.9
30. 3.72	7.0	7.0	7.0	7.0	7.12.72	6.8	6.9	6.9	6.9
7. 4.72	6.95	7.0	7.0	7.0	21.12.72	6.8	6.8	6.8	6.8
14. 4.72	7.1	7.1	7.1	7.0	4. 1.73	6.6	6.7	6.7	6.8
20. 4.72	7.1	7.1	7.1	7.0	17. 1.73	6.5	6.6.	6.6	6.7
27. 4.72	7.05	7.05	7.05	7.05	1. 2.73	6.7	6.8	6.8	6.7
4. 5.72	7.05	7.1	7.1	7.0	15. 2.73	6.7	6.7	6.7	6.8
17. 5.72	6.9	7.05	7.0	7.0	1. 3.73	6.8	6.7	6.75	6.8
29. 5.72	7.0	7.1	7.0	7.0	15. 3.73	6.85	6.8	6.8	6.7
5. 6.72	7.1	7.1	7.15	7.0	28. 3.73	7.0	7.0	7.0	6.9
12. 6.72	7.1	7.15	7.05	7.0	12. 4.73	7.1	7.1	7.1	6.9
19. 6.72	7.1	7.0	7.1	7.0	26. 4.73	7.2	7.1	7.1	6.9
27. 6.72	7.1	7.2	7.2	7.0	2. 5.73	7.1	7.1	7.1	7.0
4. 7.72	7.2	7.2	7.2	7.1	10. 5.73	7.1	7.1	7.1	7.0
10. 7.72	7.25	7.15	7.2	7.25	24. 5.73	7.1	7.1	7.1	6.8
18. 7.72	7.4	7.3	7.2	7.1	7. 6.73	7.2	7.2	7.1	6.9
26. 7.72	7.3	7.2	7.1	7.1	24. 6.73	7.1	7.0	7.0	6.9
1. 8.72	7.4	7.3	7.2	7.05	6. 7.73	7.2	7.2	7.1	7.1
8. 8.72	7.4	7.4	7.2	7.0	24. 7.73	7.3	7.2	7.2	7.0
15. 8.72	7.4	7.25	7.25	7.15	2. 8.73	7.4	7.3	7.2	7.0
22. 8.72	7.2	7.2	7.2	7.2	17. 8.73	7.3	7.3	7.3	7.1
29. 8.72	7.1	7.1	7.05	7.0	4. 9.73	-	-	-	-

Table 15. Loch Lomond - North Basin

pH

Date	Surface	3 m	5 m	10 m	Date	Surface	3 m	5 m	10 m
23.12.71	6.8.	6.75	6.8	6.8	6. 9.72	7.2	7.2	7.1	7.1
7. 1.72	6.7	6.6	6.7	6.7	12. 9.72	7.1	7.1	7.1	7.1
20. 1.72	6.6	6.7	6.7	6.6	27. 9.72	7.0	7.0	6.9	7.0
3. 2.72	6.7	6.5	6.6	6.6	11.10.72	6.95	6.95	6.9	7.0
17. 2.72	6.6	6.5	6.6	6.7	25.10.72	-	-	-	-
2. 3.72	6.5	6.6	6.6	6.5	2.11.72	-	-	-	-
16. 3.72	6.6	6.7	6.7	6.6	23.11.72	6.8	6.7	6.7	6.7
30. 3.72	6.7	6.7	6.7	6.6	7.12.72	6.7	6.6	6.6	6.6
7. 4.72	6.75	6.8	6.8	6.75	21.12.72	6.6	6.6	6.7	6.65
14. 4.72	6.85	6.9	6.9	6.9	4. 1.73	6.6	6.6	6.6	6.6
20. 4.72	6.9	6.9	6.9	6.9	17. 1.73	6.6	6.5	6.5	6.5
27. 4.72	6.8	6.8	6.8	6.8	1. 2.73	6.7	6.6	6.55	6.6
4. 5.72	6.9	6.8	6.8	6.8	15. 2.73	6.5	6.45	6.5	6.5
17. 5.72	6.9	6.8	6.8	6.8	1. 3.73	6.6	6.6	6.6	6.6
29. 5.72	7.05	7.0	6.9	6.9	15. 3.73	6.7	6.65	6.7	6.7
5. 6.72	6.9	6.9	6.9	6.85	28. 3.73	-	-	-	-
12. 6.72	6.8	6.8	6.9	6.9	12. 4.73	6.8	6.8	6.8	6.8
19. 6.72	6.8	6.8	6.85	6.85	26. 4.73	6.75	6.75	6.75	6.75
27. 6.72	7.0	7.0	7,05	7.05	2. 5.73	-	-	-	-
4. 7.72	-	-	-	-	10. 5.73	6.7	6.8	6.7	6.8
10. 7.72	6.9	6.9	7.0	7.0	24. 5.73	6.9	6.7	6.65	6.7
18. 7.72	7.0	7.0	7.0	6.95	7. 6.73	6.8	6.7	6.75	6.8
26. 7.72	7.05	7.05	7.0	6.9	24. 6.73	6.8	6.8	6.7	6.7
1. 8.72	7.2	7.15	6.9	6.95	6. 7.73	6.9	6.9	6.9	6.9
8. 8.72	7.1	7.1	7.05	7.0	24. 7.73	7.0	7.0	6.9	6.9
15. 8.72	7.1	7.1	6.95	7.1	2. 8.73	7.0	6.9	6.9	6.95
22. 8.72	7.0	7.0	7.0	7.0	17. 8.73	6.9	6.9	6.9	6.9
29. 8.72	7.0	6.9	6.9	6.85	4. 9.73	-	-	-	-

Table 16a. Temperature-oxygen Profile for Loch Lomond - South Basin

	27.11.71		10.11.71		23.12.71		20.1.72		3.2.72		17.2.72	
	Temp	% O_2	Temp	% O_2	Temp	% O_2	Temp	% O_2	Temp	% O_2	Temp	% O_2
Surface	10.4	96	8.5	94	5.8	108	4.5	96	5.1	97	4.2	110
1 m depth	10.4	96	8.5	94	5.8	105	4.5	96	5.0	98	4.1	108
3 m "	10.5	96	8.5	95	5.8	100	4.5	102	5.0	97	4.1	107
5 m "	10.5	96	8.5	97	5.8	100	4.5	97	4.9	97	3.9	105
7 m "	10.3	98	8.5	98	5.8	100	4.5	95	4.7	97	3.8	100
9 m "	10.3	98	8.5	99	5.8	100	4.5	94	4.6	97	3.8	100
11 m "	10.3	99	8.6	99	5.8	100	4.5	91	4.4	97	3.8	98
13 m "	10.3	99	8.6	99	5.8	100	4.5	89	4.3	97	3.8	98
15 m "	10.3	99	8.6	99	5.8	100	4.5	88	4.2	97	3.8	98
17 m "	10.3	96	8.7	99	5.8	100	4.5	84	4.2	97	3.8	98
19 m "	10.3	94	8.7	94	5.8	100	4.5	84	4.1	97	3.8	98
20 m "	10.3	94	8.7	94	5.8	100	4.5	84	4.0	97	3.8	98

	2.3.72		16.3.72		27.4.72		4.5.72		16.5.72		5.6.72	
	Temp	% O_2	Temp	% O_2	Temp	% O_2	Temp	% O_2	Temp	% O_2	Temp	% O_2
Surface	4.1	99	4.3	96	8.6	94	9.3	97	8.9	100	9.7	102
1 m depth	4.0	101	4.3	98	8.6	94	9.2	97	8.9	104	9.7	99
3 m "	4.0	103	4.2	98	8.3	95	8.8	97	8.9	101	9.7	100
5 m "	4.0	103	4.2	98	8.3	94	8.7	96	8.8	99	9.7	100
7 m "	4.0	101	4.1	99	8.1	94	8.5	96	8.8	99	9.7	99
9 m "	4.0	101	4.0	99	7.9	94	8.3	96	8.8	98	9.7	99
11 m "	4.0	92	3.9	99	7.5	94	8.1	96	8.8	99	9.7	99
13 m "	4.0	92	3.9	99	7.4	94	7.9	96	8.7	95	9.7	99
15 m "	4.0	92	3.9	99	7.4	94	7.7	94	8.6	94	9.7	99
17 m "	4.0	92	3.9	99	7.3	92	7.5	94	8.5	94	9.7	99
19 m "	4.0	92	3.9	99	7.2	92	7.5	94	8.3	94	9.7	99
20 m "	4.0	91	3.9	99	7.1	92	7.3	92	8.1	94	9.6	99

Table 16b. Temperature-oxygen Profile for Loch Lomond - South Basin

	19.6.72		21.6.72		10.7.72		26.7.72		1.8.72		8.8.72	
	Temp	% O_2	Temp	% O_2	Temp	% O_2	Temp	% O_2	Temp	% O_2	Temp	% O_2
Surface	12.2	101	13.7	102	14.3	96	17.5	86	17.0	96	16.1	96
1 m depth	12.1	101	13.7	102	14.3	94	17.5	86	17.0	96	16.0	92
3 m "	12.1	101	13.6	101	14.2	95	16.6	88	17.0	93	16.0	92
5 m "	12.0	102	13.6	100	14.1	95	15.8	89	17.0	89	15.7	90
7 m "	12.0	102	13.6	100	14.0	95	15.0	88	15.7	88	15.6	90
9 m "	12.0	102	13.6	100	13.9	94	14.1	88	15.1	85	15.0	90
11 m "	12.0	100	13.6	100	13.9	93	13.8	88	14.2	82	14.5	90
13 m "	12.0	99	13.6	98	13.8	93	13.2	88	13.5	82	13.7	90
15 m "	12.0	99	13.6	98	13.7	93	13.1	84	13.5	82	13.5	90
17 m "	11.9	98	13.6	98	13.6	93	13.0	84	13.5	82	13.3	90
19 m "	11.9	98	13.6	98	13.5	93	13.0	84	13.5	82	13.1	90
20 m "	11.8	98	13.1	98	13.4	93	13.0	84	13.5	80	13.0	90

	22.8.72		29.8.72		6.9.72		12.9.72		27.9.72		25.10.72	
	Temp	% O_2	Temp	% O_2	Temp	% O_2	Temp	% O_2	Temp	% O_2	Temp	% O_2
Surface	15.5	91	15.0	93	15.8	93	13.85	85	13.4	88	11.5	83
1 m depth	15.1	93	15.0	93	15.8	93	13.85	85	13.4	88	11.5	83
3 m "	15.1	94	15.0	93	15.8	93	13.85	86	13.4	88	11.5	83
5 m "	15.0	84	15.0	93	15.8	90	13.85	87	13.4	88	11.5	83
7 m "	15.0	84	15.0	93	15.7	90	13.85	87	13.4	88	11.5	83
9 m "	14.9	84	15.0	93	15.7	88	13.85	88	13.4	88	11.5	83
11 m "	14.7	84	14.1	93	15.0	83	13.85	89	13.4	88	11.5	83
13 m "	14.5	88	13.9	93	14.6	82	13.85	89	13.4	88	11.5	83
15 m "	14.3	86	13.7	86	14.6	82	13.85	89	13.4	88	11.5	83
17 m "	14.1	84	13.5	87	14.6	82	13.85	89	13.4	88	11.5	83
19 m "	13.8	82	13.2	87	14.1	82	13.85	88	13.4	88	11.5	83
20 m "	13.4	82	13.0	87	14.1	82	13.85	88	13.4	88	11.5	83

Table 17a. Temperature-oxygen Profile for Loch Lomond - Middle Basin

	27.10.71		10.11.71		23.12.71		20.1.72		3.2.72		2.3.72	
	Temp	% O_2	Temp	% O_2	Temp	% O_2	Temp	% O_2	Temp	% O_2	Temp	% O_2
Surface	10.3	94	9.0	94	6.2	91	5.3	96	5.1	96	4.0	93
1 m depth	10.5	94	9.1	94	6.2	91	5.3	100	5.1	96	4.1	98
2 m "	10.5	95	9.1	96	6.2	91	5.3	100	5.0	96	4.1	100
3 m "	10.6	96	9.1	96	6.2	91	5.3	100	5.0	96	4.1	100
4 m "	10.6	96	9.1	98	6.2	91	5.3	97	4.9	96	4.1	100
5 m "	10.6	97	9.1	98	6.2	91	5.3	92	4.7	96	4.1	100
6 m "	10.5	98	9.1	98	6.2	91	5.3	92	4.5	95	4.1	100
7 m "	10.5	98	9.1	98	6.2	91	5.3	92	4.4	96	4.1	100
8 m "	10.5	98	9.1	98	6.2	91	5.3	92	4.3	96	4.1	100
9 m "	10.5	98	9.1	96	6.1	91	5.3	92	4.3	96	4.1	100
10 m "	10.5	99	9.1	95	6.0	91	5.3	92	4.3	96	4.1	100
11 m "	10.5	99	9.1	95	6.0	91	5.3	89	4.3	96	4.1	100
12 m "	10.5	98	9.1	95	6.0	91	5.3	89	4.3	96	4.1	100
13 m "	10.5	98	9.1	95	6.0	91	5.3	89	4.3	96	4.1	100
14 m "	10.5	98	9.1	95	6.0	91	5.3	89	4.2	96	4.1	100
15 m "	10.5	98	9.1	95	6.0	91	5.3	89	4.2	96	4.1	100
16 m "	10.5	98	9.1	95	6.0	91	5.3	89	4.2	96	4.1	100
17 m "	10.5	98	9.1	95	6.0	91	5.3	89	4.2	96	4.1	100
18 m "	10.5	98	9.1	95	6.0	91	5.3	89	4.2	96	4.1	100
19 m "	10.5	96	9.1	95	6.0	91	5.3	89	4.2	96	4.1	100
20 m "	10.4	96	9.1	95	6.0	91	5.3	86	4.1	96	4.1	100
22 m "	10.3	96	9.1	94	6.0	91	5.3	86	4.1	96	4.1	100
25 m "	10.2	91	9.0	94	6.0	91	5.3	86	4.1	96	4.1	100
30 m "	8.8	88	8.8	94	6.0	91	5.3	86	4.1	96	4.1	100
35 m "	8.2	86	8.2	90	6.0	91	5.3	86	4.1	96	41.	100
40 m "	7.8	85	7.8	88	6.0	91	5.3	85	4.1	96	4.1	100
45 m "	7.8	85	7.6	88	6.0	91	5.3	81	4.1	96	4.1	100
50 m "	7.8	85	7.4	88	6.0	91	5.3	81	4.1	96	4.1	100

Table 17b. Temperature-oxygen Profile for Loch Lomond - Middle Basin

	16.3.72		30.3.72		27.4.72		4.5.72		16.5.72		26.6.72	
	Temp	% O_2	Temp	% O_2	Temp	% O_2	Temp	% O_2	Temp	% O_2	Temp	% O_2
Surface	4.8	92	5.0	92	7.8	101	8.2	96	8.6	104	11.1	101
1 m depth	4.7	92	5.0	92	7.5	100	8.1	94	8.3	103	11.1	102
2 m "	4.6	92	5.0	92	7.3	100	8.1	94	8.3	101	11.1	103
3 m "	4.3	92	5.0	92	7.2	100	7.9	92	7.8	101	11.1	104
4 m "	4.3	92	5.0	92	7.0	100	7.5	92	7.8	100	11.1	104
5 m "	4.3	92	5.0	92	6.9	99	7.4	92	7.8	100	11.1	104
6 m "	4.3	92	5.0	92	6.9	99	7.2	92	7.8	100	11.1	104
7 m "	4.1	92	5.0	92	6.9	99	7.1	90	7.8	100	11.0	104
8 m "	4.1	92	5.0	92	6.9	99	7.0	92	7.8	100	11.0	103
9 m "	4.1	92	5.0	92	6.8	99	6.9	90	7.8	100	11.0	100
10 m "	4.0	92	5.0	92	6.7	97	6.9	91	7.8	100	11.0	100
11 m "	4.0	91	5.0	92	6.7	97	6.8	93	7.8	100	11.0	100
12 m "	4.0	91	5.0	92	6.7	97	6.6	93	7.8	100	11.0	100
13 m "	4.0	91	5.0	92	6.7	97	6.6	95	7.8	100	11.0	100
14 m "	4.0	91	5.0	92	6.7	97	6.6	96	7.8	100	11.0	100
15 m "	4.0	91	5.0	92	6.7	97	6.6	96	7.8	100	11.0	100
16 m "	4.0	91	5.0	92	6.5	97	6.6	96	7.6	100	10.0	91
17 m "	4.0	91	5.0	92	6.3	97	6.6	96	7.5	97	9.2	92
18 m "	4.0	91	5.0	92	6.2	97	6.6	96	7.5	97	8.3	92
19 m "	4.0	91	5.0	92	6.2	97	6.6	96	7.5	97	8.2	92
20 m "	4.0	91	5.0	91	6.2	97	6.6	96	7.3	95	7.9	98
22 m "	4.0	91	5.0	91	6.8	97	6.6	96	7.0	95	7.8	100
25 m "	4.0	91	5.0	91	6.2	97	6.6	96	6.9	95	7.7	100
30 m "	4.0	91	5.0	91	6.2	97	6.6	96	6.9	95	7.7	100
35 m "	4.0	91	5.0	91	6.2	97	6.6	96	6.9	94	7.7	100
40 m "	4.0	91	5.0	91	6.2	97	6.6	96	6.9	94	7.7	100
45 m "	4.0	91	5.0	91	6.2	97	6.6	96	6.9	94	7.7	100
50 m "	4.0	91	5.0	91	6.2	97	6.6	96	6.9	94	7.7	100

Table 17c. Temperature-oxygen Profile for Loch Lomond - Middle Basin

	26.7.72		8.8.72		22.8.72		27.9.72		11.10.72		25.10.72	
	Temp	% O_2	Temp	% O_2	Temp	% O_2	Temp	% O_2	Temp	% O_2	Temp	% O_2
Surface	17.6	86	15.3	95	15.3	104	13.0	90	12.4	92	10.9	88
1 m depth	16.9	86	15.2	95	14.9	100	13.3	90	12.4	92	10.9	88
2 m "	16.9	86	15.2	98	14.6	98	13.3	90	12.4	92	10.9	88
3 m "	16.7	86	14.9	95	14.6	95	13.3	90	12.4	92	10.9	88
4 m "	14.9	86	14.9	95	14.6	95	13.3	90	12.4	92	10.9	88
5 m "	13.9	86	14.9	95	14.6	95	13.3	90	12.4	92	10.9	88
6 m "	12.8	90	14.9	95	14.6	95	13.3	90	12.4	91	10.9	88
7 m "	11.7	89	14.9	95	14.6	95	13.3	90	12.4	91	10.9	88
8 m "	11.4	90	14.9	95	14.6	95	13.3	90	12.4	90	10.9	88
9 m "	11.1	91	14.8	95	14.6	95	13.3	90	12.4	90	10.9	88
10 m "	10.8	91	14.1	93	14.1	93	13.3	90	12.4	90	10.9	88
11 m "	-	92	13.3	93	14.0	92	13.3	90	12.4	90	-	-
12 m "	-	93	11.9	93	13.9	92	13.3	90	12.4	90	-	-
13 m "	10.3	93	11.7	93	13.5	92	13.3	90	12.4	90	10.0	85
14 m "	-	92	11.5	93	13.1	92	13.3	90	12.4	90	10.0	85
15 m "	9.6	92	11.5	90	12.7	92	13.3	90	12.4	90	10.0	84
16 m "	-	92	11.3	90	12.5	92	12.1	80	12.4	90	10.0	84
17 m "	-	92	10.8	90	12.3	92	11.5	80	12.4	90	10.0	84
18 m "	9.0	92	10.7	90	12.1	92	11.0	80	12.4	90	10.0	83
19 m "	-	92	10.4	90	11.9	92	10.8	80	12.4	90	10.0	83
20 m "	8.6	92	10.1	90	11.0	92	10.6	82	12.4	90	10.0	83
22 m "	8.1	92	9.6	90	10.8	92	9.9	83	12.0	89	10.0	83
25 m "	8.0	92	9.4	88	10.4	92	9.8	83	11.8	88	10.0	82
30 m "	7.9	92	9.3	88	10.0	90	9.0	83	11.4	85	10.0	82
35 m "	7.9	92	9.0	88	9.6	90	8.8	83	11.1	83	10.0	82
40 m "	7.9	92	8.4	90	9.1	90	8.8	83	10.2	80	10.0	82
45 m "	7.9	92	8.0	90	8.5	90	8.8	83	10.2	80	10.0	82
50 m "	7.9	92	8.0	90	8.5	90	8.8	83	10.2	80	10.0	82

Table 18a. Temperature-oxygen Profile for Loch Lomond - North Basin

	27.10.71		10.11.71		23.12.71		20.1.72		3.2.72		2.3.72	
	Temp	% O_2	Temp	% O_2	Temp	% O_2	Temp	% O_2	Temp	% O_2	Temp	% O_2
Surface	9.6	96	7.8	96	6.2	110	5.7	93	5.2	97	4.8	98
1 m depth	9.7	96	7.8	92	6.2	100	5.7	95	5.3	97	4.9	99
2 m "	9.7	91	7.8	92	6.5	98	5.7	95	5.1	97	4.9	100
3 m "	9.9	90	7.8	92	6.5	95	5.7	90	5.1	97	4.9	99
5 m "	10.0	90	7.9	92	6.5	92	5.7	88	5.0	96	4.9	98
6 m "	10.1	90	8.0	93	6.5	92	5.7	88	4.9	95	4.9	98
7 m "	10.1	90	8.0	93	6.5	92	5.7	88	4.7	95	4.9	98
8 m "	10.1	90	8.1	93	6.5	92	5.7	88	4.6	94	4.9	98
9 m "	10.1	90	8.1	93	6.5	92	5.7	88	4.5	92	4.9	98
10 m "	10.2	90	8.1	95	6.5	92	5.6	88	4.4	92	4.9	98
11 m "	10.2	90	8.1	95	6.5	92	5.6	88	4.3	92	4.9	98
12 m "	10.2	89	8.1	95	6.5	92	5.5	85	4.3	88	4.9	97
13 m "	10.2	89	8.1	95	6.5	92	5.5	85	4.3	88	4.9	97
14 m "	10.2	89	8.1	95	6.5	92	5.5	85	4.3	88	4.9	97
15 m "	10.2	89	8.1	95	6.5	92	5.5	85	4.3	88	4.9	97
17 m "	10.2	89	8.1	95	6.5	92	5.5	85	4.3	88	4.9	97
19 m "	10.2	89	8.1	95	6.5	92	5.5	85	4.3	93	4.9	97
20 m "	10.2	89	8.1	95	6.3	92	5.5	85	4.2	93	4.9	97
25 m "	9.0	84	7.9	93	6.3	92	5.5	85	4.2	93	4.9	97
30 m "	8.0	84	7.0	92	6.2	92	5.4	85	4.1	92	4.9	97
35 m "	7.5	84	6.6	91	6.1	92	5.4	85	4.1	92	4.9	97
40 m "	6.6	89	6.0	93	5.9	92	5.3	85	4.1	92	4.9	97
50 m "	5.9	91	5.9	93	5.8	92	5.2	85	4.1	92	4.9	97
60 m "	5.9	92	5.7	93	5.6	92	5.1	80	4.1	92	4.9	97
80 m "	5.8	92	5.2	93	5.4	92	5.0	80	4.1	92	4.9	97
100 m "	5.1	92	5.1	93	5.1	92	4.9	80	4.1	92	4.9	97
120 m "	5.1	92	4.9	93	4.8	92	4.8	80	4.1	92	4.9	97
150 m "	5.1	92	4.9	93	4.8	92	4.7	80	4.1	92	4.9	97

Table 18b. Temperature-oxygen Profile for Loch Lomond - North Basin

	16.3.72		30.3.72		27.4.72		4.5.72		16.5.72		26.6.72	
	Temp	% O_2	Temp	% O_2	Temp	% O_2	Temp	% O_2	Temp	% O_2	Temp	% O_2
Surface	4.8	96	4.5	96	7.2	98	6.8	101	8.3	96	13.0	90
1 m depth	4.7	97	4.5	97	7.2	99	6.7	99	8.3	96	13.0	90
2 m "	4.7	98	4.5	97	7.2	99	6.7	98	8.3	96	13.0	90
3 m "	4.6	97	4.5	98	7.2	99	6.7	97	8.0	96	13.0	90
5 m "	4.6	97	4.5	98	7.2	99	6.7	97	8.0	96	13.0	90
6 m "	4.6	97	4.4	98	7.1	99	6.7	97	8.0	96	12.9	90
7 m "	4.6	97	4.4	98	7.1	98	6.7	97	7.8	96	12.6	90
8 m "	4.6	98	4.4	98	7.1	98	6.7	97	7.6	96	12.4	90
9 m "	4.6	98	4.5	98	6.8	97	6.7	97	7.4	96	12.1	90
10 m "	4.6	98	4.5	98	6.8	95	6.5	96	7.4	96	11.7	90
11 m "	4.5	98	4.5	98	6.5	94	6.5	96	7.3	96	11.4	90
12 m "	4.5	98	4.5	98	6.3	93	6.5	96	7.2	96	11.2	90
13 m "	4.5	98	4.4	98	6.2	92	6.5	96	7.2	96	11.0	90
14 m "	4.5	98	4.4	98	6.2	92	6.5	96	7.2	96	10.8	90
15 m "	4.5	98	4.4	98	6.2	92	6.4	96	7.2	96	10.3	90
17 m "	4.5	98	4.4	98	6.2	92	6.4	96	7.2	96	10.1	90
19 m "	4.5	98	4.4	98	6.2	92	6.4	96	7.2	96	9.8	90
20 m "	4.5	100	4.4	98	6.2	94	6.4	96	6.7	96	9.4	90
25 m "	4.4	100	4.4	100	6.1	95	6.3	96	6.7	96	8.6	91
30 m "	4.4	100	4.4	100	6.0	95	6.2	96	6.7	96	8.1	88
35 m "	4.4	100	4.4	100	5.9	95	6.1	96	6.7	96	7.3	88
40 m "	4.4	99	4.4	99	5.8	95	6.0	95	6.1	94	7.3	88
50 m "	4.4	99	4.4	99	5.5	93	5.2	95	5.6	93	6.8	88
60 m "	4.4	99	4.3	99	5.4	92	5.1	95	5.4	93	6.2	88
80 m "	4.2	99	4.2	99	4.9	92	4.9	95	4.9	93	5.85	88
100 m "	4.1	90	4.1	99	4.8	92	4.8	91	4.9	93	5.6	88
120 m "	4.1	90	4.1	92	4.5	92	4.7	91	4.9	93	5.5	88
150 m "	4.1	90	4.1	92	4.5	92	4.5	91	4.9	93	5.5	88

Table 18c. Temperature-oxygen Profile for Loch Lomond - North Basin

	26.7.72		8.8.72		22.8.72		27.9.72		11.10.72		25.10.72	
	Temp	% O_2	Temp	% O_2	Temp	% O_2	Temp	% O_2	Temp	% O_2	Temp	% O_2
Surface	16.1	86	15.8	91	14.9	88	12.7	95	12.1	92	9.6	97
1 m depth	16.1	87	15.7	91	14.5	88	12.7	95	12.1	92	9.6	97
2 m "	16.1	86	15.7	93	14.1	88	12.7	95	12.1	91	9.7	93
3 m "	16.1	86	15.7	93	14.1	88	12.7	95	12.1	92	10.1	92
5 m "	16.1	86	15.7	93	14.1	88	12.7	95	12.1	91	10.2	90
6 m "	15.1	90	15.7	93	14.1	88	12.7	95	12.1	92	10.3	89
7 m "	14.2	89	15.7	93	14.1	88	12.7	95	12.1	92	10.3	88
8 m "	13.1	90	15.7	93	14.1	88	12.7	95	12.1	92	10.3	88
9 m "	12.2	91	15.7	93	14.1	88	12.7	95	12.1	92	10.3	88
10 m "	11.8	91	15.7	95	14.1	88	12.7	95	12.1	92	10.3	88
11 m "	11.5	92	15.0	93	13.8	86	12.7	92	12.1	92	10.3	88
12 m "	-	-	14.3	89	13.5	84	12.7	92	12.1	92	10.3	88
13 m "	10.8	93	13.9	89	13.0	86	12.7	92	12.1	92	10.3	88
14 m "	-	-	13.0	89	12.85	88	12.7	91	12.1	92	10.3	88
15 m "	10.0	92	12.5	89	12.2	90	12.7	91	12.1	92	10.3	88
17 m "	-	-	11.9	89	12.0	92	12.7	91	12.1	92	10.3	88
19 m "	-	-	11.3	89	18.0	92	12.7	91	12.1	92	10.3	88
20 m "	9.0	92	10.8	92	11.8	92	10.2	85	12.1	92	10.3	86
25 m "	8.2	92	10.2	92	10.0	92	9.5	88	11.0	88	10.1	84
30 m "	8.2	92	9.0	92	9.5	92	8.8	90	10.0	88	9.6	83
35 m "	8.0	92	8.5	92	9.0	92	8.4	90	8.6	88	8.6	88
40 m "	7.7	92	8.0	92	8.5	92	7.8	90	8.1	88	6.5	89
50 m "	7.1	92	7.0	92	8.0	92	7.0	90	6.9	88	6.1	90
60 m "	7.0	92	6.6	92	7.1	92	6.6	90	6.5	88	5.85	90
80 m "	6.3	92	6.1	92	6.8	92	6.0	90	5.9	85	5.4	90
100 m "	5.8	92	5.9	92	5.9	92	5.8	90	5.8	85	5.4	90
120 m "	5.5	92	5.6	92	5.8	92	5.6	90	5.8	80	5.4	90
150 m "	5.5	92	5.6	92	5.8	92	5.6	90	5.8	72	5.4	90

Table 19a. Temperature -Oxygen Profile for Lake of Menteith and Loch Rusky

		18.10.72		1.11.72		15.11.72		29.11.72		27.12.72		10.1.73	
		Temp	% O_2	Temp	% O_2	Temp	% O_2	Temp	% O_2	Temp	% O_2	Temp	% O_2
Lake of Menteith	Surface	11.9	82	8.4	90	5.6	95	4.6	103	3.4	110	4.3	115
	1 m depth	11.9	81	8.4	90	5.6	94	4.6	98	3.4	100	4.2	110
	2 m "	11.9	81	8.4	90	5.6	93	4.5	98	3.4	100	4.1	102
	3 m "	11.9	81	8.4	90	5.6	92	4.5	89	3.4	100	4.0	103
	4 m "	11.9	79	8.4	90	5.6	92	4.5	89	3.4	100	4.0	103
	5 m "	11.9	78	8.4	88	5.6	92	4.5	89	3.4	100	4.0	103
	6 m "	11.9	77	8.4	88	5.6	92	4.5	80	3.4	100	4.0	103
	7 m "	11.9	77	8.4	88	5.6	92	4.5	80	3.4	100	4.0	103
Loch Rusky	Surface	11.4	78	8.3	91	5.1	86	3.4	97	3.1	108	4.1	118
	1 m "	11.0	78	8.3	91	5.1	86	3.4	98	3.1	105	4.0	110
	2 m "	11.0	73	8.3	91	5.1	86	3.4	96	3.1	105	4.0	103
	3 m "	11.0	73	8.4	90	5.1	86	3.4	91	3.1	100	4.0	100
	4 m "	11.0	73	8.5	89	5.1	87	3.4	88	3.1	100	4.0	100
	5 m "	11.0	73	8.5	89	5.1	87	3.4	86	3.1	100	4.0	100
	6 m "	11.0	73	8.6	88	5.0	88	3.4	84	3.1	100	4.0	100
	7 m "	11.0	73	8.6	88	5.0	86	3.4	84	3.1	100	4.0	100
	8 m "	11.0	73	8.6	88	5.0	86	3.4	84	3.1	100	4.0	100
	9 m "	11.0	73	8.6	88	5.0	86	3.4	84	3.1	100	4.0	100
	10 m "	11.0	73	8.6	88	5.0	86	3.4	84	3.1	100	4.0	100
	11 m "	11.0	73	8.6	88	5.0	86	3.4	84	3.1	100	4.0	100
	12 m "	11.0	73	8.6	88	5.0	86	3.4	84	3.1	100	4.0	100
	13 m "	11.0	73	8.6	88	5.0	86	3.4	84	3.1	100	4.0	100
	14 m "	11.0	73	8.6	88	5.0	86	3.4	84	3.1	100	4.0	100

Table 19b. Temperature-Oxygen Profile for Lake of Menteith and Loch Rusky

		24.1.73		7.2.73		21.2.73		8.3.73		26.3.73		20.4.73	
		Temp	% O_2	Temp	% O_2	Temp	% O_2	Temp	% O_2	Temp	% O_2	Temp	% O_2
Lake of Menteith	Surface	4.2	124	4.2	95	4.5	100	5.1	97	7.2	95	9.0	94
	1 m depth	4.1	124	4.1	95	4.5	100	5.0	95	7.2	95	9.0	92
	2 m "	4.0	124	4.0	95	4.5	100	4.5	95	7.0	95	9.0	91
	3 m "	3.65	121	3.9	95	4.5	100	4.3	94	7.0	95	9.0	90
	4 m "	3.5	121	3.9	95	4.5	100	4.1	94	7.0	96	9.0	88
	5 m "	3.2	121	3.9	95	4.5	100	4.0	91	7.0	95	9.0	87
	6 m "	3.2	120	3.9	95	4.5	100	4.0	91	7.0	95	9.0	85
	7 m "	3.2	120	3.9	95	4.5	100	4.0	91	7.0	95	9.0	85
Loch Rusky	Surface	2.0	110	3.95	96	4.5	93	4.3	91	6.8	93	8.0	93
	1 m depth	2.0	110	3.7	96	4.5	92	4.3	91	6.8	91	8.0	92
	2 m "	2.0	90	3.5	95	4.5	90	4.1	90	6.8	90	8.0	90
	3 m "	2.0	85	3.3	96	4.5	88	4.1	90	6.8	89	8.0	85
	4 m "	2.0	80	3.1	96	4.5	80	4.1	90	6.8	88	8.0	85
	5 m "	2.0	70	3.0	96	4.5	75	4.1	90	6.8	87	8.0	85
	6 m "	2.0	70	3.0	90	4.5	75	4.0	88	6.8	87	8.0	85
	7 m "	2.0	70	3.0	90	4.5	75	4.0	88	6.8	87	8.0	85
	8 m "	2.0	70	3.0	90	4.5	75	4.0	88	6.8	87	8.0	85
	9 m "	2.0	70	3.0	90	4.5	75	4.0	88	6.8	87	8.0	85
	10 m "	2.0	70	3.0	90	4.5	75	4.0	88	6.8	97	8.0	85
	11 m "	2.0	70	3.0	90	4.5	75	4.0	88	6.8	87	8.0	85
	12 m "	2.0	70	3.0	90	4.5	75	4.0	88	6.8	87	8.0	85
	13 m "	2.0	70	3.0	90	4.5	75	4.0	88	6.8	87	8.0	85
	14 m "	2.0	70	3.0	90	4.5	75	4.0	88	6.8	87	8.0	85

Table 19c. Temperature-Oxygen Profile for Lake of Menteith and Loch Rusky

		3.5.73		17.5.73		14.6.73		28.6.73		11.7.73		26.7.73	
		Temp	% O_2	Temp	% O_2	Temp	% O_2	Temp	% O_2	Temp	% O_2	Temp	% O_2
Lake of Menteith	Surface	9.7	96	10.8	80	13.8	102	19.2	96	19.0	93	20.0	90
	1 m depth	9.7	95	10.8	80	13.8	102	19.0	96	19.0	93	20.0	90
	2 m "	9.6	94	10.8	80	13.8	102	18.6	96	19.0	93	20.0	90
	3 m "	9.6	93	10.8	79	13.8	102	18.6	96	19.0	93	20.0	90
	4 m "	9.6	92	10.8	78	13.8	102	18.6	96	19.0	93	20.0	90
	5 m "	9.6	90	10.8	77	13.8	102	18.6	96	19.0	93	20.0	90
	6 m "	9.6	90	10.8	77	13.8	102	18.6	96	19.0	93	20.0	90
	7 m "	9.6	90	10.8	77	13.8	102	18.6	96	19.0	93	20.0	90
Loch Rusky	Surface	9.5	115	10.8	84	12.4	98	19.0	96	18.4	88	19.0	90
	1 m "	9.5	115	10.6	85	12.4	98	19.0	96	18.1	88	19.0	90
	2 m "	9.5	115	10.6	85	12.4	98	19.0	96	18.1	88	19.0	90
	3 m "	9.5	110	10.5	86	12.4	98	15.8	93	17.0	81	18.3	82
	4 m "	9.5	110	10.5	86	12.4	97	14.8	82	16.4	81	17.4	81
	5 m "	9.5	110	10.4	86	12.4	97	12.3	82	15.8	78	16.5	74
	6 m "	9.5	110	10.3	86	12.4	97	12.2	82	15.3	78	16.0	73
	7 m "	9.5	105	10.3	86	12.4	97	12.2	82	15.3	83	16.0	82
	8 m "	9.5	102	10.3	86	12.4	97	12.2	82	15.3	83	16.0	83
	9 m "	9.5	100	10.2	86	12.4	97	12.2	82	15.3	83	16.0	83
	10 m "	9.5	100	10.2	86	12.4	97	12.2	82	15.3	83	16.0	83
	11 m "	9.5	100	10.2	86	12.4	97	12.2	82	15.3	83	16.0	83
	12 m "	9.5	100	10.2	86	12.4	97	12.2	82	15.3	83	16.0	83
	13 m "	9.5	100	10.2	86	12.4	97	12.2	82	15.3	83	16.0	83
	14 m "	9.5	100	10.2	86	12.4	97	12.2	82	15.3	83	16.0	83

Table 20a. Temperature-Oxygen Profile for Loch Achray and Loch Ard

		18.10.72		1.11.72		15.11.72		29.11.72		27.12.72		10. 1.73	
		Temp	% O_2	Temp	% O_2	Temp	% O_2	Temp	% O_2	Temp	% O_2	Temp	% O_2
Loch Achray	Surface	11.4	84	9.7	81	6.7	82	5.4	90	4.0	102	4.0	112
	1 m depth	11.4	84	9.7	81	6.7	81	5.4	90	4.0	103	4.0	110
	2 m "	11.4	84	9.7	81	6.7	81	5.4	90	4.0	102	4.0	108
	3 m "	11.4	84	9.7	82	6.7	81	5.4	90	4.0	102	4.0	105
	4 m "	11.4	84	9.6	82	6.7	81	5.4	90	4.0	100	4.0	105
	5 m "	11.4	84	9.5	83	6.7	81	5.4	90	4.0	100	4.0	105
	6 m "	11.4	84	9.4	83	6.7	81	5.4	90	4.0	100	4.0	105
	7 m "	11.3	84	9.3	83	6.7	81	5.4	90	4.0	100	4.0	105
	8 m "	11.2	84	9.2	84	6.7	81	5.4	90	4.0	100	4.0	105
	9 m "	11.0	84	9.2	84	6.7	81	5.4	90	4.0	100	4.0	105
	10 m "	10.8	84	9.2	84	6.7	81	5.4	90	4.0	100	4.0	105
	11 m "	10.8	84	9.2	84	6.7	81	5.4	90	4.0	100	4.0	105
	12 m "	10.8	84	9.2	84	6.7	81	5.4	90	4.0	100	4.0	105
	15 m "	10.8	84	9.2	84	6.7	81	5.4	90	4.0	100	4.0	105
	20 m "	10.8	84	9.2	84	6.7	81	5.4	90	4.0	100	4.0	105
Loch Ard	Surface	11.9	85	10.7	80	8.05	84	6.3	88	5.1	103	5.1	103
	1 m depth	11.9	85	10.7	82	8.05	84	6.2	88	5.1	103	5.0	103
	2 m "	11.9	85	10.5	80	8.0	84	6.1	88	5.0	103	5.0	103
	3 m "	11.8	83	10.3	83	8.0	84	6.0	88	5.0	103	5.0	103
	4 m "	11.7	81	10.3	80	8.0	84	5.9	88	5.0	103	5.0	103
	5 m "	11.6	81	10.3	78	8.0	84	5.7	88	5.0	100	5.0	103
	6 m "	11.6	81	10.3	76	8.0	84	5.6	88	5.0	100	5.0	103
	7 m "	11.0	78	10.3	76	8.0	84	5.5	88	5.0	100	5.0	103
	8 m "	10.6	74	10.3	76	8.0	84	5.4	88	5.0	100	5.0	103
	9 m "	10.6	73	10.3	76	8.0	84	5.4	88	5.0	100	5.0	103
	10 m "	10.6	72	10.3	76	8.0	84	5.4	88	5.0	100	5.0	103
	11 m "	10.6	70	10.3	76	8.0	84	5.4	88	5.0	100	5.0	103
	12 m "	10.6	68	10.3	76	8.0	84	5.4	88	5.0	100	5.0	103
	15 m "	10.6	68	10.3	76	8.0	84	5.4	88	5.0	100	5.0	103
	20 m "	10.6	68	10.3	76	8.0	84	5.4	88	5.0	100	5.0	103

Table 20b. Temperature-Oxygen Profile for Loch Achray and Loch Ard

		24.1.73		7.2.73		21.2.73		8.3.73		26.3.73		20.4.73	
		Temp	% O_2	Temp	% O_2	Temp	% O_2	Temp	% O_2	Temp	% O_2	Temp	% O_2
Loch Achray	Surface	4.2	110	4.5	95	4.8	96	4.8	90	6.0	92	8.0	95
	1 m depth	4.2	110	4.5	95	4.8	96	4.7	89	6.0	93	8.0	94
	2 m "	4.2	110	4.5	95	4.8	96	4.6	88	6.0	93	8.0	94
	3 m "	4.2	110	4.3	95	4.6	96	4.6	87	5.6	90	8.0	94
	4 m "	4.2	110	4.3	95	4.5	96	4.6	86	5.6	90	8.0	94
	5 m "	4.2	110	4.2	95	4.5	96	4.6	85	5.6	90	8.0	94
	6 m "	4.2	110	4.1	95	4.3	96	4.6	83	5.6	90	8.0	94
	7 m "	4.2	110	4.1	95	4.3	96	4.6	82	5.6	90	8.0	94
	8 m "	4.2	110	4.1	95	4.3	96	4.5	82	5.6	90	8.0	94
	9 m "	4.2	110	4.1	95	4.3	96	4.5	81	5.6	90	8.0	94
	10 m "	4.2	110	4.1	95	4.3	96	4.4	79	5.6	90	8.0	94
	11 m "	4.2	110	4.1	95	4.3	96	4.4	77	5.6	90	8.0	94
	12 m "	4.2	110	4.1	95	4.3	96	4.4	76	5.6	90	8.0	94
	15 m "	4.2	110	4.1	95	4.3	96	4.4	76	5.6	90	8.0	94
	20 m "	4.2	110	4.1	95	4.3	96	4.4	76	5.6	90	8.0	94
Loch Ard	Surface	4.4	110	4.5	94	4.5	94	4.8	95	6.0	92	7.0	94
	1 m depth	4.4	110	4.5	95	4.5	94	4.8	95	6.0	92	7.0	94
	2 m "	4.4	110	4.5	94	4.5	94	4.8	95	6.0	92	7.0	94
	3 m "	4.4	110	4.5	94	4.5	94	4.7	93	6.0	92	7.0	94
	4 m "	4.4	110	4.5	94	4.5	94	4.6	91	6.0	92	7.0	94
	5 m "	4.4	110	4.5	94	4.5	94	4.6	91	6.0	92	7.0	94
	6 m "	4.4	110	4,5	94	4.5	94	4.5	91	6.0	92	7.0	94
	7 m "	4.4	110	4.5	94	4.5	94	4.5	91	6.0	92	7.0	94
	8 m "	4.4	110	4.5	94	4.5	94	4.4	91	6.0	92	7.0	94
	9 m "	4.4	110	4.5	94	4.5	94	4.4	91	6.0	92	7.0	94
	10 m "	4.4	110	4.5	94	4.5	94	4.4	91	6.0	92	7.0	94
	11 m "	4.4	110	4.5	94	4.5	94	4.4	89	6.0	92	7.0	94
	12 M "	4.4	110	4.5	94	4.5	94	4.4	88	6.0	92	7.0	94
	15 m "	4.4	110	4.5	94	4.5	94	4.4	88	6.0	92	7.0	
	20 m "	4.4	110	4.5	94	4.5	94	4.4	88	6.0	92	7.0	94

Table 20c. Temperature-Oxygen Profile for Loch Achray and Loch Ard

		3. 5. 73		17. 5. 73		14. 6. 73		28. 6. 73		26. 7. 73		8. 8. 73	
		Temp	% O_2	Temp	% O_2	Temp	% O_2	Temp	% O_2	Temp	% O_2	Temp	% O_2
Loch Achray	Surface	8.5	92	10.4	96	13.0	98	18.7	100	18.6	92	15.8	92
	1 m depth	8.5	92	10.0	96	13.0	98	18.7	98	18.6	92	15.5	90
	2 m "	8.5	92	10.0	96	13.0	98	18.2	96	18.5	93	15.5	88
	3 m "	8.5	92	10.0	96	13.0	98	16.0	94	18.2	93	15.5	88
	4 m "	8.5	92	10.0	96	12.4	98	14.5	89	16.3	86	15.0	88
	5 m "	8.5	92	10.0	96	11.6	98	13.3	89	15.1	85	15.0	88
	6 m "	8.5	92	10.0	96	11.4	98	12.1	89	14.2	85	15.0	88
	7 m "	8.5	92	9.8	96	11.2	97	11.8	89	13.3	84	15.0	88
	8 m "	8.5	92	9.5	96	11.2	96	11.5	89	13.3	88	15.0	88
	9 m "	8.5	92	9.3	96	11.2	96	11.2	89	13.3	88	15.0	88
	10 m "	8.5	92	9.0	96	11.2	96	10.8	88	13.3	88	15.0	88
	11 m "	8.5	92	9.0	96	10.4	95	9.7	84	13.3	88	15.0	88
	12 m "	8.5	92	8.8	96	10.1	94	9.4	84	13.3	88	15.0	86
	15 m "	8.5	92	8.8	96	8.7	92	9.0	84	13.3	88	15.0	86
	20 m "	8.5	92	8.8	96	8.7	92	9.0	84	13.3	88	15.0	86
Loch Ard	Surface	8.5	93	9.4	93	12.8	106	18.6	112	18.3	88	16.1	93
	1 m depth	8.5	94	9.2	90	12.8	106	18.6	112	18.3	88	16.0	94
	2 m "	8.5	94	9.0	88	12.8	106	18.1	109	18.1	88	15.9	96
	3 m "	8.5	94	8.9	88	12.7	105	17.5	108	16.9	86	15.8	96
	4 m "	8.5	94	8.0	88	12.6	103	15.2	104	15.4	80	15.7	96
	5 m "	8.5	94	8.0	87	12.5	102	14.1	104	15.2	80	15.6	96
	6 m "	8.0	94	8.0	86	12.4	101	13.9	103	15.2	80	15.5	94
	7 m "	8.0	94	8.0	80	12.2	100	13.3	99	15.2	80	15.5	94
	8 m "	8.0	94	8.0	76	12.0	98	12.6	99	15.2	80	15.5	94
	9 m "	8.0	94	8.0	76	11.9	97	12.3	97	15.2	80	15.5	94
	10 m "	8.0	94	8.0	76	11.8	97	11.9	96	15.2	80	15.5	94
	11 m "	8.0	94	8.0	76	11.8	97	11.2	96	15.2	80	15.5	94
	12 m "	8.0	94	8.0	76	11.8	97	11.2	96	15.2	80	15.5	94
	15 m "	8.0	94	8.0	76	11.8	97	11.2	92	15.2	80	15.5	94
	20 m "	3.0	94	8.0	76	11.8	97	11.2	92	15.2	80	15.5	94

Table 21. Chlorophyll a (μg/1.) & total Phytoplankton (cells/1. or Colonies/1.).

	South Basin		Middle Basin		North Basin	
Date	Chlorophyll	Total Phytoplankton	Chlorophyll	Total Phytoplankton	Chlorophyll	Total Phytoplankton
11.10.72	-	182133	0.1	77254	0.08	35455
25.10.72	0.09	112422	0.083	38972	-	-
2.11.72	-	-	-	-	-	-
23.11.74	0.06	47524	0.043	40428	0.0743	14368
7.12.72	0.035	30499	0.062	43368	0.025	18589
21.12.72	0.04	33619	0.02	40090	0.0146	38867
4. 1.73	0.04	10458	0.025	20379	0.0146	28977
17. 1.73	0.045	23050	0.05	9659	0.014	15708
1. 2.73	0.05	29152	0.063	27456	0.0127	11497
15. 2.73	0.045	41609	0.025	22984	0.0256	11102
1. 3.73	0.0418	46908	0.036	24356	0.0346	19219
15. 3.73	0.151	103909	0.059	52664	0.0626	24054
28. 3.73	0.33	456455	0.200	-	-	-
12. 4.73	0.181	115632	0.173	75204	0.13	56430
26. 4.73	0.150	68648	0.188	204855	0.198	143515
2. 5.73	0.102	-	0.086	-	-	-
10. 5.73	0.09	20674	0.059	101047	0.0783	54480
24. 5.73	0.09	26279	0.075	53749	0.0127	56330
7. 6.73	0.202	78069	0.051	-	0.041	-
24. 6.73	0.348	222474	0.1218	63650	0.03	50131
6. 7.73	0.36	235794	0.2752	191704	0.138	175882
24. 7.73	0.204	117785	0.25	142224	0.204	229928
2. 8.73	0.221	68796	0.254	67987	0.127	101666
17. 8.73	0.204	57670	0.104	44271	0.127	40298
4. 9.73	0.15	-	0.075	-	0.08	-

Table 22. Chlorophyll a (μg/l.) & total Phytoplankton (cells/l. or colonies/l.)

	Lake of Menteith		Loch Rusky		Loch Achray		Loch Ard	
Date	Chlorophyll	Total Phytoplankton	Chlorophyll	Total Phytoplankton	Chlorophyll	Total Phytoplankton	Chlorophyll	Total Phytoplankton
18.10.72	0.138	421987	0.18	541599	0.04	70972	0.03	57297
1.11.72	0.108	395630	0.1	595874	0.03	47683	0.035	36715
15.11.72	0.605	1043097	0.09	236310	0.02	49667	0.025	41264
29.11.72	0.14	603487	0.14	184867	0.03	11408	0.025	41006
13.12.72	0.12	704610	0.14	225218	0.03	10216	0.024	21406
27.12.72	0.08	372601	0.1	216685	0.02	8929	0.022	32478
10. 1.73	2.89	342095	0.09	-	0.03	8567	0.025	28733
24. 1.73	0.2758	258759	0.128	62064	0.03	12142	0.027	9067
7. 2.73	0.337	324134	0.0897	150125	0.05	50553	0.03	25246
21. 2.73	0.338	256995	0.135	118455	0.03	12551	0.025	24131
8. 3.73	0.801	973328	0.2735	266283	0.04	30366	0.025	50162
26. 3.73	0.932	1381893	0.424	1197801	0.03	33366	0.1259	84208
8. 4.73	-	-	-	-	-	-	-	-
20. 4.73	1.34	1629203	1.0846	3243469	0.04	61536	0.1757	103318
3. 5.73	1.9	2131348	0.5342	3320999	0.08	27163	-	78056
17. 5.73	1.6	1630892	0.2401	883767	0.26	962948	0.2697	269905
1. 6.73	0.7339	752801	0.2030	35898	0.06	14385	0.12	84502
14. 6.73	0.321	276312	0.2034	35603	0.06	14178	0.085	72616
28. 6.73	0.263	85211	0.202	168145	0.02	87510	0.15	104483
11. 7.73	0.225	227089	0.761	1808527	0.04	30680	0.3484	575482
26. 7.73	0.281	751656	0.796	1985888	0.31	1099966	0.152	272328
8. 8.73	0.962	1904196	2.795	16058799	0.20	591351	0.1987	350872
23. 8.73	1.96	3595786	3.2	16739232	0.175	178942	0.1586	277813
20. 9.73	0.36	557948	1.9	10346367	0.08	126460	0.15	161468

Table 23a Loch Lomond - South Basin

Main Phytoplankton Organisms - in cell numbers/l, or colonies of cells/l (see p. 158).

	1979											
Surface	2/3	16/3	30/3	7/4	14/4	20/4	27/4	4/5	16/5	29/5	5/6	12/6
Melosira	44360	100086	274687	317126	852380	617564	27496	6929	5224	9532	8936	2405
Asterionella	769	7314	6062	962	15494	12703	6062	2283	15494	2983	11869	19568
Tabellaria	1278	-	1429	5004	3464	3134	5499	5004	5705	21309	24517	35515
Cyclotella (1)	3849	2245	8982	6094	10586	24975	3528	481	3566	-	357	783
Cyclotella (2)	1141	2231	14893	28871	28916	4445	4674	481	866	783	357	357
Fragilaria	96	-	137	-	-	-	192	-	481	549	1374	3725
Coelosphaerium	417	701	302	302	192	192	357	481	481	357	192	866
Anabaena	-	-	-	-	-	-	-	-	-	-	12506	-
Mallamonas	-	-	-	-	-	-	-	-	-	-	-	-
Dinobryon	-	-	-	-	-	-	-	-	-	-	-	-
Ceratium	-	-	-	-	-	-	-	-	-	-	-	-
Peridinium	-	-	-	-	-	41	-	-	-	-	-	137
Botryococcus	-	137	-	-	-	-	-	192	247	-	-	-
Staurastrum	481	137	137	-	96	192	-	137	-	192	137	192
3 Metres Depth												
Melosira	23830	88357	236329	130329	779244	342088	38864	10992	16056	17600	22350	1152
Asterionella	3848	768	-	768	-	6264	6264	2856	17704	6264	17704	23464
Tabellaria	578	3132	3423	2349	7380	2349	7380	2598	2598	9624	13611	18661
Cyclotella (1)	2749	4701	8615	7607	8661	11640	4354	948	3725	1649	549	701
Cyclotella (2)	302	1251	11823	11228	14619	6599	4701	549	481	481	302	-
Fragilaria	-	-	-	-	-	-	137	302	192	426	426	192
Coelosphaerium	357	302	41	-	426	302	96	357	192	-	137	-
Anabaena	-	-	-	-	-	-	-	-	-	-	-	-
Mallamonas	-	-	-	-	-	-	-	-	-	-	-	-
Dinobryon	-	-	-	-	-	-	-	-	-	-	-	-
Ceratium	-	-	-	-	-	-	-	-	-	-	-	-
Peridinium	-	-	-	41	-	-	-	96	-	-	-	-
Botryococcus	96	-	41	192	-	-	96	-	-	-	96	-
Staurastrum	618	357	41	-	-	137	-	-	192	426	-	426

Table 23b Loch Lomond - South Basin

Main Phytoplankton Organisms - in cell numbers/l, or colonies of cells/l (see p. 158).

	1973											
Surface	19/6	27/6	4/7	10/7	18/7	26/7	1/8	8/8	15/8	22/8	29/8	6/9
Melosira	2130	1787	3753	3753	-	-	-	2103	2349	1443	768	906
Asterionella	29512	35286	39136	43627	-	2114	2499	-	4907	959	1344	959
Tabellaria	32537	3918	18804	6596	3505	2504	6255	6255	23505	6255	21767	32078
Cyclotella (1)	481	4701	6140	7423	8982	13244	35011	29237	22959	16726	17276	13564
Cyclotella (2)	1374	-	481	1374	1512	10723	11502	19843	10356	3391	5820	8890
Fragilaria	1044	426	137	866	-	192	-	783	481	457	-	302
Coelosphaerium	192	302	481	618	302	357	783	481	137	618	426	618
Anabaena	-	-	18230	16085	40000	87072	54768	-	-	1536	3072	2192
Mallamonas	-	-	-	-	-	-	-	-	-	-	-	-
Dinobryon	-	192	426	783	1512	247	-	-	96	-	-	-
Ceratium	-	-	481	-	-	96	866	948	618	481	701	481
Peridinium	137	192	302	137	426	192	137	357	618	192	192	-
Botryococcus	-	481	-	137	192	1251	618	357	192	-	-	302
Staurastrum	481	426	1141	1251	192	481	-	618	357	481	426	866
3 metres Depth												
Melosira	-	-	8244	4330	685	-	-	8028	4698	2130	1812	685
Asterionella	-	-	53360	30432	9128	-	2856	-	1536	1536	1536	2416
Tabellaria	2942	19486	14103	2349	2598	-	1443	1443	14103	17974	23529	34766
Cyclotella (1)	-	-	2007	3725	6553	-	35012	26351	22226	15764	13198	17460
Cyclotella (2)	-	-	481	1851	3895	-	11503	27588	7928	4701	8157	-
Fragilaria	948	-	357	481	426	-	-	357	192	-	192	549
Coelosphaerium	-	-	357	481	481	-	783	357	701	783	618	866
Anabaena	-	-	4608	14832	37584	-	48524	20000	11182	11176	7497	2466
Mallamonas	-	-	481	-	237	-	-	-	-	-	547	1012
Dinobryon	-	192	549	1251	1374	-	783	302	-	-	-	-
Ceratium	-	-	357	-	-	-	866	-	426	302	426	426
Peridinium	-	-	-	-	-	-	137	192	357	357	137	948
Botryococcus	-	-	-	-	-	-	-	-	192	-	-	-
Staurastrum	-	-	426	948	1374	-	783	426	481	1044	426	426

Table 23c Loch Lomond - South Basin

Main Phytoplankton Organisms - in cell numbers/1, or colonies of cells/1 (see p. 158).

	1972							1973				
Surface	12/9	27/9	11/10	25/10	23/11	7/12	21/12	4/1	17/1	1/2	15/2	1/3
Melosira	5004	1443	1924	4564	8245	9070	23505	3464	10035	13473	27771	33407
Asterionella	15491	21492	91424	32078	7308	7987	2982	-	6062	7308	2499	4907
Tabellaria	61408	94403	72864	55450	23505	6255	2405	1428	1924	2196	5004	1704
Cyclotella (1)	21584	5132	3895	3574	4124	3725	3725	4701	1814	4582	4701	5820
Cyclotella (2)	16543	3620	2007	-	-	-	-	-	-	-	-	-
Fragilaria	-	948	3162	3299	618	948	-	-	137	137	96	-
Coelosphaerium	481	618	1044	4701	1251	1141	618	481	701	866	783	357
Anabaena	-	1096	-	-	-	-	-	-	-	-	-	-
Mallamonas	426	2703	4701	3162	481	-	-	-	-	-	-	-
Dinobryon	-	-	-	-	-	137	-	-	-	-	-	-
Ceratium	481	866	-	-	-	-	-	-	-	-	-	-
Peridinium	-	192	-	-	-	-	-	-	-	-	-	-
Botryococcus	357	-	247	-	-	137	-	-	137	96	-	137
Staurastrum	866	1141	1374	4701	618	481	192	192	426	357	137	-
3 Metres Depth												
Melosira	4682	4698	2886	4698	8244	37608	14512	6264	6264	41426	52800	68928
Asterionella	29800	3408	38496	24928	6928	2856	3408	768	6928	1538	5608	8352
Tabellaria	32994	60630	32859	27360	2349	2598	1443	1071	1443	2349	2598	2103
Cyclotella (1)	19797	7470	4701	4701	4701	4701	3725	2777	1814	5866	4701	4701
Cyclotella (2)	8753	5133	4701	-	357	137	-	-	-	-	137	137
Fragilaria	302	192	1044	866	-	302	302	-	137	-	-	-
Coelosphaerium	618	866	481	1649	2213	618	618	426	701	701	618	481
Anabaena	-	-	-	-	-	-	-	-	-	-	-	-
Mallamonas	2300	1700	-	-	-	-	-	-	-	-	-	-
Dinobryon	-	-	-	-	-	-	-	-	-	-	-	-
Ceratium	137	426	-	-	-	-	-	-	-	-	-	-
Peridinium	-	-	-	192	-	-	-	-	-	-	-	-
Botryococcus	-	-	96	-	137	247	-	-	137	96	137	-
Staurastrum	866	1251	2005	2777	866	426	192	866	426	357	302	357

Table 23d Loch Lomond - South Basin

Main Phytoplankton Organisms - in cell numbers/l, or colonies of cells/l (see p. 158).

	1973											
Surface	15/3	28/3	12/4	26/4	10/5	24/5	7/6	24/6	6/7	24/7	2/8	17/8
Melosira	60940	403644	81388	28870	2062	16056	8757	1510	-	-	-	-
Asterionella	28550	20209	16681	7308	4907	2982	17946	41381	17643	2114	-	-
Tabellaria	5004	8028	3464	14908	4176	2804	37578	45277	173775	35561	19064	13564
Cyclotella (1)	2007	8707	7149	4857	3437	2213	6461	3116	3437	10952	8340	24746
Cyclotella (2)	4701	12281	4353	10036	4582	701	549	618	-	2566	9119	9715
Fragilaria	-	1141	302	481	247	137	549	2383	1695	1374	783	783
Coelosphaerium	2213	426	701	357	247	192	481	247	357	701	426	618
Anabaena	-	-	-	576	-	-	-	122226	27144	57538	24684	-
Mallamonas	-	-	-	-	-	-	-	2007	3849	302	302	783
Dinobryon	-	-	-	-	-	192	2007	2007	1512	1044	481	481
Ceratium	-	-	-	-	-	-	302	783	1649	1044	481	481
Peridinium	-	192	-	96	137	192	1649	2213	3725	618	481	426
Botryococcus	96	-	-	137	96	-	137	137	192	948	1251	1044
Staurastrum	-	481	302	701	357	192	481	192	357	618	866	1814
3 Metres Depth												
Melosira	156912	531318	460000	251163	20132	11216	-	2688	2304	960	-	1370
Asterionella	31896	29800	2007	11021	2688	1536	-	19432	37608	-	-	-
Tabellaria	14103	6021	4701	1141	1141	2349	-	34233	157460	34644	18972	9210
Cyclotella (1)	4701	13886	12013	8038	4701	4701	-	4701	4701	8661	2257	19889
Cyclotella (2)	948	9944	5007	2514	767	1508	-	12514	547	1251	7241	8982
Fragilaria	-	481	-	-	-	192	-	701	1141	701	1374	1251
Coelosphaerium	783	866	357	357	426	481	-	701	357	302	481	481
Anabaena	-	-	-	-	-	1041	-	33089	9996	16824	2304	4224
Mallamonas	-	-	-	-	-	-	-	-	1300	2007	1141	-
Dinobryon	-	-	-	-	-	-	-	-	1512	576	1374	481
Ceratium	-	-	-	-	-	96	-	1036	701	426	1374	481
Peridinium	-	-	-	-	-	-	-	192	1044	-	-	-
Botryococcus	137	137	-	-	-	-	-	-	192	618	2007	426
Staurastrum	426	426	247	96	96	481	-	426	357	426	866	1044

Table 24a Loch Lomond - Middle Basin

Main Phytoplankton organisms - in cell numbers/l, or colonies of cells/l (see p. 158).

	1972											
Surface	2/3	16/3	30/3	7/4	14/4	20/4	27/4	4/5	16/5	29/5	5/6	12/6
Melosira	36661	50000	61408	86887	137481	97886	52701	45827	40327	26762	11065	1785
Asterionella	672	4907	1344	6636	5841	7308	6062	7308	8757	5481	9618	6636
Tabellaria	2804	768	5496	3132	18804	5496	14900	6596	18804	18804	16131	17230
Cyclotella (1)	549	1141	2428	4701	4536	3711	4995	2199	2213	2213	2460	357
Cyclotella (2)	192	549	1044	5178	7332	4857	3574	618	426	701	1274	2213
Fragilaria	-	-	-	-	-	96	96	137	280	357	481	426
Coelosphaerium	192	426	302	302	302	302	247	302	247	481	192	866
Anabaena	-	-	-	-	-	-	-	-	-	-	-	-
Mallamonas	-	-	-	-	-	-	-	-	-	-	-	-
Dinobryon	-	-	-	-	-	-	-	-	-	-	-	-
Ceratium	-	-	-	-	49	-	-	-	-	-	-	-
Peridinium	-	-	-	-	41	-	96	192	192	-	-	302
Botryococcus	-	96	-	96	247	137	-	192	-	-	-	137
Staurastrum	41	247	-	302	-	137	-	-	192	137	192	192
3 Metres Depth												
Melosira	45093	71490	68740	96886	97886	126482	125932	70390	33324	28412	18140	4810
Asterionella	1344	-	-	-	6062	-	13192	6264	6928	6264	6928	6928
Tabellaria	768	1428	2472	14298	3464	3132	3132	12098	9840	7149	18514	21263
Cyclotella (1)	1044	2153	3391	2932	2795	2841	4078	2337	2460	1314	1649	-
Cyclotella (2)	357	618	3162	4701	3162	6278	4353	2213	1141	1314	701	783
Fragilaria	96	96	-	-	-	-	-	-	192	-	302	357
Coelosphaerium	192	-	192	192	357	302	247	247	426	357	-	426
Anabaena	-	-	-	-	-	-	-	-	-	96	-	-
Mallamonas	-	-	-	-	-	-	-	-	-	-	-	-
Dinobryon	-	-	-	-	-	-	-	-	-	-	-	-
Ceratium	-	-	-	-	-	-	-	-	-	-	-	-
Peridinium	-	-	-	-	-	-	-	96	-	96	481	-
Botryococcus	-	-	-	-	-	-	-	-	-	-	-	137
Staurastrum	-	-	-	-	137	137	137	-	-	-	426	481

Table 24b Loch Lomond - Middle Basin

Main Phytoplankton organisms - in cell numbers/l, or colonies of cells/l (see p. 158).

	1972											
Surface	19/6	27/6	4/7	10/7	18/7	28/7	1/8	8/8	15/8	22/8	29/8	6/9
Melosira	4564	768	548	1704	548	-	-	3132	548	548	1208	-
Asterionella	17001	43624	32907	7308	2114	1344	2499	-	-	4326	2114	1344
Tabellaria	19430	5004	18804	8852	2804	2804	4564	2196	3464	1704	5496	6048
Cyclotella (1)	426	192	783	783	4949	3482	35011	17417	14206	11410	11365	16406
Cyclotella (2)	2474	426	783	1251	4701	5453	11502	14068	4078	2932	7973	13931
Fragilaria	481	701	618	549	426	481	426	481	192	137	137	41
Coelosphaerium	481	701	426	357	302	866	783	866	948	1044	783	783
Anabaena	-	-	16488	2856	17525	28528	28528	1644	3804	822	822	2499
Mallamonas	-	-	-	-	-	357	549	866	1694	4701	2460	948
Dinobryon	192	192	192	4701	4701	2007	948	192	192	357	192	-
Ceratium	-	-	192	192	426	1141	866	137	247	247	481	2007
Peridinium	-	41	357	1044	701	302	137	426	1044	2231	192	192
Botryococcus	-	192	-	-	866	866	2213	-	-	96	426	-
Staurastrum	426	-	-	302	701	866	783	192	-	-	192	481
3 Metres Depth												
Melosira	10992	3570	3020	-	-	-	-	1536	2416	1536	1536	-
Asterionella	37608	37760	33728	-	6928	-	2614	-	-	-	10008	6928
Tabellaria	15947	14664	7515	-	7256	1924	1924	3464	1704	1924	4176	3464
Cyclotella (1)	866	3162	2007	-	7332	26900	21721	21951	16224	16360	10631	17735
Cyclotella (2)	1512	-	701	-	4124	14756	21721	10723	3574	4720	6232	17505
Fragilaria	426	549	247	-	192	426	-	302	-	-	-	357
Coelosphaerium	783	481	357	-	192	618	618	357	426	481	866	357
Anabaena	-	-	2304	-	24732	28528	7550	2302	5608	-	-	1370
Mallamonas	-	-	-	-	192	549	1814	1044	1814	4701	1814	549
Dinobryon	-	-	357	-	701	4701	866	426	-	-	-	-
Ceratium	137	-	357	-	426	1251	302	426	4701	1251	302	192
Peridinium	192	192	137	-	783	192	357	302	302	137	137	-
Botryococcus	-	-	302	-	701	1374	948	-	-	-	192	192
Staurastrum	426	618	866	-	701	481	-	357	426	192	481	481

Table 24c. Loch Lomond - Middle Basin

Main Phytoplankton organisms - in cell numbers/l, or colonies of cells/l (see p. 158).

	1972							1973				
Surface	12/9	27/9	11/10	25/10	23/11	7/12	21/12	5/1	17/1	1/2	15/2	1/3
Melosira	1208	-	548	3090	22350	28206	32907	14896	3464	18804	14900	18147
Asterionella	2982	18284	41702	11227	3365	4326	259	-	672	672	1344	1344
Tabellaria	18804	27037	24059	14847	6599	5315	768	1428	1428	3464	3132	2196
Cyclotella (1)	21902	7011	5224	4701	2795	2774	4701	2007	1141	1328	1328	1283
Cyclotella (2)	31712	11915	2657	1328	618	137	-	-	-	-	357	192
Fragilaria	-	-	-	302	426	192	-	-	-	-	-	-
Coelosphaerium	426	481	426	783	1251	1374	302	701	1814	701	866	618
Anabaena	3708	3708	-	-	-	-	-	-	-	-	-	-
Mallamonas	618	618	866	247	-	-	-	-	-	-	-	-
Dinobryon	-	-	-	-	-	-	-	-	-	-	-	-
Ceratium	481	302	-	-	-	-	-	-	-	-	-	-
Peridinium	302	-	-	-	-	-	-	-	-	-	-	-
Botryococcus	-	302	-	-	357	-	96	-	137	481	41	137
Staurastrum	1044	1251	1141	1044	618	426	-	866	866	1814	783	302
3 Metres Depth												
Melosira	1536	2416	1536	16056	17704	37608	5608	10992	-	12096	33450	41792
Asterionella	10999	17704	12464	10008	10008	6264	1536	-	-	1922	-	3848
Tabellaria	18804	18804	27496	18804	3464	1704	1704	2472	-	384	3464	768
Cyclotella (1)	16543	8248	3391	4701	3391	3725	866	1374	-	2007	2658	948
Cyclotella (2)	18330	16268	5040	4701	618	-	-	783	-	-	-	-
Fragilaria	247	137	426	192	-	-	-	-	-	-	-	-
Coelosphaerium	618	783	618	701	618	701	481	426	-	948	866	783
Anabaena	-	-	1090	-	-	-	-	-	-	-	-	-
Mallamonas	96	96	-	-	-	-	-	-	-	-	-	-
Dinobryon	-	-	247	426	-	-	-	-	-	-	-	-
Ceratium	426	701	137	-	-	-	-	-	-	-	-	-
Peridinium	-	-	192	-	-	-	-	-	-	-	-	-
Botryococcus	192	426	96	192	192	-	426	-	-	192	137	-
Staurastrum	1251	426	701	357	426	137	137	426	-	426	426	192

Table 24d. Loch Lomond - Middle Basin

Main Phytoplankton organisms - in cell numbers/l, or colonies of cells/l (see p. 158).

	1973											
Surface	15/3	28/3	12/4	26/4	10/5	24/5	7/6	21/6	6/7	24/7	2/8	17/8
Melosira	22730	-	65532	139680	55542	1428	-	-	2196	-	548	384
Asterionella	23417	-	3367	51647	16360	33682	-	40740	9618	1344	-	-
Tabellaria	768	-	3132	2804	21812	2084	-	12098	166260	64707	43077	5496
Cyclotella (1)	3482	-	1374	4582	4903	12882	-	2062	1625	2566	5178	18972
Cyclotella (2)	866	-	1044	4701	618	701	-	137	192	2978	9897	12327
Fragilaria	-	-	-	-	357	302	-	41	782	481	302	196
Coelosphaerium	247	-	192	357	137	866	-	357	357	618	866	783
Anabaena	-	-	-	-	-	-	-	822	2142	62691	1152	576
Mallamonas	-	-	-	-	-	-	-	-	247	481	1044	1649
Dinobryon	-	-	-	-	-	357	-	4811	2007	-	-	-
Ceratium	-	-	-	96	-	-	-	481	1374	2213	783	357
Peridinium	192	-	-	-	-	701	-	1374	2213	192	192	-
Botryococcus	-	-	137	192	192	-	-	96	866	2460	3162	1649
Staurastrum	481	-	426	302	247	302	-	192	426	701	1512	426
3 Metres Depth												
Melosira	57920	-	-	202104	98152	12528	-	-	-	-	-	-
Asterionella	22728	-	-	59024	3848	3408	-	25536	8352	1096	768	768
Tabellaria	1208	-	-	2804	2988	12280	-	14480	186608	192472	93120	18696
Cyclotella (1)	3575	-	-	4582	2704	2475	-	2887	2007	3025	5408	14940
Cyclotella (2)	-	-	-	4701	426	426	-	-	-	2429	14527	5866
Fragilaria	-	-	-	-	-	137	-	137	1141	426	426	426
Coelosphaerium	481	-	-	357	302	481	-	302	302	481	192	426
Anabaena	-	-	-	-	-	-	-	-	2416	20192	-	-
Mallamonas	-	-	-	-	-	-	-	137	426	1044	2007	4701
Dinobryon	-	-	-	-	-	549	-	4812	2007	132	-	-
Ceratium	-	-	-	96	-	-	-	192	302	701	426	1044
Peridinium ;	96	-	-	-	-	481	-	783	1044	137	96	96
Botryococcus	137	-	-	192	192	137	-	137	302	783	2213	357
Staurastrum	426	-	-	302	247	302	-	549	618	481	866	701

Table 25a. Loch Lomond - North Basin

Phytoplankton in number of cells/litre or in colonies /litre (see Page 158).

	1972											
Surface	2/3	16/3	30/3	7/4	14/4	20/4	27/4	4/5	16/5	29/5	5/6	12/6
Melosira	1510	5688	27770	26384	54442	43718	16704	18144	16488	8412	5772	41
Asterionella	-	768	2418	1538	17704	14512	37608	6928	3408	9128	3848	3848
Tabellaria fen.	1704	1412	5496	11108	3464	6048	3463	6595	6044	5004	4564	8852
Tabellaria floc.	11273	8569	2213	481	701	96	96	192	357	137	..	137
Cyclotella 1	302	2612	2987	2213	1374	4701	2460	4761	2231	2777	426	-
Cyclotella 2	-	426	-	1044	1251	3725	7064	4701	2213	3024	2199	3725
Fragilaria	-	-	-	-	-	-	-	-	-	-	96	-
Coelosphaerium	302	192	426	701	357	302	357	96	701	426	701	2007
Anabaena	-	-	-	-	-	-	-	-	-	-	-	-
Mallamonas	-	-	-	-	-	-	-	-	-	-	-	-
Dinobryon	-	-	-	-	-	-	-	-	-	-	-	-
Peridinium	-	-	-	-	-	-	-	-	357	-	-	137
Ceratium	-	-	-	-	-	-	-	-	-	-	-	-
Staurastrum	357	-	-	-	96	96	-	96	-	-	-	-
3 metres depth												
Melosira	960	5196	11410	21619	25020	31604	21984	12528	19788	5772	7416	12
Asterionella	1536	-	-	8000	17000	10008	5608	6928	3848	3848	6264	3848
Tabellaria fen.	8852	13748	12648	45092	20104	10008	5004	5004	8852	5004	9532	5496
Tabellaria floc.	357	4701	1251	1374	701	549	192	-	-	481	192	137
Cyclotella 1	701	1374	2007	4701	2007	1374	866	1814	2007	1814	701	-
Cyclotella 2	-	426	192	-	-	-	2213	618	-	1649	2704	1814
Fragilaria	-	-	-	192	-	-	-	-	-	-	-	-
Coelosphaerium	137	192	302	137	-	-	302	357	357	192	302	-
Anabaena	-	-	-	-	-	-	-	-	-	-	-	-
Mallamonas	-	-	-	-	-	-	-	-	-	-	-	-
Dinobryon	-	-	-	-	-	-	-	-	-	-	-	-
Peridinium	-	-	-	-	-	-	-	-	426	137	-	96
Ceratium	-	-	-	-	-	-	-	-	96	96	-	-
Staurastrum	137	137	426	-	-	-	192	-	192	-	-	137

Table 25b. Loch Lomond - North Basin

Phytoplankton in number of cells/litre or in colonies/litre (see page 158).

	1972											
Surface	19/6	27/6	4/7	10/7	18/7	26/7	1/8	8/8	15/8	22/8	29/8	6/9
Melosira	247	481	302	481	-	-	-	137	137	-	357	-
Asterionella	9128	3408	5496	37608	29800	19680	17704	22216	29800	26029	8352	3848
Tabellaria fen.	14114	6596	4565	18804	548	8028	2804	3464	768	1924	3132	4564
Tabellaria floc.	-	-	192	-	-	302	-	192	302	192	137	-
Cyclotella 1	1044	1251	618	3116	4701	8798	10311	10403	10860	8752	8982	16268
Cyclotella 2	2978	1814	2749	2657	3024	7149	22684	7332	3299	2245	5545	18743
Fragilaria	192	192	302	701	1044	357	357	-	192	-	-	-
Coelosphaerium	481	481	1044	1251	3162	2007	1814	866	866	866	783	701
Anabaena	-	-	5112	12528	14094	17226	6426	4998	-	-	-	1728
Mallamonas	-	357	1374	2460	2777	3725	4701	3725	2777	1512	581	-
Dinobryon	-	-	-	192	783	4701	1649	-	-	-	-	-
Peridinium	-	-	192	137	-	357	192	192	948	426	137	137
Ceratium	-	-	192	426	1141	1814	783	357	357	-	426	137
Staurastrum	192	192	192	426	1044	1251	1374	866	426	192	426	357
3 Metres depth												
Melosira	-	-	-	-	-	-	-	-	1704	-	768	-
Asterionella	-	1704	17704	6928	5608	1536	5608	1536	4944	3848	10008	-
Tabellaria fen,	-	3132	5004	4564	3464	2804	1924	3132	768	7256	4176	-
Tabellaria floc.	-	-	426	-	-	481	-	192	137	618	137	-
Cyclotella 1	-	481	1251	4701	4701	4701	9532	9395	18606	10357	10632	-
Cyclotella 2	-	2007	4701	3725	4170	5453	8249	5270	4701	4701	6232	-
Fragilaria	-	137	137	948	2007	701	-	-	-	-	-	-
Coelosphaerium	-	-	618	783	426	866	1251	549	866	481	866	-
Anabaena	-	-	-	4530	22518	25102	21650	12025	-	2377	-	-
Mallamonas	-	-	-	948	2460	4701	3725	2777	4701	357	-	-
Dinobryon	-	-	-	948	4701	4701	2007	-	-	-	-	-
Peridinium	-	96	-	137	302	302	783	481	192	-	137	-
Ceratium	-	-	137	-	247	1141	192	96	481	426	302	-
Staurastrum	-	-	192	357	618	1251	481	618	866	-	481	-

Table 25c. Loch Lomond - North Basin

Phytoplankton in number of cells/litre or in colonies/litre (see page 158).

	1972							1973				
Surface	12/9	27/9	11/10	25/10	23/11	7/12	21/12	5/1	17/1	1/2	15/2	1/3
Melosira	-	-	-	-	3481	9396	37344	21768	10392	6426	8658	15660
Asterionella	6264	3848	13192	-	3848	3408	-	1096	768	328	-	-
Tabellaria fen.	548	4176	7256	-	3463	3464	548	3132	1428	384	768	1924
Tabellaria floc.	481	302	192	-	426	302	-	-	-	-	-	96
Cyclotella 1	25663	5361	5224	-	1251	-	357	1814	1251	3162	481	701
Cyclotella 2	16222	16497	7378	-	426	481	-	192	-	-	-	-
Fragilaria	-	-	-	-	302	-	-	-	-	-	-	-
Coelosphaerium	426	481	426	-	357	618	618	357	1044	783	426	481
Anabaena	-	1096	-	-	-	-	-	-	-	-	-	-
Mallamonas	302	481	302	-	-	-	-	-	-	-	-	-
Dinobryon	-	-	-	-	-	-	-	-	-	-	-	-
Peridinium	-	-	137	-	-	-	-	96	137	-	-	-
Ceratium	426	302	302	-	-	-	-	-	-	-	-	-
Staurastrum	426	481	426	-	357	-	-	357	96	192	481	357
3 Metres Depth												
Melosira	-	768	384	-	3464	1924	5004	2804	4698	10269	4284	37250
Asterionella	7584	10992	4944	-	10008	2416	-	-	-	-	-	-
Tabellaria fen.	1924	18804	3132	-	2472	2472	1924	3132	1924	548	4564	4176
Tabellaria floc.	866	302	-	-	481	-	302	-	426	357	866	481
Cyclotella 1	10265	4701	5774	-	3725	783	426	1251	1141	618	618	2213
Cyclotella 2	13336	12373	6920	-	-	-	-	357	-	-	-	-
Fragilaria	-	137	-	-	-	137	192	-	-	-	-	-
Coelosphaerium	426	426	783	-	357	247	426	-	426	357	866	481
Anabaena	-	-	-	-	-	-	-	-	-	-	-	-
Mallamonas	-	-	192	-	-	-	-	-	-	-	-	-
Dinobryon	-	-	-	-	-	-	-	-	-	-	-	-
Peridinium	96	137	-	-	-	-	-	-	-	-	-	-
Ceratium	426	426	357	-	-	-	-	-	-	-	-	-
Staurastrum	481	357	481	-	357	-	-	783	426	357	481	192

Table 25d. Loch Lomond - North Basin

Phytoplankton in number of cells/litre or in colonies/litre (see p. 158).

	1973											
Surface	15/3	28/3	12/4	26/4	10/5	24/5	7/6	24/6	6/7	24/7	2/8	17/8
Melosira	17226	-	44154	103422	36278	19788	-	137	-	96	-	41
Asterionella	3408	-	6928	29800	6264	5608	-	6264	3687	-	1536	-
Tabellaria fen.	1924	-	1208	3464	8064	11915	-	20347	134181	195223	70390	17964
Tabellaria floc.	247	-	2213	3725	1044	-	-	-	192	481	-	-
Cyclotella 1	618	-	247	1649	1251	16589	-	6701	5833	3460	7378	9532
Cyclotella 2	357	-	481	701	1044	481	-	8294	5000	3024	12739	6553
Fragilaria	-	-	-	-	-	302	-	357	783	426	426	-
Coelosphaerium	-	-	137	137	302	-	-	426	481	866	1374	1374
Anabaena	-	-	-	-	-	-	-	1096	15422	20784	3014	1096
Mallamonas	-	-	-	-	-	-	-	866	5865	1649	866	618
Dinobryon	-	-	-	-	-	96	-	4491	2007	137	137	426
Peridinium	-	-	-	-	-	137	-	549	866	357	-	-
Ceratium	-	-	-	-	-	137	-	-	247	1814	481	481
Staurastrum	137	-	866	481	137	-	-	192	618	1251	1814	1251
3 Metres Depth												
Melosira	12528	-	-	75216	48400	16000	-	685	685	384	-	384
Asterionella	3408	-	-	17704	3408	3848	-	6264	10008	3848	3408	1096
Tabellaria fen.	1924	- -	-	1704	2472	16316	-	13380	117132	175976	60492	14848
Tabellaria floc.	247	-	-	137	618	192	-	-	481	426	-	-
Cyclotella 1	618	-	-	2704	12684	4701	-	1141	2658	1649	7103	14619
Cyclotella 2	357	-	-	481	2777	783	-	3300	-	3620	12098	9807
Fragilaria	-	-	-	-	247	-	-	192	4701	1374	481	-
Coelosphaerium	247	-	-	137	137	357	-	192	618	866	1649	866
Anabaena	-	-	-	-	-	-	-	-	10101	19980	2466	-
Mallamonas	-	-	-	-	-	-	-	2213	4701	2213	783	426
Dinobryon	-	-	-	-	-	866	-	4701	1814	865	1141	96
Peridinium	-	-	-	-	-	357	-	-	1374	302	-	-
Ceratium	-	-	-	-	-	-	-	549	1141	783	481	357
Staurastrum	137	-	-	192	96	302	-	192	866	618	357	866

Table 26a Lake of Menteith

Main Phytoplankton Organisms - in cell numbers/l, or colonies of cells/l (see p. 158).

	1972						1973					
Surface	18/10	1/11	15/11	29/11	13/12	27/12	10/1	24/1	7/2	21/2	8/3	26/3
Melosira	6264	20347	105860	279269	413140	194581	28871	163327	249115	224368	940645	944402
Asterionella	3408	31608	37608	45093	42894	39961	19680	13931	10631	20530	20530	-
Fragilaria	3849	2777	1512	866	866	701	481	426	96	96	302	96
Tabellaria	164	384	-	5682	11108	-	-	-	548	-	768	-
Cyclotella	-	-	96	866	1251	426	96	-	426	1814	357	4078
Coelosphaerium	52976	32078	26671	19568	3941	9898	72956	10036	5361	3574	2007	2007
Anabaena (1)	336736	278261	850915	231884	211720	120840	170109	68648	5112	5608	-	64891
Anabaena (2)	-	-	-	-	-	1233	-	-	49493	19052	7854	358917
Anabaena (3)	-	-	-	-	-	-	-	-	-	-	-	-
Microcystis	357	1970	1695	-	-	-	1374	-	-	-	-	-
Botryococcus	1251	2152	3391	3162	783	948	27037	783	1044	357	481	866
Staurastrum	9402	9402	1251	866	426	192	-	-	41	-	-	-
Ceratium	96	-	-	-	-	-	-	-	-	-	-	-
3 Metres Depth												
Melosira	-	20352	221802	209704	400344	268540	-	206226	213654	-	1295536	944402
Asterionella	1096	22216	26400	30064	37608	-	-	1096	20160	-	69288	20160
Fragilaria	96	2777	783	481	481	1281	-	-	137	-	-	137
Tabellaria	-	-	14664	18804	4564	4176	-	-	-	-	-	-
Cyclotella	-	--	-	-	481	549	-	-	-	-	783	9807
Coelosphaerium	4701	29329	17185	12969	4701	13759	-	8707	7286	-	3725	866
Anabaena (1)	25102	36288	925519	130872	4608	-	-	31752	84618	-	31752	11529
Anabaena (2)	-	-	-	-	-	-	-	-	6588	-	-	4446
Anabaena (3)	-	-	-	-	-	-	-	-	-	-	-	-
Microcystis	701	6701	4701	701	-	-	-	-	-	-	-	-
Botryococcus	-	1649	4701	1251	-	866	-	357	866	-	1141	302
Staurastrum	618	2777	4701	1251	-	481	-	-	-	-	-	-
Ceratium												

Table 26b Lake of Menteith

Main Phytoplankton Organisms - in cell numbers/l, or colonies of cells/l (see p. 158).

	1 9 7 3										
Surface	20/4	3/5	17/5	1/6	14/6	28/6	11/7	26/7	8/8	23/8	20/9
Melosira	1089399	791890	400253	2466	11410	2400	-	39990	30195	83160	143667
Asterionella	4944	10992	186974	148112	13198	11365	30240	30240	36280	169559	52632
Fragilaria	192	2007	3528	11273	9852	5545	5407	3354	618	1957	3127
Tabellaria	-	-	-	-	768	3464	47010	18060	9480	26121	43535
Cyclotella	946	948	-	-	-	-	-	1806	1202	-	-
Coelosphaerium	866	3725	866	426	2460	2231	1065	7353	4582	1372	8248
Anabaena (1)	89820	1127344	895276	496764	200722	52212	121899	52212	20000	8000	8000
Anabaena (2)	442597	173226	137481	90737	35745	4944	9620	52632	65990	34599	14280
Anabaena (3)	-	-	-	-	-	52212	121899	52800	1691016	3243864	268087
Microcystis	-	-	-	-	-	96	342	17028	5957	6530	1202
Botryococcus	137	192	-	247	357	481	2610	4515	1372	3435	2370
Staurastrum	-	-	247	701	866	1044	3780	8127	4009	3437	-
Ceratium	-	-	-	-	357	948	549	25200	39754	8248	-
3 Metres Depth											
Melosira	1214232	590616	243980	-	-	-	4116	31992	5760	9060	164542
Asterionella	3408	37608	87624	-	-	6264	6040	56824	62000	44264	58824
Fragilaria	426	4701	4701	-	6095	4701	11753	3254	240	-	1065
Tabellaria	1704	-	-	-	-	1924	8660	18060	23020	42000	18660
Cyclotella	302	426	-	-	426	-	1753	1806	343	1065	480
Coelosphaerium	481	948	2322	-	1141	1814	2165	7357	2610	1753	11753
Anabaena (1)	210716	512520	703714	-	46161	108123	121000	151371	46161	5163	481
Anabaena (2)	58695	92580	312540	-	79188	84618	141036	352944	11761	-	5760
Anabaena (3)	-	-	-	-	-	-	-	151371	620026	246813	65688
Microcystis	-	-	302	-	-	-	-	17028	4123	9313	755
Botryococcus	137	-	137	-	357	302	1203	4515	1065	893	240
Staurastrum	-	-	426	-	481	357	2160	8127	2165	343	103
Ceratium	-	-	137	-	4595	-	4595	44118	15925	32995	240

Table 27a Loch Rusky

Main Phytoplankton organisms - in cell numbers/l, or colonies of cells/l (see p.158).

	1972						1973					
Surface	18/10	1/11	15/11	29/11	13/12	27/12	10/1	24/1	7/2	21/2	8/3	26/3
Melosira	8412	52752	102285	132073	212728	207687	-	58866	149980	113925	258097	1063553
Asterionella	80655	134914	37608	5602	1538	3408	-	-	768	3408	2856	87245
Fragilaria	-	1044	426	-	96	-	-	-	-	-	-	-
Tabellaria	1208	6415	51876	36661	9840	4176	-	548	2804	-	4176	30976
Cyclotella	-	-	481	481	137	137	-	-	-	-	426	4903
Coelosphaerium	6003	5168	4701	1833	357	618	-	783	1347	481	302	701
Anabaena	420141	367074	32652	3456	-	-	-	-	-	-	1644	4284
Botryococcus	-	481	783	192	-	-	-	618	1251	302	-	426
Staurastrum	4701	783	701	701	-	-	-	-	-	-	-	-
Ceratium	-	-	-	-	-	-	-	-	-	-	-	-
Peridinium	-	96	-	-	-	96	-	-	-	-	-	41
Mallamonas	-	-	-	-	-	-	-	-	-	-	-	-
5 Metres Depth												
Melosira	-	51966	140784	235368	117672	234246	-	167184	-	-	221064	1254936
Asterionella	127216	180376	-	-	-	-	-	-	-	-	2416	150680
Fragilaria	-	1044	-	-	-	96	-	-	-	-	-	-
Tabellaria	-	-	48760	24564	20348	2472	-	2804	-	-	3132	35744
Cyclotella	96	1374	783	481	481	-	-	549	-	-	549	6324
Coelosphaerium	4701	6095	1814	4701	481	948	-	2213	-	-	137	426
Anabaena	140784	70515	29520	-	1644	1644	-	-	-	-	1644	-
Botryococcus	866	137	783	-	-	-	-	357	-	-	-	192
Staurastrum	3162	618	357	481	-	192	-	-	-	-	-	-
Ceratium	-	-	-	-	-	-	-	-	-	-	-	-
Peridinium	96	-	-	-	-	96	-	-	-	-	-	-
Mallamonas	-	-	-	-	-	-	-	-	-	-	-	-

Table 27b Loch Rusky

Main Phytoplankton organisms - in cell numbers/1, or colonies of cells/1 (see p. 158).

	1973										
Surface	20/4	3/5	17/5	1/6	14/6	28/6	11/7	26/7	8/8	23/8	20/9
Melosira	2430664	700800	240000	-	17226	12080	-	7410	-	-	-
Asterionella	769893	9349000	149600	-	-	1098	114567	74500	-	-	-
Fragilaria	137	-	-	-	-	192	1752	3780	11739	2165	1372
Tabellaria	30426	231600	377200	8028	2472	1428	24600	18330	296000	200263	47010
Cyclotella	3725	322	-	-	-	-	-	-	-	-	-
Coelosphaerium	192	1128	999	357	481	302	3780	5384	16000	17987	7676
Anabaena	7416	27864	97524	9372	3014	140138	1580344	1652063	15840000	16497000	10270970
Botryococcus	137	322	322	192	192	96	3780	11752	14190	1372	3780
Staurastrum	357	5160	10707	1833	3207	1374	9738	17299	12800	6170	6150
Ceratium	-	-	-	302	701	1044	22900	25204	148800	4582	892
Peridinium	96	225	838	426	481	357	880	1065	16800	9165	2610
Mallamonas	-	-	-	-	-	1121	35745	95892	18000	-	1370
5 Metres Depth											
Melosira	3035593	579840	-	-	8658	-	-	-	15480	-	-
Asterionella	417944	815360	-	-	-	-	-	10738	-	-	-
Fragilaria	-	-	-	-	-	137	-	137	4515	5533	755
Tabellaria	40695	223360	-	-	1704	18804	-	17132	176472	173232	4260
Cyclotella	1649	903	-	-	-	96	-	-	-	-	480
Coelosphaerium	137	1806	-	-	302	137	-	4515	5805	11753	2165
Anabaena	-	90408	-	-	11544	7668	-	364000	1847748	4842090	2911860
Botryococcus	192	-	-	-	426	-	-	4515	3999	1065	893
Staurastrum	481	722	-	-	4801	1649	-	6579	4515	2165	480
Ceratium	-	-	-	-	302	-	-	2838	29600	2853	-
Peridinium	302	-	-	-	137	866	-	4515	3354	1753	-
Mallamonas	-	-	-	-	-	755	-	52800	8127	755	755

Table 28a Loch Achray

Main Phytoplankton Organisms in cell numbers/l, or colonies of cells/l (see p. 158).

	1972						1973					
Surface	18/10	1/11	15/11	29/11	13/12	27/12	10/1	24/1	7/2	21/2	8/3	26/3
Melosira	-	-	17064	7668	8652	7668	7854	10962	49401	7854	27522	26544
Asterionella	37608	34095	-	-	-	-	-	-	-	2856	-	-
Tabellaria fen.	-	1428	16497	536	548	548	384	384	548	1704	1704	1704
Tabellaria floc.	-	137	-	96	357	247	137	-	-	-	-	137
Fragilaria	-	-	-	-	96	41	-	-	-	-	-	-
Cyclotella	-	618	426	-	426	192	-	-	-	-	481	481
Coelosphaerium	302	426	-	-	-	41	96	302	-	41	96	96
Anabaena	24732	1728	1728	-	-	-	-	-	-	-	-	4226
Staurastrum	481	426	1141	1374	137	192	96	96	357	96	426	-
Mallamonas	-	-	-	-	-	-	-	-	-	-	-	-
Dinobryon	-	-	-	-	-	-	-	-	-	-	-	-
Pseudokephyrion	1347	5649	48	-	-	-	-	-	-	-	-	-
5 Metres Depth												
Melosira	492	-	-	7668	12528	-	-	14094	63522	70938	84618	14721
Asterionella	-	1096	1536	-	-	-	-	-	-	-	-	1976
Tabellaria fen.	384	-	2472	3464	164	-	-	164	548	3132	1208	1428
Tabellaria floc.	-	-	-	-	1251	-	-	-	-	-	192	357
Fragilaria	-	96	137	-	137	-	-	-	-	-	-	137
Cyclotella	-	783	192	-	302	-	-	-	-	96	2460	302
Coelosphaerium	-	41	137	-	-	-	-	137	-	-	-	-
Anabaena	1644	-	-	-	-	-	-	-	-	-	-	1788
Staurastrum	866	549	192	2007	-	-	-	96	357	481	-	-
Mallamonas	-	-	-	-	-	-	-	-	-	-	-	-
Dinobryon	-	-	-	-	-	-	-	-	-	-	-	-
Pseudokephyrion	-	3162	-	357	-	-	-	-	-	-	-	-

Table 28b Loch Achray

Main Phytoplankton Organisms in cell numbers/l, or colonies of cells/l (see p. 158).

	1973										
Surface	20/4	3/5	17/5	1/6	14/6	28/6	11/7	26/7	8/8	23/8	20/9
Melosira	56456	10224	704000	10582	4224	1152	-	-	-	-	-
Asterionella	1536	768	26832	-	-	-	-	-	-	-	-
Tabellaria fen.	1428	1428	32508	-	-	548	1270	-	-	-	3572
Tabellaria floc.	701	357	1290	1814	783	-	-	-	-	-	-
Fragilaria	-	-	-	-	-	96	-	-	-	-	893
Cyclotella	866	903	2838	-	-	-	342	-	-	893	5155
Coelosphaerium	-	96	-	192	137	96	-	-	-	892	755
Anabaena	-	-	-	-	4226	1344	4796	748800	369600	143660	80655
Staurastrum	-	192	2838	1096	1536	302	892	-	5160	11783	4535
Mallamonas	-	-	-	-	-	-	-	1202	44118	5018	4595
Dinobryon	-	-	-	-	-	481	16841	-	1451	-	-
Pseudokephyrion	-	6721	114979	-	2405	1814	2655	345200	132354	8315	26360
5 Metres Depth											
Melosira	-	13319	44118	-	-	-	-	-	-	-	-
Asterionella	-	1536	14448	-	1536	1096	240	-	-	-	-
Tabellaria fen.	-	1208	18784	-	3464	1924	1372	-	13416	7832	343
Tabellaria floc.	-	357	361	-	866	1512	1065	-	-	343	-
Fragilaria	-	-	361	-	-	137	-	-	-	-	-
Cyclotella	-	-	361	-	-	-	-	-	-	-	1065
Coelosphaerium	-	-	-	-	-	-	-	-	-	-	-
Anabaena	-	-	-	-	-	4224	5040	-	63984	7680	5488
Staurastrum	-	-	722	-	192	481	343	-	2322	2165	1752
Mallamonas	-	-	-	-	-	-	-	-	7353	1203	1753
Dinobryon	-	-	-	-	-	-	893	-	-	240	-
Pseudokephyrion	-	192	70880	-	1292	1251	4575	-	18834	4534	11753

Table 29a Loch Ard

Main Phytoplankton Organisms - in cell numbers/1, or colonies of cells/1 (see p. 158).

	1972						1973					
Surface	18/10	1/11	15/11	29/11	13/12	27/12	10/1	24/1	7/2	21/2	8/3	26/3
Melosira	328	1539	-	1536	2856	21964	10992	3408	12528	10582	31345	38642
Asterionella	23096	13931	1536	13192	1536	1536	4944	-	2856	6400	12000	25000
Tabellaria fen.	-	768	8852	13198	10815	3792	4564	548	1924	1345	5004	18804
Tabellaria floc.	-	192	137	866	701	-	-	301	137	137	-	192
Fragilaria	-	192	-	-	-	-	-	-	-	-	-	-
Cyclotella	21126	8936	9486	9944	5224	4032	4811	2474	5040	4857	866	783
Coelosphaerium	2007	1141	357	1141	137	866	1141	481	618	192	302	96
Anabaena	1536	2886	1536	168	-	-	-	-	-	-	-	384
Staurastrum	701	302	783	302	137	96	-	426	192	-	-	-
Dinobryon	481	3162	-	137	-	-	-	-	-	-	-	-
Mallamonas	137	-	-	-	-	-	-	-	-	-	-	-
Peridinium	-	-	41	-	-	96	-	-	-	137	96	-
Ceratium	-	-	-	-	-	-	-	-	-	-	-	-
5 Metres Depth												
Melosira	-	1644	1536	-	5355	-	6390	2055	13856	-	22518	84618
Asterionella	17704	10008	3848	-	1536	-	-	-	-	-	2426	22518
Tabellaria fen.	-	768	7256	-	18804	-	1704	-	988	-	2472	18804
Tabellaria floc.	137	-	192	-	618	-	-	-	-	-	-	192
Fragilaria	-	-	-	-	-	-	-	-	-	-	96	-
Cyclotella	26900	13152	13152	-	5224	-	4701	3849	3116	-	4674	948
Coelosphaerium	701	302	481	-	137	-	1251	783	1141	-	-	137
Anabaena	3624	1440	5772	-	-	-	-	-	-	-	-	-
Staurastrum	-	357	866	-	137	-	-	137	192	-	426	481
Dinobryon	137	247	-	-	-	-	-	-	-	-	-	-
Mallamonas	-	-	-	-	-	-	-	-	-	-	-	-
Peridinium	-	-	-	-	-	-	-	-	-	-	96	-
Ceratium	-	-	-	-	-	-	-	-	-	-	-	-

Table 29b **Loch Ard**

Main Phytoplankton Organisms - in cell numbers/l, or colonies of cells/l (see p. 158).

					1 9 7 3						
Surface	20/4	3/5	17/5	1/6	14/6	28/6	11/7	26/7	8/8	23/8	20/9
Melosira	27384	27522	35000	54643	61499	11410	-	-	-	-	-
Asterionella	50593	17704	3408	-	1096	768	-	-	-	-	-
Tabellaria fen.	21813	28412	18697	8028	2804	3484	18140	24645	47010	37250	31620
Tabellaria floc.	866	481	481	5545	426	137	-	617	-	-	-
Fragilaria	-	-	137	-	-	96	345	948	617	103	-
Cuclotella	426	426	-	-	-	-	-	617	2007	5617	9315
Coelosphaerium	481	192	1141	137	192	426	3666	3780	4617	2852	2082
Anabaena	1536	2466	208696	3456	1728	84618	526781	216532	267858	211545	72560
Staurastrum	-	357	618	783	426	948	4582	4701	5017	3127	-
Dinobryon	-	1357	1374	10952	3162	137	3780	4701	4122	1372	-
Mallamonas	-	-	-	-	-	-	549	2007	3780	4701	481
Peridinium	96	-	357	481	247	701	3666	3128	247	-	-
Ceratium	-	137	-	-	247	948	1372	4701	6848	-	-
5 Metres Depth											
Melosira	-	8652	32510	-	38334	1920	-	-	-	-	-
Asterionella	-	2418	-	-	-	-	-	-	-	-	-
Tabellaria fen.	-	18804	70252	-	1426	3464	1920	31620	176472	4812	3572
Tabellaria floc.	-	481	3251	-	761	512	480	948	2322	1374	481
Fragilaria	-	-	-	-	-	96	-	-	-	-	343
Cyclotella	-	481	-	-	-	-	343	240	6579	343	893
Coelosphaerium	-	247	1153	-	192	-	755	755	8127	1203	2165
Anabaena	-	-	-	-	4284	4416	72560	176295	171312	28048	17040
Staurastrum	-	302	1806	-	357	302	1203	755	1806	893	480
Dinobryon	-	137	1806	-	1251	618	343	343	903	1065	-
Mallamonas	-	-	-	-	-	-	480	2610	3999	480	347
Peridinium	-	-	929	-	357	192	7905	240	-	-	240
Ceratium	-	-	516	-	-	302	347	4123	12900	480	-