THE ANNUAL CYCLE OF NUTRIENTS AND PHYTOPLANKTON DYNAMICS IN A SHALLOW MONOMICTIC LAKE IN SCOTLAND (LOCH RUSKY)

Thesis submitted in accordance with the requirements of the University of Glasgow for the degree of Master of Science

by

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DEDICATION

To my family

(A mi familia)

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SUMMARY

Loch Rusky showed monomictic characteristics, with thermal stratification occurring through the summer. Dissolved oxygen was depleted in the hypolimnion in the late summer but remained near saturation levels through the seasons of water mixing. Changes in the nutrient concentrations in the water (such as nitrate, phosphate and silicate) were related to phytoplankton community changes (e.g. Diatom spring increase), external supply (e.g. nitrate, sulphate, chloride, COD) and dissolved oxygen levels (e.g. phosphate).

The seasonal phytoplankton community started to increase its biomass in April, reaching a single summer peak in July and later a small autumnal peak before falling to lower population numbers after November. The spring community was dominated by diatoms such as *Asterionella formosa* and *Melosira italica*, the summer by Cryptomanadales such as *Cryptomonas ovata* and *Rhodomonas minuta* var *nanoplanctica* which attained a very rapid maximum in biomass in mid-summer and by colonial Cyanobacteria in the autumn.

The primary production was correlated with the phytoplankton standing crop only in early spring, showing small peaks in mid-summer and winter months. An analysis of

variance in the method on the routine Carbon-14 method showed fairly low variance for the whole method although, cell rupture during filtration particularly affecting nanoplankton, could mask the production results in summer.

The diversity calculated by the Shannon-Weaver index was strongly influenced by the relative abundance of few species. The maximum phytoplankton diversity was registered in winter.

The seasonal succession pattern of the zooplankton population was dominated by Rotifera such as Keratella cochlearis and Polyarthra remata and the copepod Diaptomus gracilis which occurred mainly in the epilimnion during summer. Cladocera was insignificantly represented in the zooplankton. Some degree of trophic relationship was observed between nannoflagellates and rotifers seasonal populations.

INTRODUCTION

1. INTRODUCTION

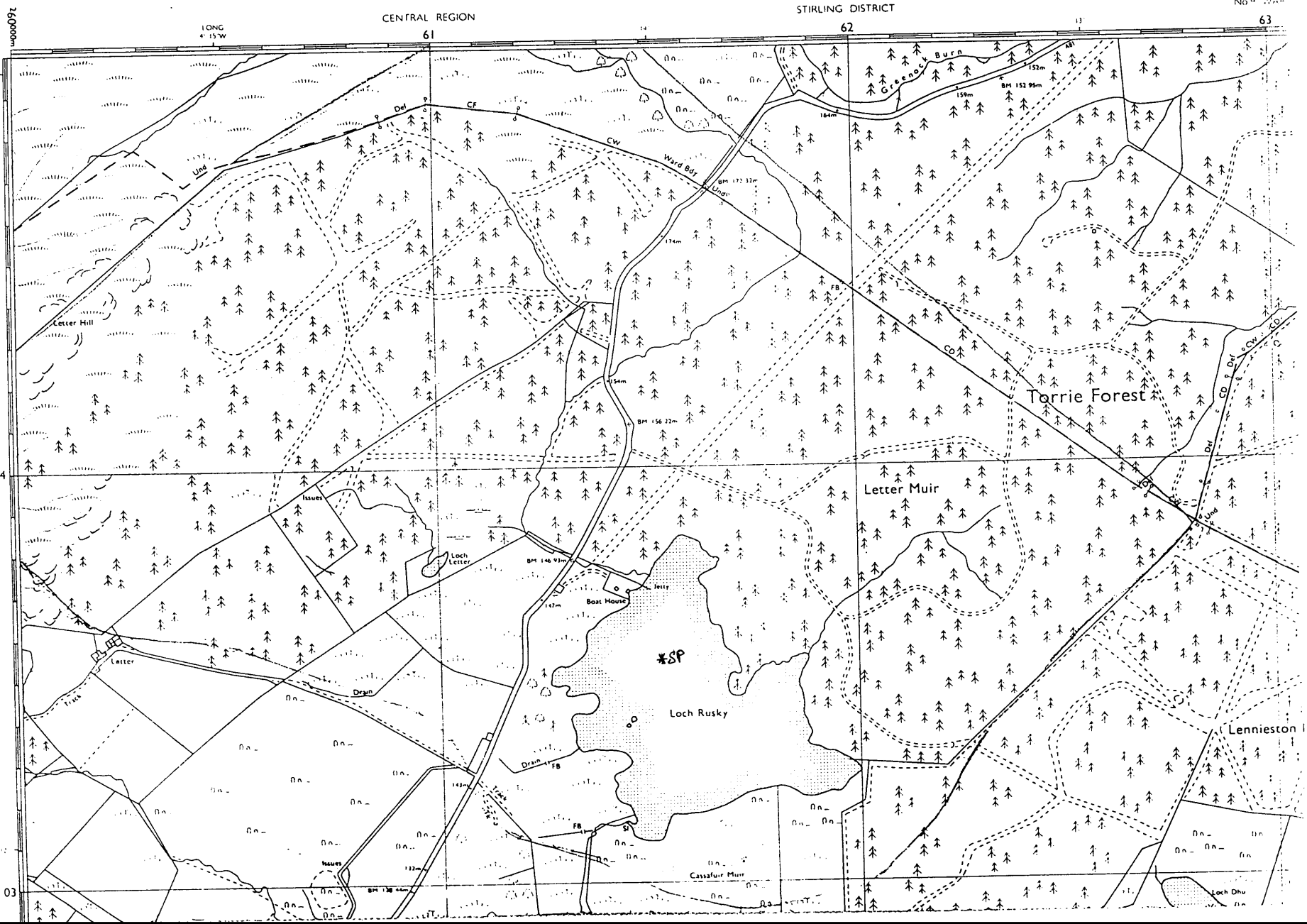
Loch Rusky as shown from Geological and Ordinance Survey maps (NN615035) lies at an elevation of 135m in the Central Region of Scotland, just to the south of the Highland Boundary Fault.(Fig.1)

The geology of the area is red sandstone of Devonian age, although the Loch itself lies on superficial drift deposits. The catchment area is 3km^2 of mainly high moorland grazed by sheep (16%) and softwood forestry plantation (86%) planted in 1969.

The Loch area is 0.2km^2 and the basin has an irregular shape with maximum length of roughly 800m and mean width about 400m, the maximum depth is 15m. There are two small islands at the West basin. The main stream flowing into the lake, Letter Burn, drains from Ben Gullipen (400m) to the north; the outflow leaves the Loch at the south-west; joining the Goodie Water which drains into the River Forth. The rate of outflow is controlled for farm use.

The Loch has been managed since 1964 for gamefishing by the Loch Rusky private Angling Club, which periodically restocks the Loch with juvenile (6months - 1 year old) rainbow trout (Salmo gairdneri) and brown trout (Salmo

Figure 1: Location of Loch Rusky and position of sampling site.


CENTRAL REGION
STIRLING DISTRICT
LONG 4° 15'W
61
62
63
260000m
Greenock Burn
BM 152.95m
Def
CF
CW
Ward Bdy
Und
BM 172.32m
Letter Hill
174m
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BM 156.22m
FB
Torrie Forest
Letter Muir
Issues
Loch Letter
BM 146.93m
Jetty
Boat House
147m
Letter
Track
Drain
Loch Rusky
Lennieston
Cassafuir Muir
BM 138.44m
Loch Dhu
03

trutta) every three - four weeks from April to September. There is, in the loch a natural population of brown trout which breeds in the Letter Burn and minnows Phoxinus phoxinus, (Mr. McKenzie, personal communication).

Loch Rusky is poorly documented, the only previous study of the limnology was Maulood, 1974). Maulood carried out a comparative study of Loch Lomond and five neighbouring lakes amongst which was Loch Rusky. The physico-chemical parameters and seasonal standing crop of the phytoplankton at two depths (surface, 5m) were recorded on this lake over a period of 12 months.

The present study aims at ascertaining the structure and dynamics of the Loch Rusky phytoplankton community in relation to its physio-chemical and biological environment. Regular fortnightly samples of water were taken over one complete year and analysed for the following: 1. Physical and Chemical, factors (e.g. temperature, dissolved oxygen, pH, micronutrients). 2. Phytoplankton standing crop by sedimentation and chlorophyll analysis. 3. Phytoplankton primary production by 14Carbon in situ incubation method. 4. Standing crop of zooplankton by sedimentation. 5. Diversity of plankton communities measured with the Shannon-Weaver index.

This study adds to the previous research the bioenergetic measurement of primary production and community structure of both phytoplankton and zooplankton. Thus the ecological basis has been set for further limnological studies on sediment and detritus food chain and scientific management of the fisheries in the Loch.

In general, the freshwaters of Scotland have great economic importance for water supply, fisheries and recreational purposes. The successful management of a fishery depends directly and indirectly upon the role of plankton in the energy transfer to the different trophic levels in a particular aquatic habitat.

MATERIALS AND METHODS

2. MATERIALS AND METHODS

2. 1. SAMPLING SITES AND FIELD SAMPLING

Samples were taken over the period October 1985 to September 1986. In general a regular fortnightly sampling programme was achieved except for the period between mid December and mid February, when samples were taken monthly.

Water samples were taken at surface, 1, 3, 5 and 10 metres depth from above the maximum water column. A 6 litres Van Dorn water sampler was used and the samples were returned to the laboratory in 1 litre polythene bottles.

2. 2. PHYSICAL AND CHEMICAL METHODS

Temperature and oxygen measurements were made using a Mackereth Mark II temperature/oxygen probe manufactured by pHox. Light was measured with a "Licor" PAR meter.

Immediately on return to the laboratory, water samples were filtered through Whatman GFA paper. Chemical analyses were completed as soon as possible and normally on the same day. Phosphate, sulphate, chloride, bicarbonate,

silicate and nitrate were analysed according to the methods of Mackereth Heron and Talling (1978), the last two spectrophotometrically. Ammonia was measured spectrophotometrically according to the method of Zadorojny *et al* (1973) and permanganate C.O.D. using Mackereth (1963) method. pH was measured using a Pye-Unicam 292 pH meter. Details of the chemical methods used are presented in Appendix I (page 402).

2. 3. PLANKTON STANDING CROP

a. Cell counts

The plankton suspended in 1l of water from October to March, and 250 ml from April onwards, was concentrated into 25ml by sedimentation using 1% Lugol's iodine solution. 500 ml were sedimented for the last sample in November and the only sample in December.

After thorough mixing the sample was poured into a chamber for counting phytoplankton using a Zeiss inverted microscope. All individuals encountered in traverses across the centre of the chamber were counted. Three complete traverses were counted. The mean colony size was calculated

for the most important colonial species. Counting was normally carried out at x640 magnification. Although this method is satisfactory for most species of algae, the Lugol's solution tends to cause colonies of buoyant Cyanobacteria (e.g. Coleosphaerium Naegelianum) to disintigrate, so they were counted separately. For this purpose, 1l water was filtered through a 4.5cm GFA glass fibre filter and the colonies on the paper counted under the x50 magnification by reflected light.

Identifications were made using Lind & Brook (1980) for desmids, Germain (1981) and Baber & Haworth (1981) for diatoms; Prescott (1962, 1964) and Belcher & Swale (1976, 1979) for others algae and Lund (1962) for Rhodomonas minuta var. nannoplanctica.

All zooplankton from the whole 25ml concentrated sample were counted under the x40 or x100 magnification of the inverted microscope. Identifications were made using Harding and Smith (1974) for Copepods; Scourfield & Harding (1958) for Cladocera, and Pontin (1978) for Rotifers. Counts were recorded on a BBC computer using a programme written by Place and May (1985).

b. Chlorophyll a

Rationale: Chlorophyll a (for all plants), b (for Chlorophyta) and c (for Chrysophyta) concentrations in water samples are used to estimate the biomass and the photosynthetic capacity of phytoplankton (UNESCO 1966). There has been doubt as to whether chlorophyll a should be considered a measure of biomass because of the relationships betwen this parameter and other measures such as cell numbers or volume is not stable under variable environmental and internal conditions. Nutrition, light, temperature and cell age can all influence the chlorophyll concentration. The change is not directly seen in the total biomass value (Meeks, 1974 and Herjula, 1976), stated chlorophyll is recommended as an indirect measure because it is linked to photosynthesis and is easier to determine than many other indirect measures which are themselves subject to similar variations in relationship to biomass.

There are three main methods for measuring chlorophyll a concentration: spectrophotometric, fluorometric and chromatographic. In this study the method based on Richards & Thompson (1952) was used, as modified by Parsons and Strickland (1963, 1968) and Talling & Driver (1963). It is based on the spectrophotometric measurement of the optical density at specific wavelengths for the main pigments

extracted in 90% acetone.

Of the solvents (acetone, methanol and pyridine) which have been used for extraction, only acetone and methanol are widely used. It is generally accepted thatt the extraction rate by methanol is superior to acetone for many green and blu-green algae (Steeman Nielsen, 1961 and Riemann, 1980). However, diatom pigments may be extracted using either acetone or alcohol (Talling and Driver, 1963). Although better results have been obtained with methanol, its use has been limited because most of its specific problems (allomerisation, pH dependence, stability of extract, health risk etc.) have not been solved satisfactorily (Nusch, 1978). Acetone shows high absorption characteristics for the principal photosynthetic pigments (Talling and Driver, 1963), but the absorption characteristics of Chlorophyll a in methanol are less well known.

Method

A one litre sample from surface 1m and 10m was filtered through a glass fibre filter (Whatman GFA), 4.25cm diameter from May onwards. The filter was placed in a centrifuge tube and 20ml of cold 90% acetone was added. The extraction took place in a dark refrigerator for 24hrs at 4⊂⊃C. A small quantity of magnesium carbonate was added

after filtration to prevent acidity and hence pigment degradation in the extract and to aid the retention. The samples were then centrifuged to remove the filter and magnesium carbonate.

Absorption of the supernatant was measured using a Pye-Unicam SP6-350 spectrophotometer in 4cm cells against a blank of 90% acetone at the following wavelengths: 750, 665, 480, 430 and 410 nm. The reading at 750nm was taken to compensate for turbidity of the sample and subtracted from each reading before calculation; 665nm presents the absorption peak characteristic of chlorophyll a; 480nm is the peak characteristic for plant carotenoids, although the results from this measurement were not used in this study; 430 and 410nm were measured to calculate degradation products of chlorophyll (e.g. phaeophytin) by reading before and after acidification with 0.25% HCl (Lorensen, 1967). The percentage degradation was calculated graphically.

Chlorophyll a was determined using the equation from Talling and Driver (1963):

$$\mu g \text{ Chl } a \text{ per sample} = 11.9 \; D665 \times (V/L)$$

where:

D665 represents the optical density reading at 665nm.

V is the volume of acetone extract in ml.

L is the length of the spectrophotometer cell in cm.

2. 4. PLANKTON PRIMARY PRODUCTIVITY.

Method

The 14C - method as originally described by Steeman-Nielsen (1952) was used. At each depth replicate water samples were taken in 125 ml dark and light incubation bottles. 0.5 ml radioactive solution containing 0.8uci from October to March and 2uci thereafter of radioactive $NaHCO_3$ was injected into each bottle, the stoppers replaced and the samples incubated for 4 hours at the depth from where they came.

After the period of incubation, the samples were returnd to the laboratory in the dark and filtered through a 0.45 mm H.A. Millipore filter. The filter together with the phytoplankton on it was placed in a vial containing 15 ml Hewlet-Packard scintillation fluor. The β - radioactivity of the samples was counted on a scintillation counter after a delay of 10 daysin the dark to allow any chemoluminescence to subside. Samples of fluor were counted for background

radiation, and original activity was measured by injecting 0.5 ml of the $NaHCO_3$ radioactive solution into a vial of fluor.

Some malfunction of the scintillation counter occurred from beginning of May onwards resulting in inaccurate readings for highly active samples such as original activity. After the fault had been corrected a definitive original activity value was calculated for each sampling date from a calibration curve plotting mean radioactivity (μci) against disintigrations per minute.

Carbon available for fixation was obtained from pH measurements and alkalinity titrations on the water according to the methods described in Heron and Mackereth (1978). From these results primary production expressed as grams carbon fixed per litre per hour was calculated for each sampling depth according to the equation in Vollenweider (1969).

$$^{12}C \text{ assimilated} = \frac{^{14}C \text{ assimilated}}{^{14}C \text{ available}} \times {}^{12}C \text{ available} \times K_{1,2,3}$$

where:

^{12}C available = calculated from alkalinity titrations and pH measurements (Mackereth and Heron, 1978)

^{14}C assimilated = (disintigrations per min - background for sample) x 1.06 discrimination factor.

^{14}C available = radioactivity added (calculated as for ^{14}C assimilated).

K_1 = an aliquot factor correcting for bottle size and amount of sample filtered.

K_2 = time factor to compensate for incubation time.

K_3 = a dimension factor to convert mg/l to mg/m_3.

Results are expressed as mg carbon fixed per m_2 loch surface per hour by integrating the area beneath the curve, and converting to the energy equivalent (Joules per mg carbon fixed).

Critique of Carbon 14 Method

The photosynthetic process is summarized by the equation describing the fixation of carbon dioxide and the manufacture of organic molecules for cellular metabolism and growth.

light

$6CO_2 + 6H_2O \xrightarrow{\text{-------}} C_6H_{12}O_6 + 6O_2$

In this redox system radiant energy is transformed into chemical energy as a result of the generation of high energy phosphate bonds. These are used in the dark to fix carbon (Vollenweider1969)

The oxygen and Carbon 14 methods for measuring phytoplankton production are based on the determination of the O_2 produced and carbon assimilated in this process, respectively.

The oxygen method measures rates of production and respiration from small changes in the amount of dissolved oxygen in light and dark bottles (Gaarder and Gran, 1927). The oxygen produced in the light bottle over a known period

of incubation, when added to the oxygen consumed in the dark bottle, gives a measure of gross productivity.

The Carbon 14 method involves the introduction of a radioactive tracer (14C normally in the form of NaHCO3) into the organic carbon for later measurement of the 14C assimilated by phytoplankton in the form of organic matter. This method assumes that the ratio of 14C taken up to 14C added is similar to the ratio of the total carbon fixed to total carbon available. To account for 12C/14C discrimination by the algae a correction coefficient of 1,06 is used.

Both methods can be carried out in situ or under experimental conditions. Neither of these two methods has proved to be definitive for measuring the photosynthesis of natural phytoplankton populations, since for each it is possible to identify a number of potential sources of error.

It is found that for certain algae, respiration rates do not remain the same in the light and in the dark, as is assumed in the oxygen method (Bunt 1965). Other important sources of error in this method are the high rate of bacterial photosynthesis shown in oxygenated waters and the possibility that plants may be able to convert radiant energy into chemical without evolution of oxygen (Arnon,

Whatley and Allen, 1958). The accuracy of titrimetric or amperometric methods in the calculation of oxygen changes is considered to be low, therefore this method is only succesful in productive waters.

The Carbon 14 method introduced by Steeman Nielsen in 1952 has been considered controversial in that an unknown quantity is being measured in the field, whether the net or gross photosynthesis or something between. The CO_2 incorporated by photosynthesis during the course of the experimental incubation may be fixed, be released from the cell as a respiration or metabolic product or be incorporated into the organism without involving photosynthetic reactions.

The relative importance of these phenomena in the cell is unknown. There is uncertainty as to the degree of refixation of respired CO_2 and the rate of cell respiration in the light. It would appear that respiration is partially suppressed or altered in the light. Measurements indicated that as irradiance is increased, CO_2 evolution from respiration is decreased, but O_2 consumption is increased (Weid & Brown, 1959), which could be consumed by a biochemical process different from respiration. According to Benson (1950), labelled products of photosynthesis do not appear to be used as substrates for

respiration and so release only $^{12}CO_2$.

These processes have a considerable bearing upon the interpretation of measurements by this method (Harris, 1980). It is generally accepted that 14C method measures something between net and gross photosynthesis. That depends upon the ratio of respiration to photosynthesis which is directly influenced by environmental conditions and the physiological condition of the algae. It is desirable to compare the two methods in a single study, and to compare photosynthesis rates during long and short incubation times.

Comparisons of the oxygen and 14C methods usually reveal agreement if a PQ ($DO_2/.DCO_2$) of about 1.2 is assumed (Ryther, 1956).

Because of its greater sensitivity, the 14C method is the only one to provide satisfactory results for oligotrophic waters. The oxygen method is more suitable for use in eutrophic waters and generally provides a crude measure of the gross photosynthesis. No completely reliable measurement of net photosynthesis is possible by either method. Sometimes the results obtained from both methods are not always comparable. The method used should always take into account the particular characteristics of the water under study and the aims of the study.

Assessment of the potential sources of bias in the determination of primary production by the Carbon 14 method

In this section the different potential sources of bias associated with the determination technique are reviewed briefly. The term "bias" in this connection is considered to be the difference between the true estimate and the acquired estimate of production under certain circumstances (Cassie, 1962).

Production estimates by the 14C method are mainly affected by: A) the inorganic carbon concentration; B) bottle material and effects of enclosure in the bottles; volume of sample; C) suspension of bottles and duration of incubation; D) filtration of samples and by the activity determination.

A. Inorganic carbon

The determination of this is considered to be a minor source of bias. The total inorganic carbon concentration can be calculated from pH, temperature and alkalinity. Nevertheless, small inaccuracies in calculation (whether of titration of alkalinity or pH measurement) can influence the results.

B. Bottle material and enclosure

The classical method of measuring primary production of phytoplankton in situ involves the enclosure of water samples in glass bottles. It has been proved that the absorption of light by glass, particularly of short wavelengths, is considerably greater than by most lake and sea waters. Ultraviolet radiation may depress photosynthetic activity near the water surface (Findenegg, 1966). This effect appears to be greatly attenuated at deeper waters.

Light conditions inside the bottle differ from the natural conditions and depend on the quality of glass (Ohle, 1958). The production in glass bottles can exceed the equivalent values in quartz bottles by 50% in sunlight conditions, but in the case of lower light conditions (such as under cloud cover or at greatest depths), the production values obtained in quartz bottles can be considerably higher thn in glass (Findenegg, 1966). Ilmavirta (1977) observed than in brownwater lakes, glass bottles have about 18% higher production values than acrylic plastic bottles in 24 hour exposures, but in 4 hour exposures the glass bottles gave only slightly higher estimates during high radiation. Discussion of the relative merits of different enclosure

materials for production measurements is summarized by Soeder and Talling, (1971), however so far no satisfactory alternative has been found to replace the glass bottle method normally used in production measurements.

By enclosing a sample in a bottle, the habitat of pelagic algae is disturbed, in that it is changed to more or less static water conditions. The suspended bottles are subjected to some dynamic water turbulance, but the natural dynamic movement of the algae is repressed inside the bottle. Turbulence has a direct influence on passive buoyancy and sedimentation in natural conditions and therefore alters the vertical distribution of the population.

Environmental factors and population characteristics may change in long incubation times in bottles. The phenomena of animal grazing, growth and the decay or colinization of green-algae or bacteria particularly on the bottle wall, may modify the total density and qualitative composition from the original population. The chemical composition of the water may also be modified and thus alter rates of plant growth and photosynthesis. Concentrations of oxygen, carbon dioxide, inorganic carbon and pH are normally changed when intense photosynthetic activity occurs in dense populations (Gessner & Pannier, 1958). Nutrients may be

depleted by algal growth, be removed by absorption onto the wall of container or be altered by zooplankton and bacterial activities (e.g. excretion).

Harris (1973 .) deserve careful consideration on the subject of the relationship between photosythesis and physiological and environmental conditions (eg. growth age, cell difusion etc).

C - Exposure and bottle suspension.

One of the greatest sources of bias in studying phytoplanktonic primary production in situ, is introduced by the period of incubation. Recommended incubation periods in the literature range from 2 to 24 hours.

There are many reasons presented to account for this range of incubation times. Generally incubation time should be as short as possible, because of the bottle effect, but in unproductive waters or in studies on the diurnal pattern of photosynthesis a longer incubation time of up to 24hrs may be necessary. Waite & Duthie (1973) suggested a technique comparing short with long (24hrs) incubation periods to give an estimate of gross productivity. The effect of the duration of exposure on production estimates is

different depending on the productivity of the lake. It is often assumed that the bottle effect tends to lower production estimates. Long exposures tends to give an underestimation of rates of photoynthesis but the integration of the results of short exposes (2-6h) was also unsatisfactory (Jones & Ilmarvita 1978) in a study on diurnal changes in primary production.

The method most widely used in the suspension of the bottle was decribed by Soeder & Talling 1971. This involves the attachment of the bottle to a line or wire and then holding it in a vertical position by means of an anchored buoy or float. Higher values have been reported for bottles suspended in the horizontal position in comparison with vertical. Differences were as high as 10%-35% (Ohle, 1958).

The volume of sample bottles seems to be inversely related to the production (Jones 1977). This effect is not clear but is related to the exchange of C14 produced between water and air at the top of the bottle during the incubation.

D- Filtration and counting determination.

The filtration process in the radiocarbon method is considered to be a major source of bias in this technique.

The volume of the filtered sample (10-200ml) does not seem to have very important effect on the activity obtained in oligotrophic lakes but the situation can be entirely reversed in very eutropic waters where high plankton density may influence the filtration time and volume of filtration. The layer on the filters in eutrophic waters tend to grow too thick (Steeman Nielsen 1975), this is important for Geiger-Muller counting but practically corrected for liquid scintillation technique.

The vacuum pressure applied to the filter should not exceed 0.5atm, to reduce the possibility of rupturing more fragile cells such as flagellates. The recommended pore size of filters is usuallly 0.45µm, (Gargas, 1975). The drying of the membrane filters seems to decrease slightly the activity obtained (Steeman Nielsen al 1975) . This is probably due to the enzymatic transformation of labelled organic matter to volatile matter.

Detailed reviews concerning the preparation of radioactive bicarbonate solution and the methods of counting the activity of filters have been given by Vollenweider (1971); Strickland & Parsons (1972) and Gargas (1975).

Difficulties associated with the counting process derive from the effects of the penetration of labelled

carbon into the filters and the so-called "escaping production". The penetration of C14 into the filters is especially important in eutrophic waters where the layer on the filter tends to be thick. The loss of labelled products derives mainly from two sources, one from the mishandling of samples during the filtration causing the rupture of cells and leakage of organic material (Sharp, 1977) and the other from the phenomenon of active cell excretion. The former can be a major reason for escaping prouction when the bulk of the phytoplankton consists of algae very sensitive to cell rupture and lysis. Evidence has been found that between 50% - 95% of fixed C 14 material could be excreted by viable algal cells as soluble organic matter during a (24h) exposure (Fogg, 1966). The ignoring of this phenomenon by other authors has led to great controversy (Sharp, 1978, McAaroson, 1978, Fogg, 1977). The error resulting from extracellular C14 precipitates is usually reduced by exposing filters to fumes of HCL.

Analysis of variance to compute the components of the errors in the routine of Carbon 14 method used

An analysis of the variance was applied to ascertain the main source of variation introduced at each stage in the routine carbon 14 method used to measure primary production.

Three sources of variation were considered:

1.) The variation between samples, to measure the variance resulting from the irregular distribution of phytoplankton within the water column. 2.) Variation between repeated filtrations. 3.) Variation for replicate counts.

The method was carried out as described by Davies (1954). From the results it should be possible to determine the absolute level of error for the method and apportion this to the various stages in the process and so identify those which deserve attention to improve the accuracy of the technique.

"S" refers to the number of samples taken from the field site; "F" the number of subsamples filtered from each sample and "C" the number of counts for each subsample. Let the variance contributed at each of these stages be σ_s^2, σ_f^2, σ_c^2 respectively. It is assumed that the variance at each stage is independent and that the distribution of phytoplankton is normal or transformable to normal, so that analysis of variance can be applied. The overall variance of the method can be shown to be the sum of variances from each stage.

The component of variance introduced at each stage is expressed as $100\ \sigma/\mu$ (percentage deviation from the mean μ).

This measure is synonymous with the coefficient of variation used in statistics.

The experiment designed to use this system of analysis was as follows: four pairs of duplicate light bottles containing sample water collected at 1 metre from Loch Lomond and Loch Rusky, were incubated for 4 hrs. following the method of Carbon-14 (see page 10, section mat and meth). Duplicate subsamples of 50ml were filtered from each bottle and replicate counts were made from each filtration subsamples. The experiment was carried out during March in the North basin of Loch Lomond and during September in Loch Rusky. The main algal populaion in L. Lomond was composed by diatoms and in L. Rusky by flagellates (e.g. Cryptomonas ovata).

The result of the coefficients of variation at the sampling stage were 17.41% (L.Rusky) and 18.79% (L.Lomond); at the filtration stage 16.56% and 19.33% respectively and at counting stage 14.48% and 12.28%. The variance for the whole method was 50.41% in Loch Lomond and 48.45% in L. Rusky (Table I).

The slight differences between pairs of results for the total and partial variance coeficients, shows that the accuracy of the routine Carbon 14 method used in the

Table I Analysis of the variance for the Carbon-14 method

	Variance (σ^2)	Standard (σ) deviation	%Deviation from μ
	Loch Rusky *		
(S) Sampling	18,377	4,287	17,410
(F) Filtration	16,632	4,078	16,560
(C) Counting	12,708	3,565	14,480
Whole method	47,717	11,930	48,450
	Loch Lomond +		
(S) Sampling	78,160	8,840	18,790
(F) Filtration	82,725	9,095	19,330
(C) Counting	33,370	5,780	12,280
Whole method	194,255	23,715	50,410

* Mean of all counts, $\mu = 24.62$, S = 8, F = 2, C = 2

\+ Mean of all counts, $\mu = 47.05$, S = 8, F = 2, C = 3

estimation of primary production remains more or less constant. This remained independant of time and space (water body). L. Lomond and L. Rusky have contrasting geological, physical and biological characteristics (Tippett, 1974, Maitland, 1981). L. Lomond is shown to be oligotrophic and the site, depth and catchment area are well contrasted to those in L. Rusky. The analysis did not reveal either significant differences between results obtained in different seasons.

There are similar coefficients values for each of the method stages. The higher variance arose during sampling and filtration. The sampling coefficient was expected and explained as a result of the heterogeneity of phytoplankton in the natural habitats. By contrast, a considerable variance is introduced at the filtration. This may arise from several sources: loss of production during manipulation of samples, penetration of radioactive products into the filters, variance introduced in the filtration of different populations and in the sequential timing of sample filtration.

The efficiency of the routine Carbon 14 method thus remains constant for the whole period of this study.

RESULTS

3. RESULTS

3. 1. PHYSICAL AND CHEMICAL ENVIRONMENTAL PARAMETERS

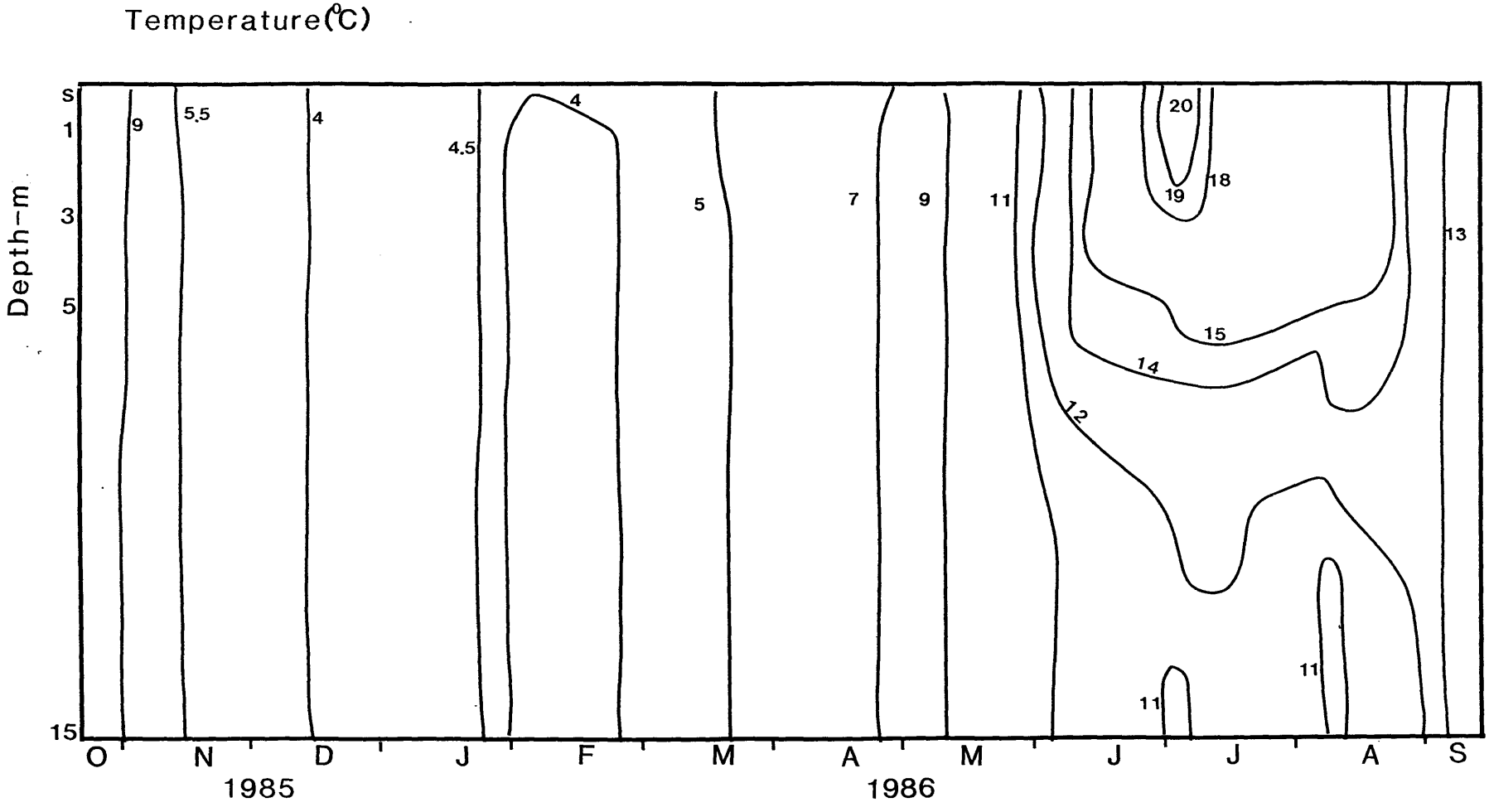
1. TEMPERATURE

Isothermal conditions were observed throughout practically the whole year under study (1985-1986), and only during the summer season from June to August was thermal stratification apparent. (Fig. 2)

The minimum (3.5°C) and maximum (20°C) temperatures were recorded at the beginning of February and July, respectively. A steep fall of 5°C occurred from the end of October to November from a surface reading of 10°C on 29th October to 5.5°C on 13th November. The temperature decreased to 4°C by the end of November, remained constant during December and January, until it reached 3.5°C in February. Although ice may have covered the lake at some time during the winter, none was observed on any sampling occasion.

From February to the middle of May, the isothermal pattern remained but the temperature showed a gradual increase from 4.5°C on 12th March to 10°C by 20th may.

Figure 2: Isopleths of water temperature from October 1985 to September 1986, expressed in degree centigrade.


Temperature(°C)
Depth-m
S
1
3
5
15
9
5.5
4
4.5
4
5
7
9
11
20
19
18
13
15
14
12
11
11
O
N
D
J
F
M
A
M
J
J
A
S
1985
1986

Stratification of the water column began at the end of May when the water was 11°C and a gradual increase in surface water temperature was recorded until July. This summer increase surface water temperatures established two clearly defined thermal regions: an upper warm circulating region and a deeper less disturbed column of water. The temperature range of the latter remained between 12.5-11°C throughout the summer. The boundary between them was shown to be irregular, deepening throughout the stratification period.

The steepest gradient of temperature with depth was obtained on 1st July, at the epilimnion, comprised the top 2m. The middle region, or metalimnion, showed a gradual decrease in temperature of 1°C per metre until the top of the hypolimnion was reached at 9m. The temperature at this depth was 12.5°C and the range from surface to the bottom was 7.5°C.

From this summer maximum, the temperature at the surface tended to fall during July and August, resulting from a mixing of the column of water by the deepening of the epilimnion. The maximum penetration of the epilimnion was reached on the 19th August, extended to 6m. Its temperature was 15°C. The metalimnion remained at the same depth

throughout July, however in August it extended down to 11m, reducing the volume of the hypolimnetic water column to the bottom 3m. The temperature gradient from the epilimnion to the bottom was reduced to 3.5°C in the middle of August.

The deepening of the epilimnion and metalimnion lead to recycling of the upper and lower column of water which restored isothermal conditions such as was observed in September, with a temperature of 12.5°C.

The single period of stratification lasting from July to October and the annual surface temperature ranged from 2 to 19°C, makes Loch Rusky monomictic.

The stratification in summer did not present a completely defined hypolimnion, where the mass of water remains unmixed and isothermal during the stratification. (Hutchinson, 1957). The functional hypolimnion in Loch Rusky was observed as a deeper water column of which the range of thermal stratification remained more or less constant, between 12°C - 11°C by contrast with upper column which included the epilimnion and metalimnion and where the gradient of temperatures were apparent during the stratification period.

The annual pattern of temperature observed on Loch

Rusky 1985 - 1986, agreed in general with that described by Maulood, 1972-73.

2. DISSOLVED OXYGEN

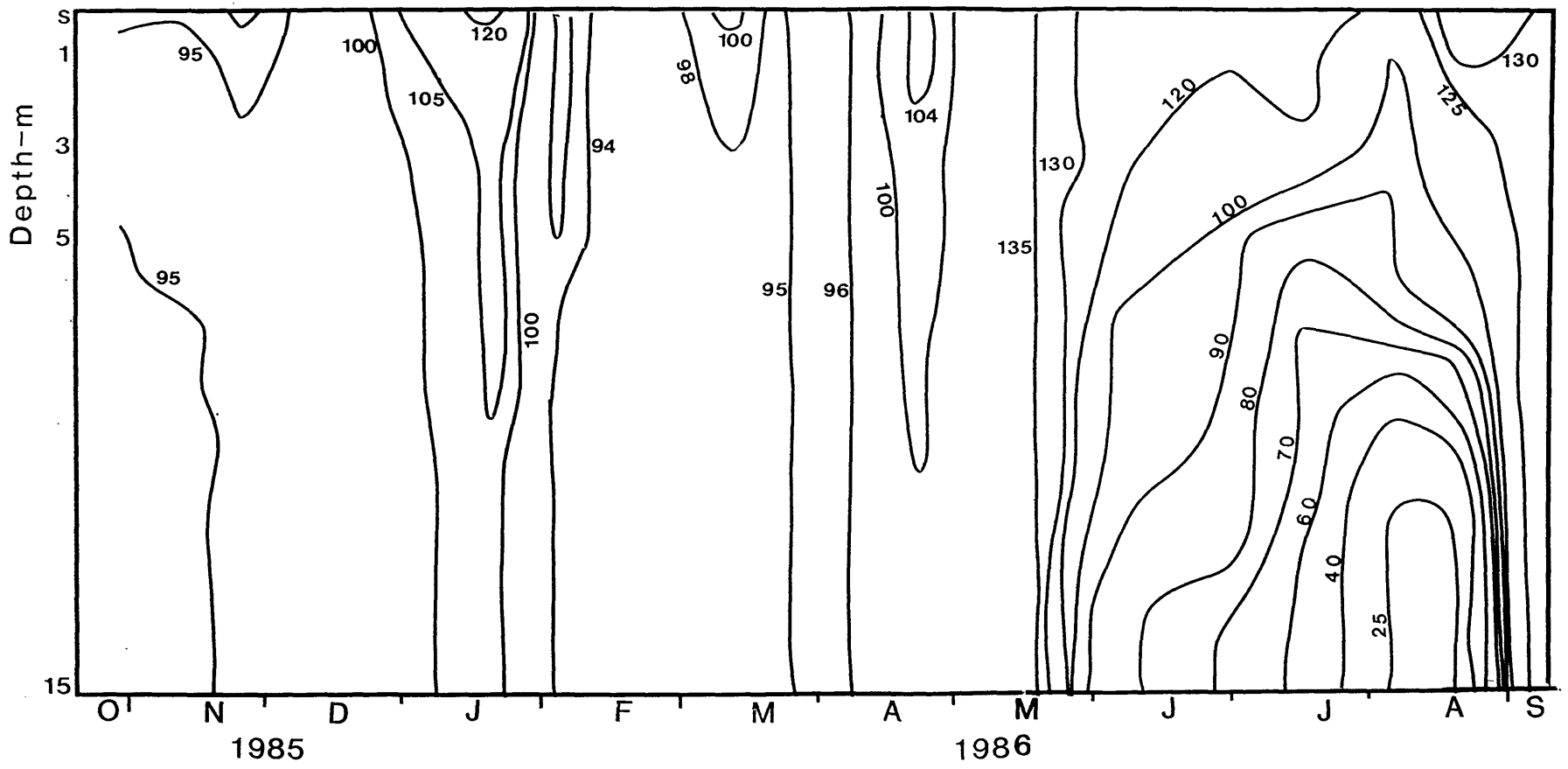
Oxygen showed a clinograde distribution for most of the year in Loch Rusky the greatest percentage saturation being at the surface (Fig 3). The surface values were never less than 90% saturation throughout the whole period of sampling. The oxygen gradient with depth was steep during the period of thermal stratification in summer and very slight or even isoclinal during the rest of the year. During October and November a negative heterograde distribution was observed, with lower oxygen values in the middle region between 1 and 6m than at the surface and bottom. The highest saturation of dissolved oxygen (135%) was registered at the surface in May and August and the lowest was at the bottom in August (21%).

The gradual fall of temperatures from October to February where isothermal conditions and mixing remained meant that levels of oxygen approached saturation throughout the water column at this period.

A decrease of atmospheric temperatures from the end

Figure 3: Isopleths of dissolved oxygen from October 1985 to September 1986, expressed as percentage saturation.

Dissolved Oxygen–%saturation



of December to the middle of January with possibility of ice-covering the Loch, could be related to the whole increase of oxygen saturation registered at this period. By January, the top 2m showed a supersaturation of 120% which could be augmented with oxygen released by algal production under the ice.

In February the oxygen concentration in the deeper water was slightly higher than at other times possibly due to the annual minimum temperatures registered at the bottom. High oxygen levels throughout the water column and saturation at the surface remained during the spring. The values from March to middle May ranged from about 135-100% at the surface to 77% at the bottom. Thermal stratification, starting at the end of May and continuing until the beginning of September, resulted in a large fall of oxygen levels in the deeper water. An epilimnetic maximum of 130% was recorded at the surface while 20% was found in the hypolimnion.

The saturation values at the bottom rose to the surface levels when the summer stratification tended disappeared by the end of August and isothermal conditions restored throughout September.

The general oxygen pattern in Loch Rusky was largely

similar to that shown for temperature. Mixing under isothermal conditions appeared to be the most important factor affording uniform saturation levels throughout the whole column of water during autumn, winter and spring. During summer, oxygen produced by photosynthesis underneath the surface appear to be the most important factor in explaining the maintenance of high oxygen levels under summer temperatures and low turbulance.

The annual oxygen pattern described for Loch Rusky by Maulood in 1972-73 agreed in general terms with that observed in the present study, except for July where Maulood described general unsaturated oxygen levels at the surface and bottom with slightly higher values between 3 and 6m, and uniform oxygen concentration with depth in August.

3. LIGHT

The results of light measurements taken on five occasions throughout the year are presented in Figure 4. Light penetration throughout the water column, expressed as a logarithmic percentage of the incident light at the surface, is plotted against depth in Figure 5. Insolation energy input was not measured in this study but

Figure 4: Incident light energy from October to November 1985 and from May to July 1986, expressed in μeinsteins.

INCIDENT LIGHT ENERGY μenst.

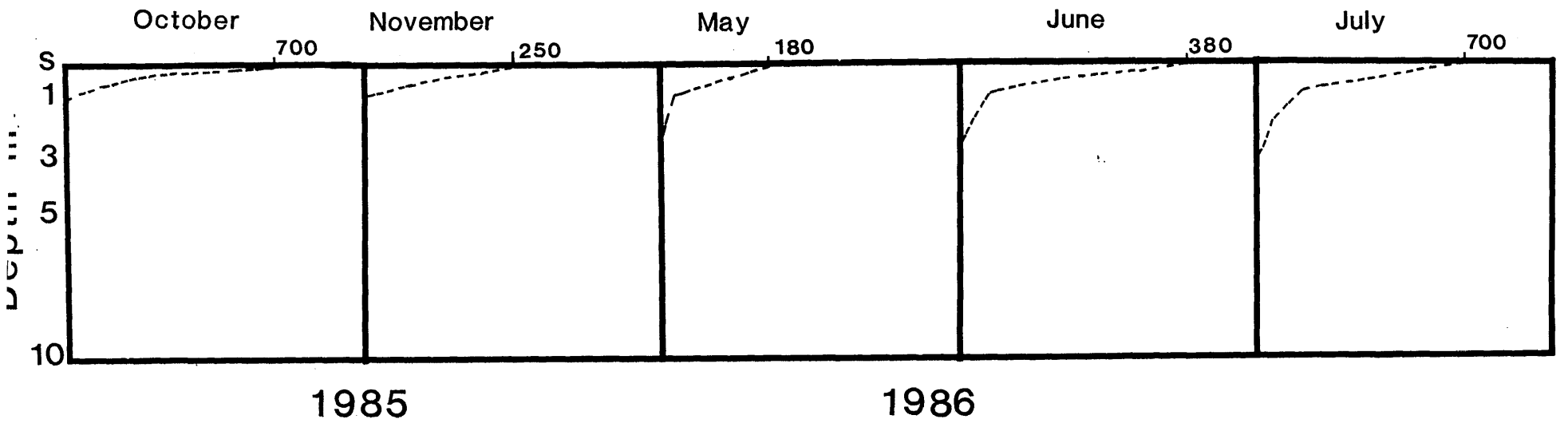
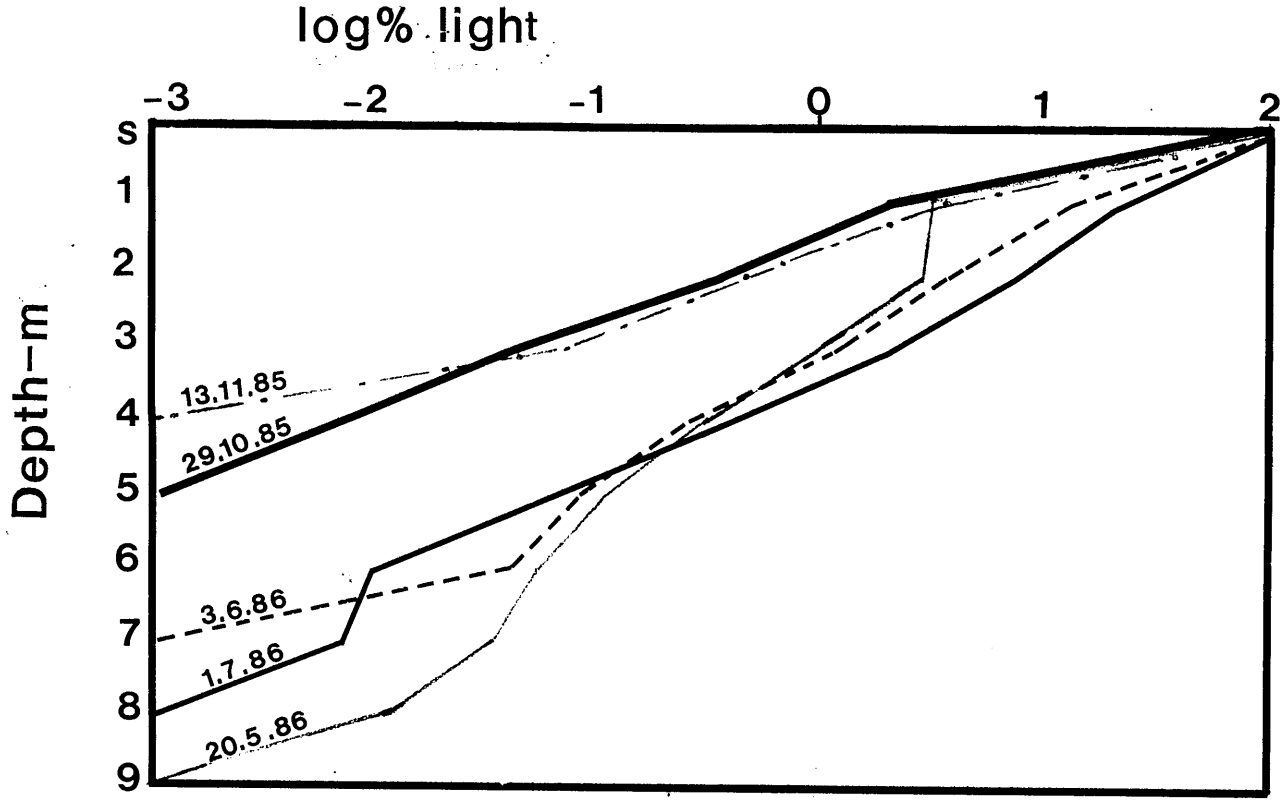


Figure 5: Penetration of incident light throughout the water column from October to November 1985 and from May to July 1986, expressed as logarithmic percentage of the incident light energy.


log% light
-3
-2
-1
0
1
2
s
1
2
3
4
5
6
7
8
9
Depth-m
13.11.85
29.10.85
3.6.86
1.7.86
20.5.86

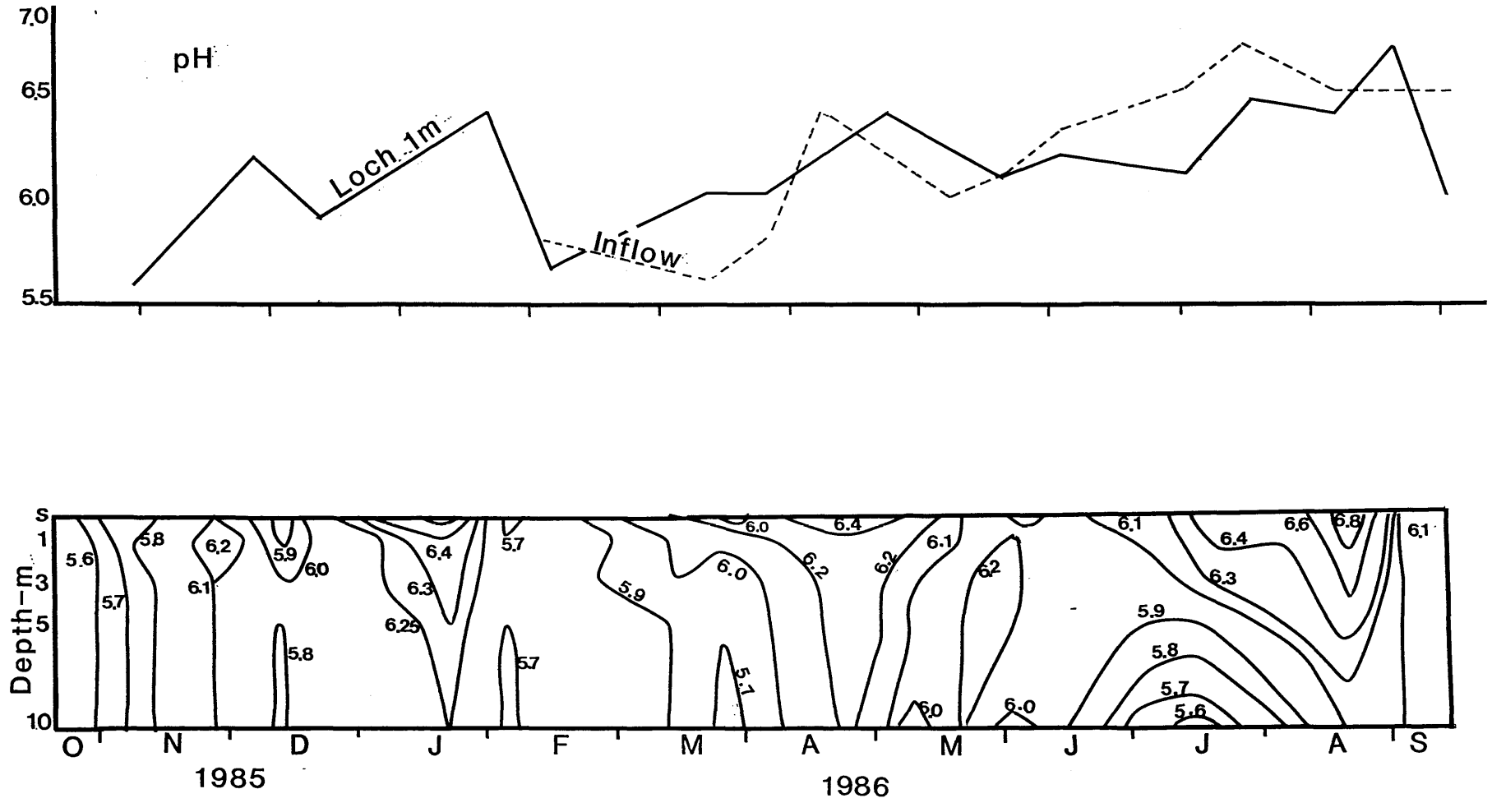
it is assumed that this is dependant upon duration of daily sunshine and cloud cover.

During early autumn the incident light at the surface remained relatively high at 700 and 250 μeinst. but the extinction to 1% throughout the water column was reached above 2m. The absorbant materials, both dissolved and in suspension, increased at this season as a result of high rainfall and seems to be the major factor responsible for poor light penetration since plankton biomass did not attain high population levels.

From autumn to winter high levels of light incident decreased by reduction in day length, increasing cloud cover during the season of high rain and by lower solar elevation. These factors are reversed through spring - summer. The greatest rate of change in day length occurs at around the vernal and autumnal equinox.

The euphotic zone defined as depth where community photosynthesis and respiration over a 24 hour period are compensated (Hutchinson, 1967) was not applicable in this study since respiration and total radiation were not measured. The incident light extinction throughout the water column to 1% where photosynthesis is usually insignificant (Talling, 1962), was judged to be more useful

Figure 6: Seasonal changes in hydrogen ion concentration (pH) at the 1m in Loch Rusky from October 1985 to September 1986 and in the main inflow from February to September 1986. Isopleths of pH from 1 to 10m.


pH
7.0
6.5
6.0
5.5
Loch 1m
Inflow
Depth-m
S
1
3
5
10
5.6
5.7
5.8
6.1
6.2
5.9
6.0
5.8
6.4
6.3
6.25
5.7
5.7
5.9
6.0
5.1
6.0
6.4
6.2
6.2
6.1
6.0
6.2
6.0
6.1
6.4
6.6
6.8
6.1
6.3
5.9
5.8
5.7
5.6
O
N
D
J
F
M
A
M
J
J
A
S
1985
1986

October to August (5.6 to 6.75) with a middle fall of values in February coinciding with the thermal minimum.

General higher pH values were recorded at the upper 3m than at the bottom. Uniform pH readings at all depths were found from October to December and in February. During January and spring, a pH gradient was observed between surface and the bottom. This difference was more pronounced in January (6.8 to 6.25) and March (6.9 to 5.65) than in April and May.

The pH gradient observed during the spring became clearly steeper in the bottom 3m during the period of thermal stratification in summer. Summer values at the surface remained high during this period when the thermal stratification disappeared, around the end of August and the pH at the bottom rose. The gradient from the surface to the bottom was 0.7 (ranging from 6.8 to 6.1).

In September the uniform and more acid conditions of autumn were restored, and lower values in the top 1m were recorded.

During this study of Loch Rusky, a range of pH values ten times more acid than those described by Maulood in 1972-1973 was found.

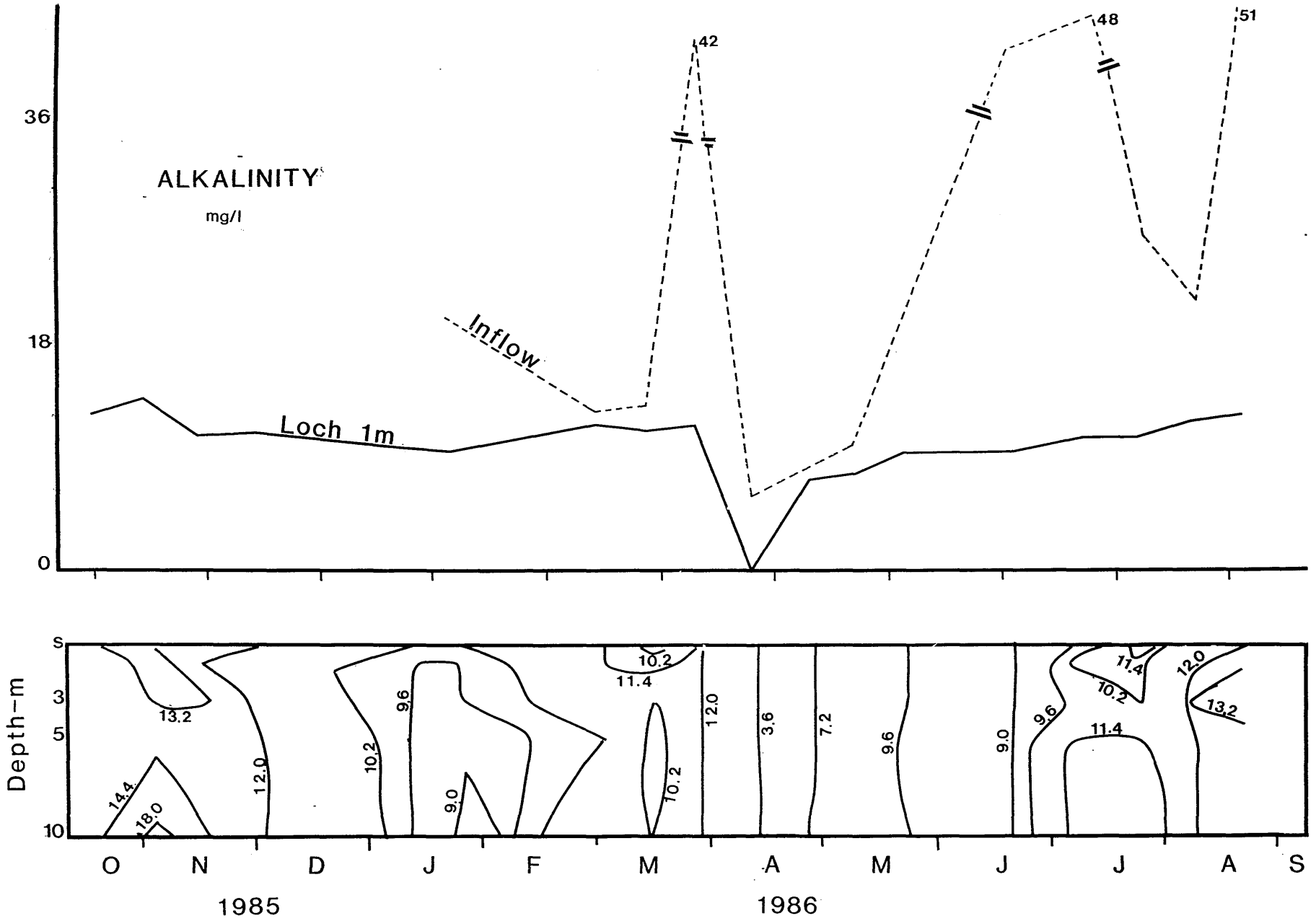
5. ALKALINITY

The maximum alkalinity measured in Loch Rusky was 18.6mg HCO_3/l at the bottom in November. The minimimum of 3mg HCO_3/l occurred during April (Fig.7) The seasonal variation in alkalinity decreased from an autumn maximum of around 13.8mg/l to lower winter values of 9.6mg HCO_3/l during January and February. From February to the beginning of April, values first increased to 12mg HCO_3/l, and later dropped steeply by the end of the month. There is some doubt about the recording of this alkalinity date. This was followed by a gradual increase in concentration.

The alkalinity depth distribution had two seasons with apparently higher values at the bottom: in November and in July and August during the period of stagnation. During winter, levels at the surface were higher than at other depths. Alkalinity differences with depth tended to reduce in March and from April to july uniform distribution was established.

After the period of stratification in summer, alkalinity increased throughout all depths. From the end of August to September a slightly larger concentration of

Figure 7: Seasonal changes in alkalinity in the Loch at the 1m from October 1985 to September 1986 and in the main inflow from February to September 1986. Isopleths of alkalinity expressed in mg/l.


ALKALINITY
mg/l
36
18
0
Inflow
Loch 1m
42
48
51
Depth-m
S
3
5
10
13.2
14.4
18.0
12.0
10.2
9.6
9.0
10.2
11.4
10.2
12.0
3.6
7.2
9.6
9.0
9.6
11.4
10.2
11.4
12.0
13.2
O
N
D
J
F
M
A
M
J
J
A
S
1985
1986

values was registerd between 1 and 5m. This gradient was reversed for October and November.

In the Letter Burn, alkalinity ranged between 6 and 52.2mg HCO_3/l. Its values were clearly higher than those of the loch itself, and wild flunctuations were seen during the year. Values in the stream were at a maximum during summer and beginning of autumn. A pronounced peak was also registered in early April before a minimum occurred later in the same month. This showed the same pattern as in the loch.

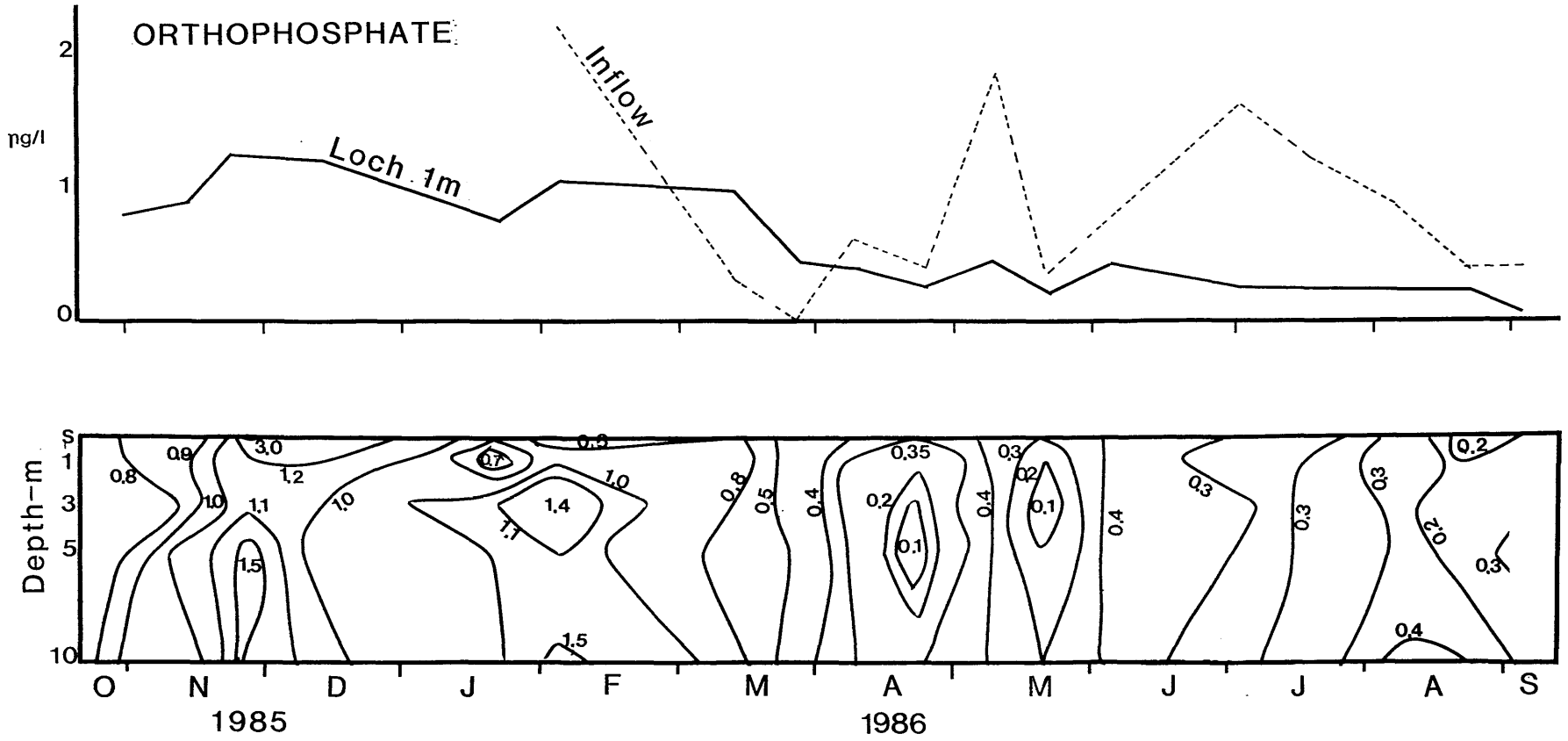
Maulood in his study in 1972-73 recorded similar alkalinity average values, but the seasonal levels pattern differed, recording higher seasonal levels during spring and summer.

6. ORTHOPHOSPHATE

The phosphate concentration in Loch Rusky during 1985/86 ranged between 3.75 and 0.1 μgPO_4-P/l. Peak values occurred in November and December with a steady decline to a minimum concentration in summer (Fig 8).

In late November the annual maximum of 3.75

Figure 8: Seasonal changes in orthophosphate in Loch Rusky at the 1m from October 1985 to September 1986 and in the main inflow from February 1986. Isopleths of orthophosphate expressed as µg/l.


ORTHOPHOSPHATE
µg/l
2
1
0
Inflow
Loch 1m
Depth-m
S
1
3
5
10
0.9
3.0
0.8
1.2
1.0
1.1
1.0
1.5
0.7
0.9
1.0
1.4
1.1
1.5
0.8
0.5
0.4
0.35
0.2
0.1
0.4
0.3
0.2
0.1
0.4
0.3
0.3
0.3
0.2
0.3
0.4
O
N
D
J
F
M
A
M
J
J
A
S
1985
1986

μgPO_4-P/l was recorded at the surface. At this time and to the end of December phosphate levels were higher at the top and bottom of the water column. Phosphate concentration at the surface declined during January and February, although was maintained in the deep waters. Throughout March and until the beginning of April phosphate tended to be uniform with depth, but there was a rapid decline of values at the end of March coinciding with the spring algal bloom, with concentrations reducing from 0.8 to 0.4μgPO_4-P/l.

This uniformity of concentration with depth disappeared in April and May when dissolved phosphate levels at the surface and bottom were higher than in the region between 1 and 5m. By the end of May the concentration was only 0.1μgPO_4-P/l.

Peak phosphate loading from the main inflow was in early May and this supply could explain the restoration of nutrient levels at this time in the loch. A similar trend was followed at the beginning of June.

During summer phosphate levels decreased from surface to bottom. In August, phosphate levels in the epilimnion fell to 0.1μgPO_4-P/l, but in the hypolimnion recovered to 0.4μgPO_4-P/l, presumably due to recycling between the sediment and water.

Mixing conditions in September restored uniform relatively high phosphate levels for autumn. The concentration of this nutrient increased steadily reaching a maximum in November and December.

The seasonal variation of phosphate levels in the Letter Burn ranged between 2.15µgPO_4-P/l in February to traces in March, and showed three irregular peaks(fig. 8). The maximumm in winter at about 2.5µgPO_4-P/l was followed by a steep drop by the end of March and two increases to around the maximum values at the beginning of May and again in July. The summer period was thus marked by higher values than in the loch itself, presumably influenced by the low inflow rate.

The seasonal phosphate pattern shown by Maulood (1972-73) was similar to that described above. The levels in the loch ranged between 18.3 and 3.1µgPO_4-P/l, being clearly greater than those shown in this study. The two studies used different methods to measure phosphate and this, together with unknown differences in fertilization practice in the catchment (see page 83), could account for the discrepancy.

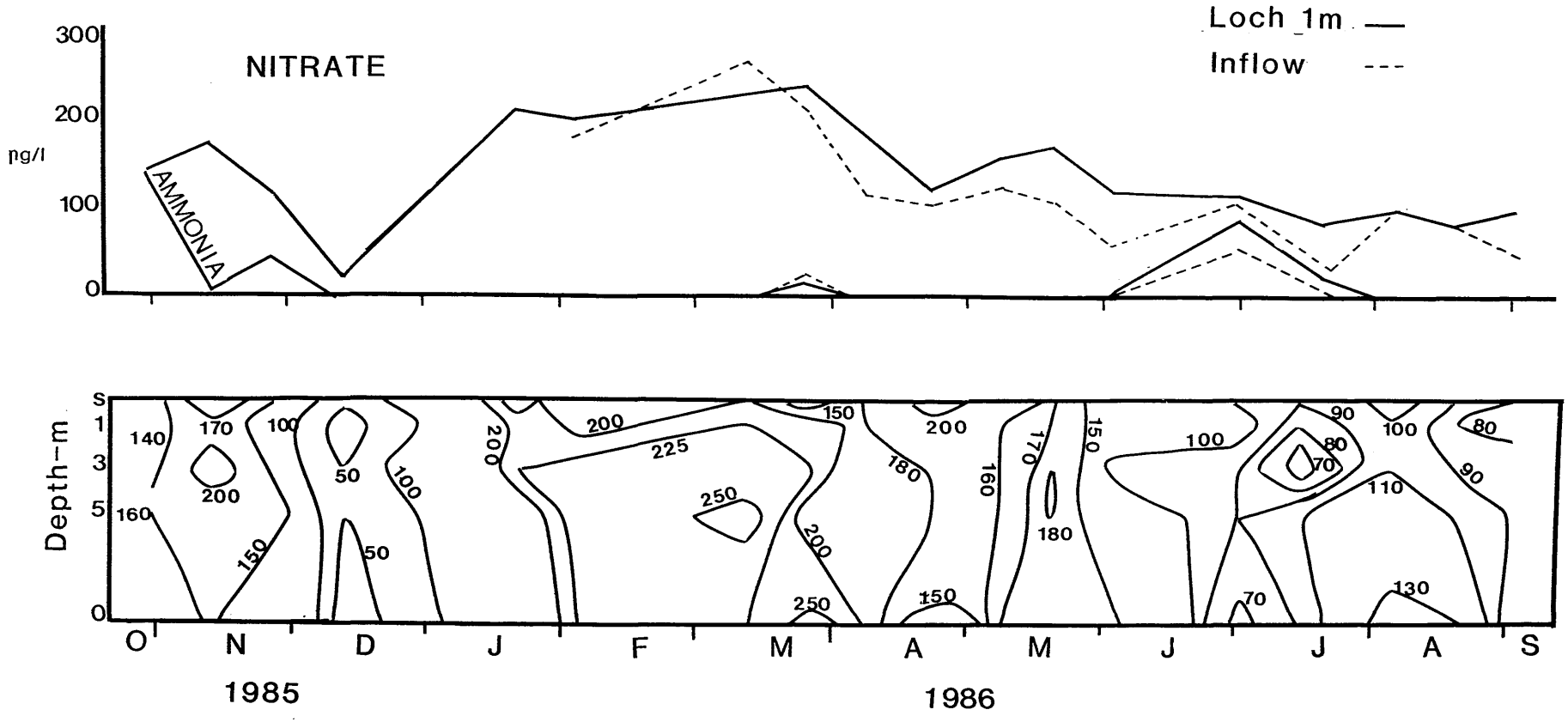
7. NITRATE

The observed nitrate concentration in Loch Rusky ranged from 265 to 15μgNO_3-N/l (Fig.9). The annual variation showed greater levels for autumn and winter with lower values in spring and summmer. The maximum value of 265μgNO_3-N/l was found on 12 March at 5m and minimum (15μgNO_3-N/l) on 12 December at 1m. The nitrate curve showed two points of steep concentration drop; one in early December when the lowest content of this nutrient was registered and the second in July in the epilimnion. In January the nitrate level was slightly higher in the top 3m than the bottom, but from February to the middle of March greater values (225 to 265ugNO_3-N/l) were concentrated between 1 and 5m, whereas at the surface values were below 200ug/l.

From March until October there was a general decline in nitrate concentration. Nitrate values during spring and until the middle of June were uniform throughout the water column except in April when observed values dropped to 125μgNO_3-N/l.

On 3rd June the maximum phytoplankton biomass was at 3m coinciding with a low nitrate concentration (80μgNO_3-N/l). By the end of June and beginning of July a

Figure 9: Seasonal changes in nitrate and ammonia in the loch at the 1m from October 1985 to September 1986 and in the main inflow from February to september 1986. Isopleths of nitrate expressed as µg/l.


Loch 1m
Inflow
NITRATE
AMMONIA
300
200
100
0
µg/l
Depth-m
S
1
3
5
0
140
170
100
200
160
150
50
50
100
200
200
225
250
150
200
250
180
160
200
170
180
150
100
90
80
70
100
80
110
90
70
130
O
N
D
J
F
M
A
M
J
J
A
S
1985
1986

gradient became established with a higher nitrate content at the surface than in deeper waters.

Summer stratification reversed this gradient and the hypolimnetic water reached 100 to 145μgNO_3-N/l against 65 to 90μgNO_3-N/l in the epilimnion.

As with phosphate, mixing conditions in September restored a uniform pattern throughout the depth of the water column, with general values rising through October and November. In October the highest nitrate concentration was found in the bottom 5m of the water column but in November it lay between 1 and 5m.

The annual minimum value was reached in mid December, followed by a gradual rise in nitrate levels until late March. This is the period when the water contained the highest nitrate levels.

There was a close correlation between the pattern of nitrate concentration in Loch Rusky and the Letter Burn (Fig. 9). The range of values for the burn was between 265 and 35μgNO_3-N/l.

Maulood's study for nitrate pattern agreed in general with the present study. In that study the loch registered

only one annual nitrate downturn, in summer. The nitrate range was between 291 and 46µgNO_3-N/l.

8. AMMONIA

The level of ammonia in Loch Rusky was almost undetectable (below 10µgNH_4-N/l) during the year under study (Fig. 9). The generally well oxygenated water conditions in the loch meant that inorganic nitrogen would exist mainly in the oxidised form viz: nitrate.

October with 128µg NH_4-N/l average value at all depths and July with 96µg NH_4-N/l were the two peaks in the seasonal pattern. In July nitrate and ammonia in both the loch and the main inflow reached similar values. The Letter Burn (fig. 9) showed the same ammonia trend described for the loch itself.

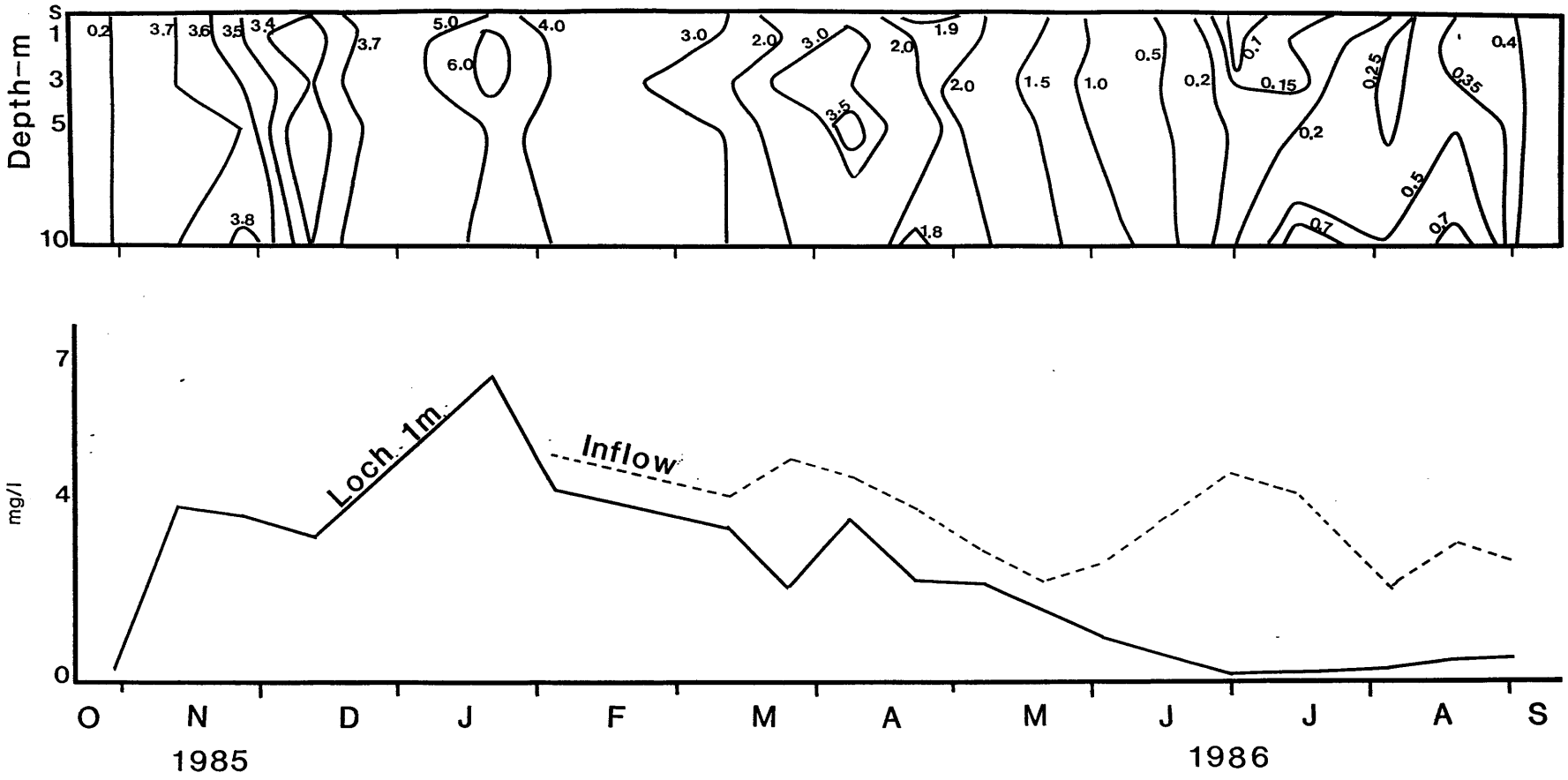
Maulood did not carry out evaluation of this nutrient in his study.

9. SILICATE

The general pattern of seasonal variation of silicate in Loch Rusky (Fig.10) distinguished a winter maximum and

Figure 10: Seasonal changes in silicate in the Loch at the 1m from October 1985 to September 1986 and in the main inflow from February to September 1986. Isopleths of silicate expressed in mg/l.

SILICATE


Depth-m
S
1
3
5
10
0.2
3.7
3.6
3.5
3.4
3.8
3.7
5.0
6.0
4.0
3.0
2.0
3.0
3.5
2.0
1.9
2.0
1.8
1.5
1.0
0.5
0.2
0.7
0.15
0.2
0.25
0.5
0.7
0.35
0.7
0.4
mg/l
7
4
0
Loch 1m
Inflow
O
N
D
J
F
M
A
M
J
J
A
S
1985
1986

marked a summer minimum when this nutrient was reduced to trace levels. This was similar to the phosphate and nitrogen patterns described earlier, particularly with nitrate. The maximum ($6.72 mg SiO_3-S/l$) recorded in January and the minimum ($0.08 mg SiO_3-S/l$) in July.

There were four periods of variation with depth evident throughout the year. January registered the peak values with higher silicate levels between 1 and 3m than at other depths. From then until September a gradual decline was apparent. During February and March surface values were higher than at the bottom, and there was a consistent depletion at 3m which persisted until May. From the end of March to June there seems to be a negative correlation between distribution of silicate with depth and phytoplankton biomass, which was primarily dominated by Diatoms. In late April were registered lower levels of silicate at the surface and at the bottom. This trend was also shown by Nitrate.

During May and June, silicate levels tended to be uniform with depth.

Silicate concentrations became a minimum in the top 3m during July. The values in deep water gradually increased from the beginning of July to the end of August.

Uniform values in September were followed by a slight decrease in October. November registered a rapid rise in concentration during the first two weeks which after a pause of two weeks continued from the beginning of December until the end of January. In December 1m and 5m showed lower values.

The Letter Burn showed two seasonal peaks, in both winter and summer. Its silicate content ranged between 4.92 and 2.06mgSiO_3-S/l and was generally higher than in the loch itself. This pattern in the main inflow was expected because of the silicate richness of the rocks in the catchment. The nutrient loading in the Letter Burn seems to be related to the weather conditions and thus its variations in flow rate. High rainfall lead to increased nutrient input to the loch and conversely low flow is associated with reduced input.

The seasonal pattern for silicate was similar to that described in Maulood's study. The silicate range in the latter was between 3.32 and 0.1mgSiO_3-S/l, a slightly higher minimum and half the levels in the maximum, compared with the present study.

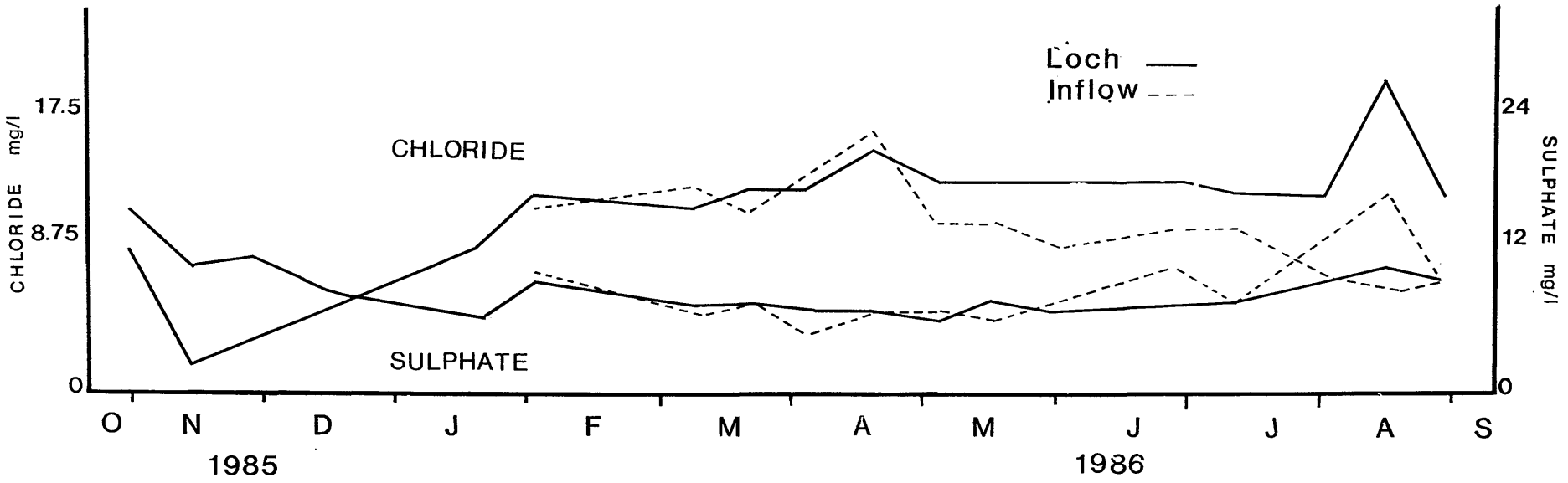
10. STRONG ACID SALTS: SULPHATE AND CHLORIDE

The chloride ion concentration changed during the year in a generally opposite way from that observed for the micronutrients (Figure. 11). The lowest values were registered in autumn, with the minimum being 5.25 mgCl/l in November. These were followed by a gradual increase during winter to reach 14.7mgCl/l by the beginning of February. This concentration increased slightly during spring to 17.5mgCl/l and from the end of April to August remained constant at 15.75mgCl/l. After a steep increase to the maximum of 0.6mgCl/l by the middle of August, chloride declined to the summer value by September and continued to fall to the minimum level in autumn.

The range of chloride in the stream was between 18.69 and 10.08 mgCl/l. Concentration in the Letter Burn was closely correlated with the levels in the loch until the end of April, although May to July were more or less constant but lower, and it showed a minimum in August instead of the increase registered in the loch.

Sulphate results were calculated jointly with nitrate as was described in the materials and methods. For the whole period the proportion of nitrate represented less than 10% of the sulphate.

Figure 11: Seasonal changes in sulphate and chloride in the loch at the 1m from October 1985 to September 1986 and in the inflow from February to September 1986. Sulphate and chloride expressed in mg/l.


Loch
Inflow
CHLORIDE
SULPHATE
CHLORIDE mg/l
SULPHATE mg/l
17.5
8.75
0
24
12
0
O
N
D
J
F
M
A
M
J
J
A
S
1985
1986

Sulphate showed generally lower values than chloride (Fig. 11) in the loch except in autumn. The highest levels at 19.2mgSO_4/l were registered in October, and showed a continuous decline from then until the end of January. Levels in spring remained approximately the same as in winter with a constant value of 12.0mgSO_4/l, and the only increase took place in August when values reached 15.36mgSO_4/l.

There was shown to be little variation of chloride and sulphate concentration with depth during the year under study. (See appendix II, page 114).

The range of concentrations in the main inflow was between 10.56 and 20.74mgSO_4/l. It showed a much more pronounced summer increase than in the loch starting in early June. The curve was more or less constant, with larger values in autumn and at the end of August. The rest of the curve followed that for the loch itself.

Maulood did not analyse chloride and sulphate.

11. C.O.D.

Dissolved organic matter can be an approximate measure of the allochthonous material received into the loch. The variation in C.O.D. within Loch Rusky followed a cyclical pattern with a peak level of 18.86mgO_2/l in November. There was a gradual decline until August, where was reached the minimum of 7.63mgO_2/l (Fig. 12).

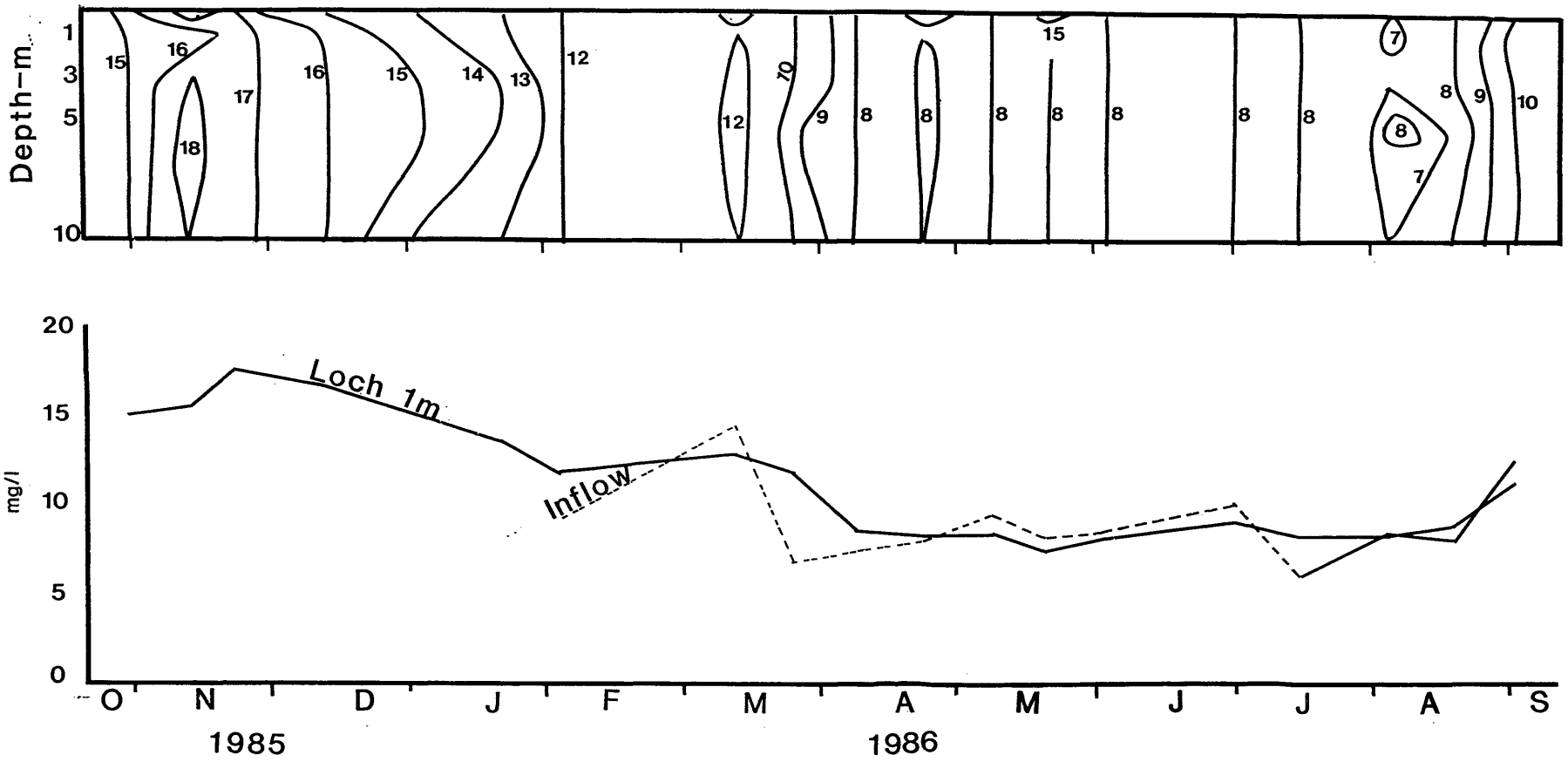
Autumn was the wettest season with the greatest supply of dissolved matter input into the loch. During November slightly decreased levels at 16mgO_2/l were recorded at 1m, with values of 18mgO_2/l throughout the rest of the water column. From this autumn peak values fell gradually during winter to 14-13mgO_2/l and remained at 8mgO_2/l from April to July. August showed values about 7mgO_2/l at the surface and 3m. From the end of August levels were increasing until 10mgO_2/l in September and 15mgO_2/l in October.

The Letter Burn did not show seasonal differences from the loch itself over the period it was sampled.

Maulood did not analyse C.O.D.

Figure 12: Seasonal changes in total dissolved organic matter (COD) in the loch at the 1m from October 1985 to September 1986 and in the main inflow from February to September 1986. Isopleths of dissolved organic matter expressed as mg/l.

C.O.D


Depth-m
1
3
5
10
15
16
17
18
16
15
14
13
12
12
10
9
8
8
8
8
15
8
8
8
7
8
7
8
9
10
20
15
10
5
0
mg/l
Loch 1m
Inflow
O
N
D
J
F
M
A
M
J
J
A
S
1985
1986

3. Results

3. 2. PHYTOPLANKTON COMMUNITY

SEASONAL CHANGES IN ALGAL BIOMASS: chlorophyll *a* and total numbers of individuals.

Chlorophylla *a* and total number of cells have been used as indices of total algal biomass. The seasonal pattern is plotted in figures 13 and 14.

The low total biomass (7 x 10^3 individuals/l) for winter increased rapidly during the last part of March to high values (16 x 10^4 ind/l) at the beginning of April when the first spring peak took place. This increase was followed by a rapid drop in numbers at the end of this month to 2 x 10^4 ind/l and by a second more attenuated peak in May. This algal stock was greatly concentrated at the surface and in the bottom 5m of the water column.

June recorded the second spring peak and the population was evenly distributed in approximately equal numbers (15 x 10^4 ind/l) at all depths. During spring the algal population was totally dominated by diatoms and the total Chlorophyll *a* content closely followed the phytoplankton

Figure 13: Seasonal changes in phytoplankton biomass at the surface 1, 3, 5 and 10m from October 1985 to September 1986. Biomass expressed as number of individuals or colonies per litre.

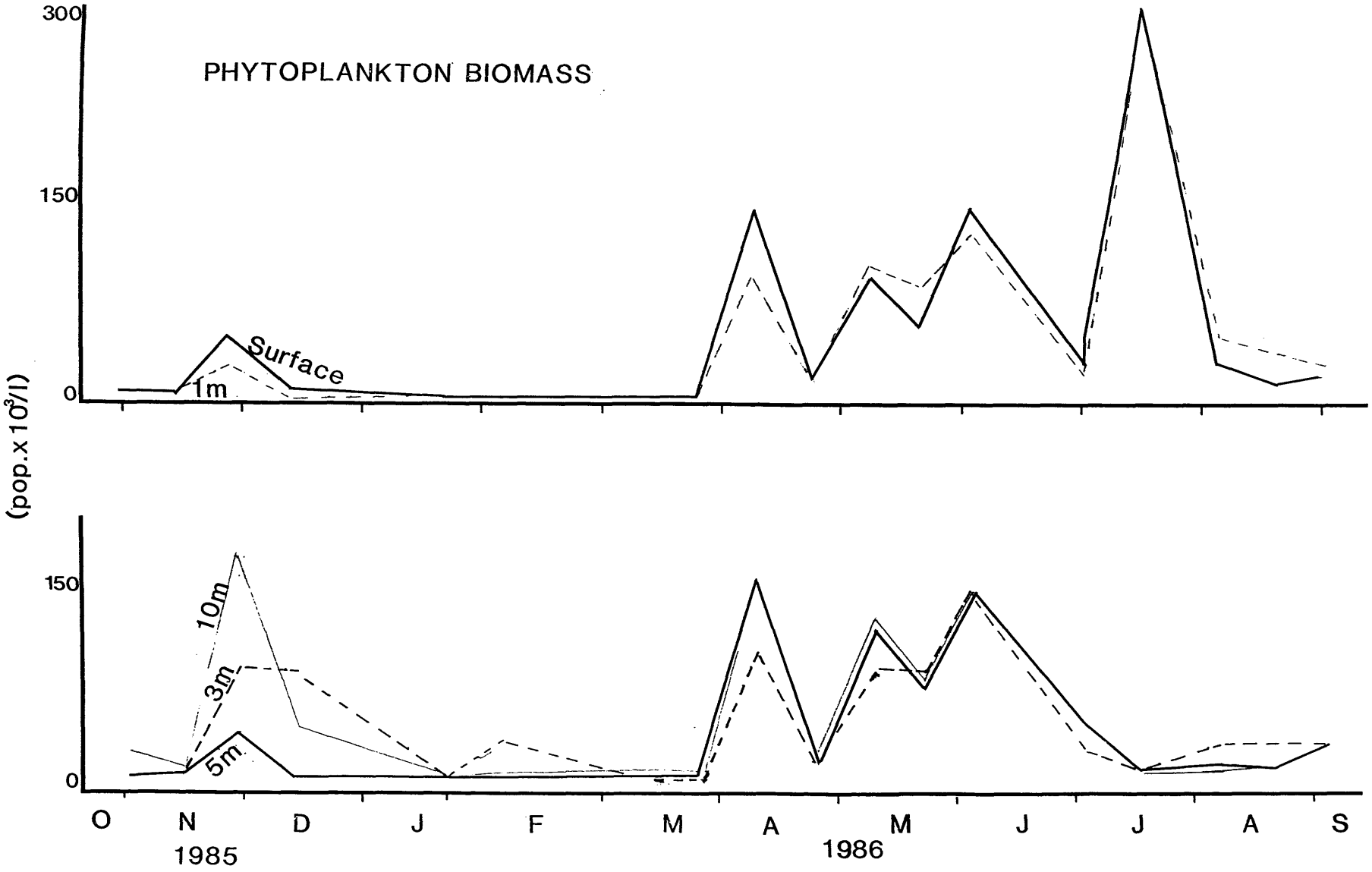
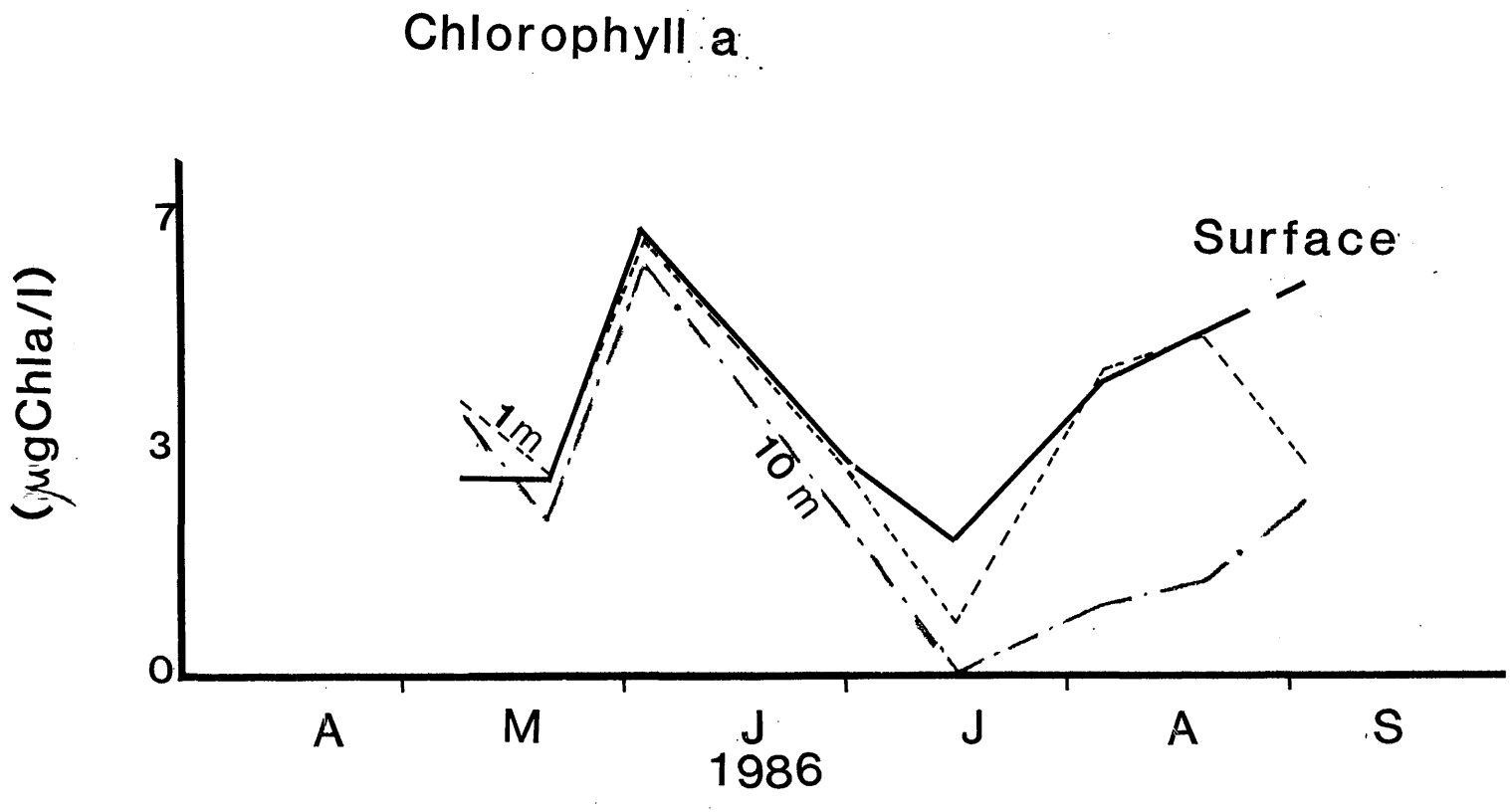

PHYTOPLANKTON BIOMASS
300
150
0
(pop.x 10³/l)
Surface
1m
150
0
10m
3m
5m
O
N
D
J
F
M
A
M
J
J
A
S
1985
1986

Figure 14: Seasonal changes in Chlorophyll a at the surface 1m and 10m from May to September 1986 expressed in µg/l.


Chlorophyll a
(µgChla/l)
7
3
0
Surface
1m
10 m
A
M
J
J
A
S
1986

counts, ranging between 2 and 6 mg/l from May to June.

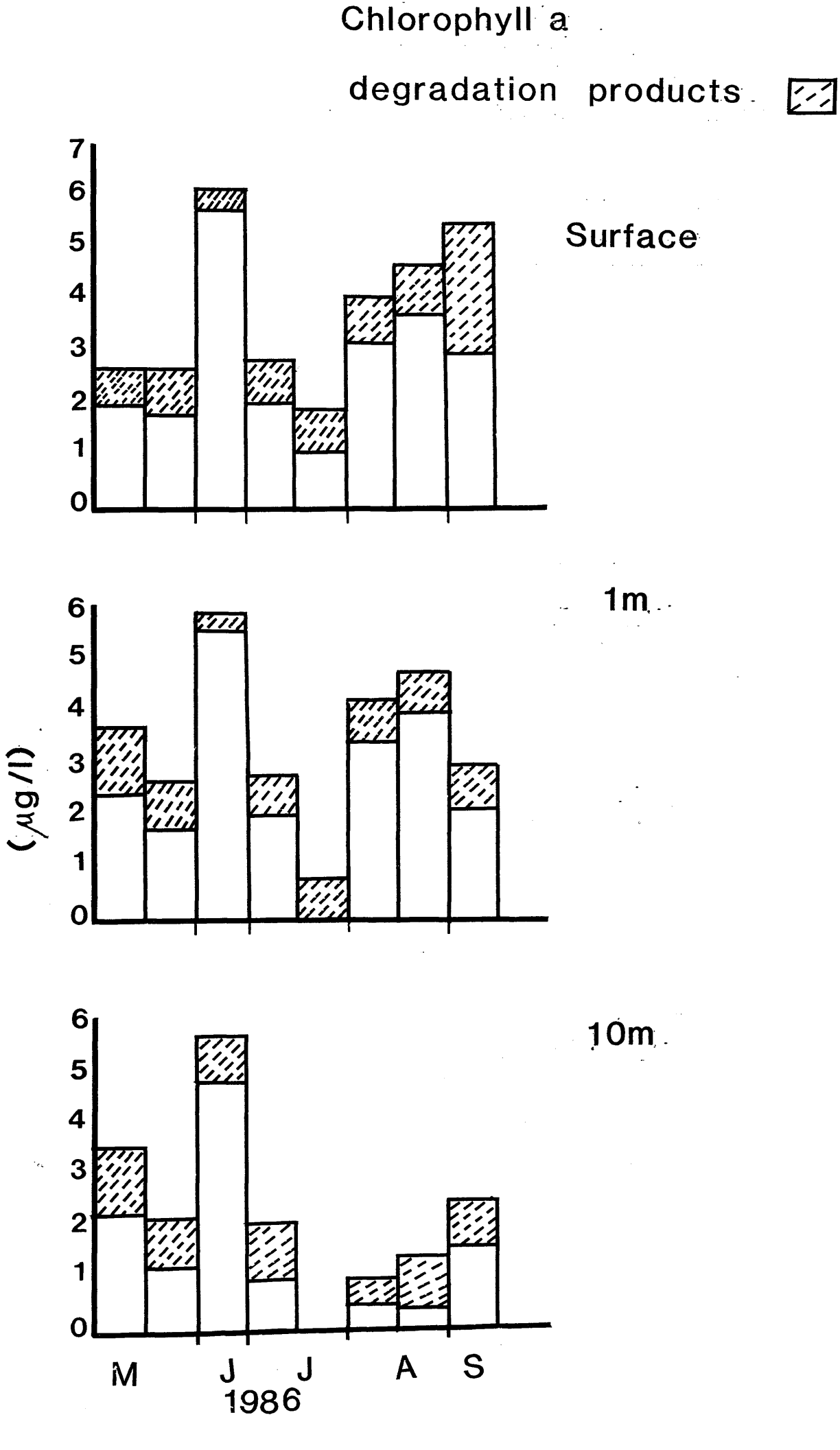
By the middle of July the algal population reached the maximum annual density of 3.10^5 ind/l in the upper 1m. Two weeks later this value declined to 3.10^4 ind/l showing a small increase throughout the summer to lead to a late autumn peak of 18.10^4 ind/l maximum biomass at the 10m in November.

The total chlorophyll a values encountered for the summer are apparantly in discrepancy with those observed by standing crop. The July biomass peak coincided with a drop of chlorophyll a concentration at all depths. During August and September, the chlorophyll levels showed a more pronounced increase in values than described for the total numbers of individuals at the same time.

The proportion of chlorophyll degradation products is shown in (Fig. 15) and remained more or less constant throughout the period under study. A slightly higher proportion of degradation products was always measured in the the deep water than at other dpeths.

The seasonal phytoplankton biomass results described by Maulood in 1972-73, followed a similar pattern to that shown in this study although he reported larger populations.

Figure 15: Vertical distribution of Chlorophyll a and degradation products from May to September 1986 expressed in µg/l.


Chlorophyll a
degradation products
Surface
1m
10m
(µg/l)
0
1
2
3
4
5
6
7
M
J
J
A
S
1986

SEASONAL CHANGES OF THE MAJOR PHYTOPLANKTON GROUPS

The seasonal succession of main phytoplankton groups recorded in Loch Rusky from October 1985 to September 1986 is shown in Fig. 16.

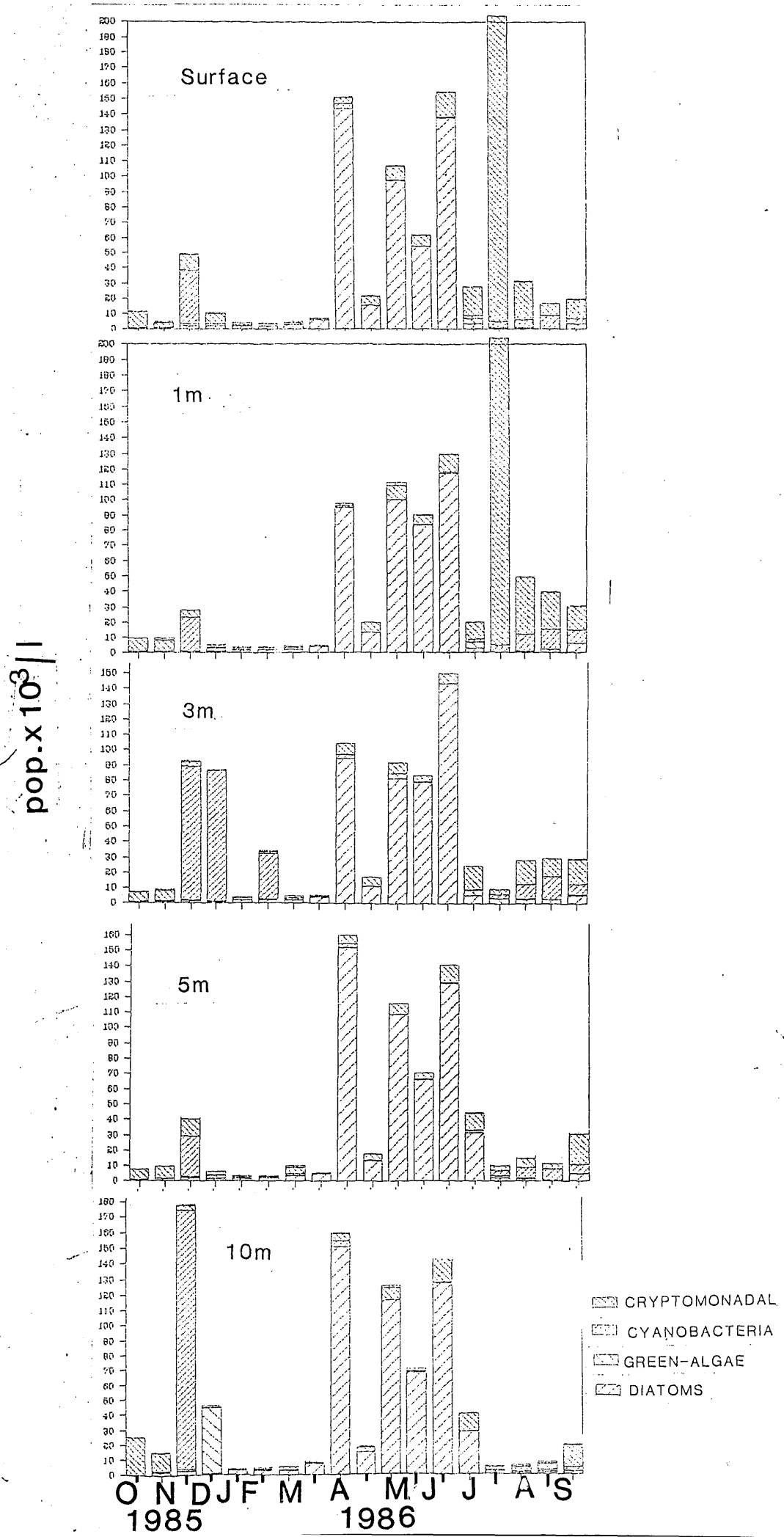
Diatoms were the most abundant and diverse phytoplankton group in this study. They were present throughout the year and clearly dominated the plankton community from March to June. The minimum representation of this group occurred during mid summer and the autumn overturn.

The variety of Diatoms species decreased from autumn to summer with a maximum diversity in the early spring (i.e. 90% of total species identified at the end of March were diatoms). The vertical distribution of diatoms showed a general trend for larger populations to concentrate in the deeper water. This was most apparent in the summer stratification and less obvious under mixing water conditions.

Cryptophyceae (Rhodomonas minuta var. nannoplanctica Skuja. and Cryptomonas ovata Ehr.) and Cyanobacteria

Figure 16: Seasonal patterns of the major phytoplankton groups at the surface 1, 3, 5 and 10m from October 1985 to September 1986.

PHYTOPLANKTON GROUPS



replaced diatoms in the phytoplankton during the summer. Cryptophyceae were largely distributed in the epilimnion and attained a rapid "bloom" in numbers in mid-summer. This group was well represented in the rest of the seasons and dominant again in the community in the early autumn. The vertical distribution tended to be uniform under mixing water conditions.

Cyanobacteria were in this study, the third most important phytoplankton taxa. They were characteristic of the latter half of the year. Small gelatinous colonies of (Chrococcus dispersus (Keisse) Lemmer and Coelosphaerium Naegelianum Unger.) represented an important proportion of phytoplankton community during the summer in the middle depths. The autumn overturn population was mainly dominated by an unidentified Cyanobacteria (see table II). This algae was characterised by large numbers of small size round cells (2.5-5μ) organized in irregularly shaped colonies with blue-green cell pigments. It occurred at all depths was most abundant at the bottom. During the rest of the year Cyanobacteria were present in insignificant numbers.

Chlorophyceae were a minor component of the phytoplankton. In December a population consisting of filamentous forms (Stigeoclonium sp. and Oedogonium sp.

Table II. Species composition of the phytoplankton.

TABLE II

SPECIES COMPOSITION OF PHYTOPLANKTON

DIVISION CHRYSOPHYTA	OCCURR.	REL. ABUND
1. Class. BACILLARIOPHYCEAE		
Achnanthes lanceolata de Brebisson	-	-
Amphora ovalis Kutz.	+	-
Amphora veneta Kutz.	-	-
Asterionella formosa Hassal	+++	...
Cocconeis placentula Ehr.	.+	.
Cyclotella comta Kutz.	-	-
Cymbela sp.	-	-
Denticula tenuis Kutz.	-	-
Eunotia lunaris (Ehr.) Grun.	+	.
Eunotia pectinalis var. minor (Kutz.)Rabh.	++	.
Eunotia pectinalis var.rostrata (Kutz.)Rabh	.+	-
Fragilaria crotonensis Kitton	+	.
Fragilaria virescens Raffs.	-	-
Frustulia rhomboides (Ehr.) de Toni.	-	-
Gomphonema acuminatum var. coronata Ehr.	-	-
Gomphonema angustatum (kutz.) Rabh.	+	.
Melosira granulata (Ehr.) Raffs.	+	.
Melosira italica (subsp.)subarctica O.Mull.	+++	..
Navicula cuspidata Kutz.	-	-
Navicula cryptocephala Kutz.	+	.
Navicula flagilarioides Krasske.	-	.
Navicula subtilissima Cleve	-	-
Navicula sp.	-	-
Nitzschia linearis W. Smith	-	-
Pinnularia gibba Ehr.	-	-
Pinnularia microstauron (Ehr.) Cleve	-	-
Stephanodiscus sp.	-	-
Surirella elegans Ehr.	-	.
Synedra acus Kutz.	++	.
Synedra affinis (Ag.) Kutz.	-	-
Synedra ulna (Nitzche) Ehr.	-	-
Tabellaria fenestrata (Lygnb) Kutz.	++	.
Tabellaria flocculosa (Roth) Kutz.	++	.

	OCCUR.	REL ABUND.
2. CLASS CHRYSOPHYCEAE		
Dinobryon divergens Imhof.	-	.
Mallomonas caudata Imhof.	-	.
Mallomonas urnaformis Prescott.	-	-
3. CLASS XANTHOPHYCEAE		
Tribonema bombycinum (Rerbes) Solier	-	-
DIVISION CHLOROPHYTA		
1. CLASS CHLOROPHYCEAE		
Ankistrodesmus falcatus (Corda) Raffs.	-	-
Chlamydomonas sp.	+	-
Coelastrum microporum Naegeli.	+	.
Dictyosphaerium pulchellum Wood	-	-
Elakatothrix gelatinosa Wille.	+	.
Oedogonium sp.1.	-	-
Oedogonium sp.2.	-	-
Oocystis crassa Wittrock	-	-
Phaerocystis Schroeteri Chodat.	-	-
Quadrigula closterioides (Bohlin) Printz.	-	.
Scenedesmus bijuga (turp.) Lagerheim.	-	-
Stigeoclonium sp.	-	..
2. CLASS ZYGNEMAPHYCEAE		
ORDER ZYGNEMATALES		
Netrium digitus (Ehr.) Itz-Roth.	-	-

	OCCUR.	R. ABUND.
ORDER DESMIDIALES		
Closterium acutum Breb.	-	-
Closterium dianae Ehr.	-	-
Closterium toxon W. West.	-	-
Cosmarium praemorsum Breb.	-	-
Cosmarium punctulatum Breb.	-	-
Gonatozygen monotaenium De Bary	-	-
Micrasterias rotata (grev.) Raffs.	-	-
Pleurotaenium coronatum (breb.) Rabenh.	-	-
Staurastrum grande Bulnh.	-	-
Staurastrum pingue Teiling	-	-
Xanthidium antilopeum (Breb) Kutz.	-	-
DIVISION EUGLENOPHYTA		
CLASS EUGLENOPHYCEAE		
Euglena sp.	-	-
Phacus sp.	-	-
DIVISION RHODOPHYTA		
CLASS RHODOPHYCEAE		
Porphyridium cruentum Naegeli.	-	-
Asterocystis smaragdina (Reinsch) Forti.	-	-
DIVISION CRYPTOPHYTA		
ORDER CRYPTOMONADALES		
Rhodomonas minuta var.nannoplanctonica Skuja.	++	...
Cryptomonas ovata Ehr.	+++	...

	OCCUR.	REL.ABUND.
CLASS DINOPHYCEAE		
Ceratium hirundirella (Muell.) Dujardin	-	--
DIVISION CYANOBACTERIA		
Anabaena flos-aquae (Lyngb.)De Brebisson	-	--
Aphanothece nidulans Richter	-	--
Botryococcus braunii Kutz.	-	.
Chroccoccus dispersus (Keissl.) Lemmer	++	..
Chroccoccus Prescottii Drouet	-	--
Coelosphaerium Naegelianium Unger	+++	.
Gloeocapsa aeruginosa (Carm.) Kutz.	-	--
Lyngbya sp.	-	--
Merismopedia elegans Var.major Smith	-	--
Microcystis aeruginosa Kutz.	-	--
Oscillatoria tenuis (Agardh) De cades	-	--
Phormidium tenue (Menegh.) Gomont	-	--
Spirulina Nordstedtii Gomont	-	--
Synechococcus aeruginosus Naegeli	-	--
Blue-green algae bacteria (unidentified)	-	...
UNCLASSIFIED		
Protozoa 1	+++	.
Protozoa 2	+	.

OCCURRENCE :		REL. ABUNDANCE :	
[100 - 75%]	+++	[50 - 10]	...
] 75 - 50%]	++	]10 - 1%]	..
] 50 - 25%]	+	] 1 -0.1%]	.
under 25%	-	under 0.1%	--

reached some importance in the bottom 5m and Coelastrum microporun Naegeli was present in the epilimnion in July.

Desmids were an insignificant component of the of chlorophyceae.

Other less abundant phytoplankton groups were Chrysophyceae represented by Mallomonas in mid-spring and Dinobryon divergens Imhof. in late summer; Dinophyceae occurred in summer with only one species Ceratium hirundirella (Muell.) Dujardin and Euglenophyceae (Phacus sp.) in spring, both never reached significant high biomass (see Table. II).

PHYTOPLANKTON SPECIES

A total of 86 different algal species was recognized in this study (Table II). The most important component of the phytoplankton was the Diatoms. They showed also the greatest species variety, (33 species identified), however Cryptophyceae had the maximum in seasonal abundance. Cyanobacteria were usually represented at times of low biomass population mainly by colonial species with high cell numbers. The Chlorophyta was infrequently present in the phytoplankton and never reached siginificant levels of abundance.

From the total number identified only eight algal species were recorded frequently enough to permit an examination of individual seasonal and vertical pattern.

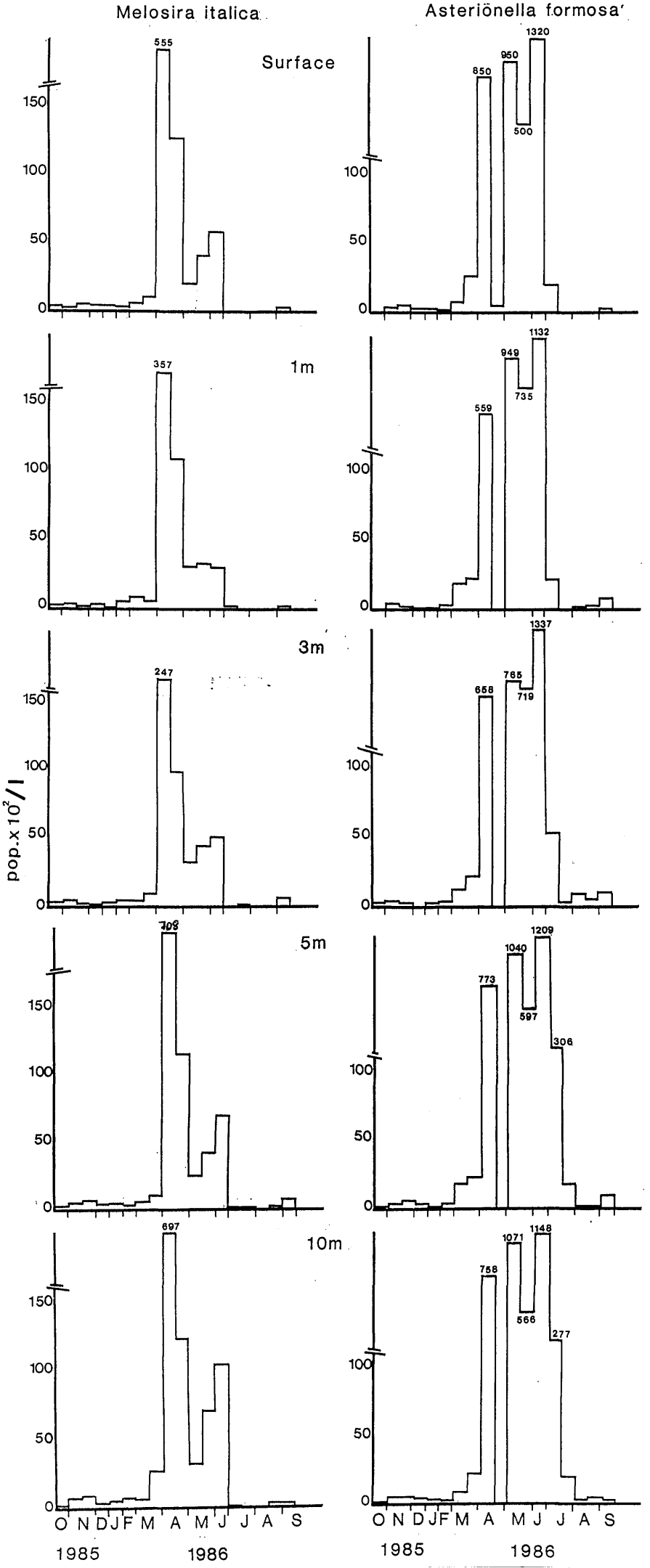
Diatoms

Asterionella formosa

Asterionella formosa was the most frequent (90% occurrence) and abundant (42% rel. abundance) diatom species of the phytoplankton in Loch Rusky (Table II). The seasonal pattern showed a large peak from March to June when the maximum population levels (13 x 10^4 ind/l) were reached, except in late April when the species was completely absent (Figure 17). A. formosa was more abundant in the bottom 5m in the early spring whereas through June it was distributed evenly with depth. In July, when thermal stratification was well defined, Asterionella formosa was almost entirely restricted to the hypolimnion, and practically disappeared during August.

A second very small increase (1 x 10^3 ind/l) at all depths occurred in September at about the time of overturn. There was no apparent late autumn peak of this species. Population numbers remained low and uniform during autumn and then dropped to winter levels. No vertical differences

Figure 17: Seasonal patterns of *Asterionella formosa* and *Melosira italica* at surface 1, 3, 5 and 10m from October 1985 to September 1986. Populations expressed as number of colonies per litre.


Melosira italica
Asterionella formosa
Surface
1m
3m
5m
10m
pop.x10²/l
555
850
950
500
1320
357
559
949
735
1132
247
658
765
719
1337
708
773
1040
597
1209
306
697
758
1071
566
1148
277
0
50
100
150
O N D J F M A M J J A S
1985
1986

in distribution were found during autumn and winter.

The cell number per colony in this study was shown to be slightly higher in the colder seasons than in spring and summer, from an average of 8 cells/colony to 6 cells/colony. (Appendix VI, page 124).

A similar seasonal pattern to that found by Maulood in 1972-73 was shown.

Melosira italica

Melosira italica shared dominence with Asterionella formosa among the diatoms in the phytoplankton in spring. Its frequency and abundance were 85% and 9% respectively (Table II). Its seasonal pattern (Figure 17), showed an apparent peak (7 x 10^4 ind/l) in the early spring. Population levels of Melosira were mainly in the bottom 5m, similar to A. formosa. The vertical distribution of M. italica showed slightly higher population density in that region for the whole year.

A second smaller spring peak (1 x 10^4 ind/l) of Melosira was registered in June but at this time its population was rather lower than A. formosa. The

alternative pulses of the two species reflect different responses to changes in water conditions. M. italica was absent during the summer, until circulation of water is re-established by September. Nevertheless in September, the increase in population was very small. As with A. formosa, there was not a clear late autumn peak and the population remained at uniform low levels during autumn and winter. Of the diatoms, M. italica was the most important in the phytoplankton community during these two seasons.

Its number of cells per colony was as A. formosa larger in the colder seasons than in summer from an average of 18 to 14 cells / colony (Appendix VI, page 124). For these two species and Tabellaria fenestrata, a particular large number in cells per colony was reported after restoring water mixing conditions in September.

Maulood reported a similar seasonal pattern of this species in 1972-73.

Tabellaria fenestrata

This was a less abundant species in the phytoplankton 0.3%, but its frequence reached 72% (Table II). It was mainly distributed during autumn and winter (figure 18) with

Figure 18: Seasonal patterns of Tabellaria fenestrata Eunotia pectinalis and Synedra acus at the surface 1, 3, 5 and 10m from October 1985 to September 1986. Populations expressed as number of individuals or colonies per litre.

a small peak in April at all depths. The species occurred irregulary during summer, mostly present in the hypolimmon. At 10m the population size was more constant than at other depths throughout the year. There was a second peak (4 x 10^2 ind/l) in November after which population numbers remained low during winter.

The number of cells per colony was lower in the colder seasons, (5 cells/colony) than spring-summer (8 cell/colony) (Appendix VI, page 124).

Previous work on the Loch (Maulood 1972-73) showed a more or less similar seasonal pattern for this species with three peaks: one in late summer, a second in autumn and the third in the spring.

Tabellaria flocculosa

This species showed lower abundance (0.14%) and frequency (61%) than T. fenestrata in the phytoplankton. (Table II). The spring peak extended until June and lower density levels were remained in the hypolimnion throughout summer. The species was almost absent throughout the water column in the early autumn. This species reappeared in November and its population density remained more or less

constant towards winter. It was at its highest density and most constant occurence at the 10m depth, as with Tabellaria fenestrata and a nearly constant population at the surface. The number of cells per colony remained more or less constant (2 cell/colony) throughout all seasons (Appendix VI, page 124).

This species was not reported in Maulood's study.

Eunotia pectinalis var. minor

This species was mainly present in the phytoplankton from February to September and always less than 500 ind/l (Figure 18). E. pectinalis var. minor is considered to be an epyphitic diatom in origin which is washed into plankton by turbulence. It had a relative frequency and occurrence similar to T. fenestrata. Its seasonal pattern had no apparent seasonal peaks, although April and September registered higher density.

There were no seasonal differences in vertical distribution except during the summer stratification when this species was poorly represented in the surface waters as is to be expected due to its epyphitic origin.

This species was not identified by Maulood in 1972-73.

Synedra acus

This species was recorded with a frequency of 69% and an abundance of 0.4%, similar to Tabellaria fenestrata. Its seasonal pattern is shown in (Figure 18).

This species was mainly dominant from autumn to spring, showing a vertical distribution in the upper waters. The population levels increased from November to winter with a maximum peak of 1 x 10^3 ind/l in late spring. A difference in vertical distribution was registered during summer with a population of 2.5 x 10^2 ind/l occurring in the epilimnion during the early summer and a similar second recorded in the bottom 5m. This latter population is likely to correspond to Fragilaria crotonensis

This species was not reported in Maulood's study.

Cryptomonadales

Cryptomonas ovata

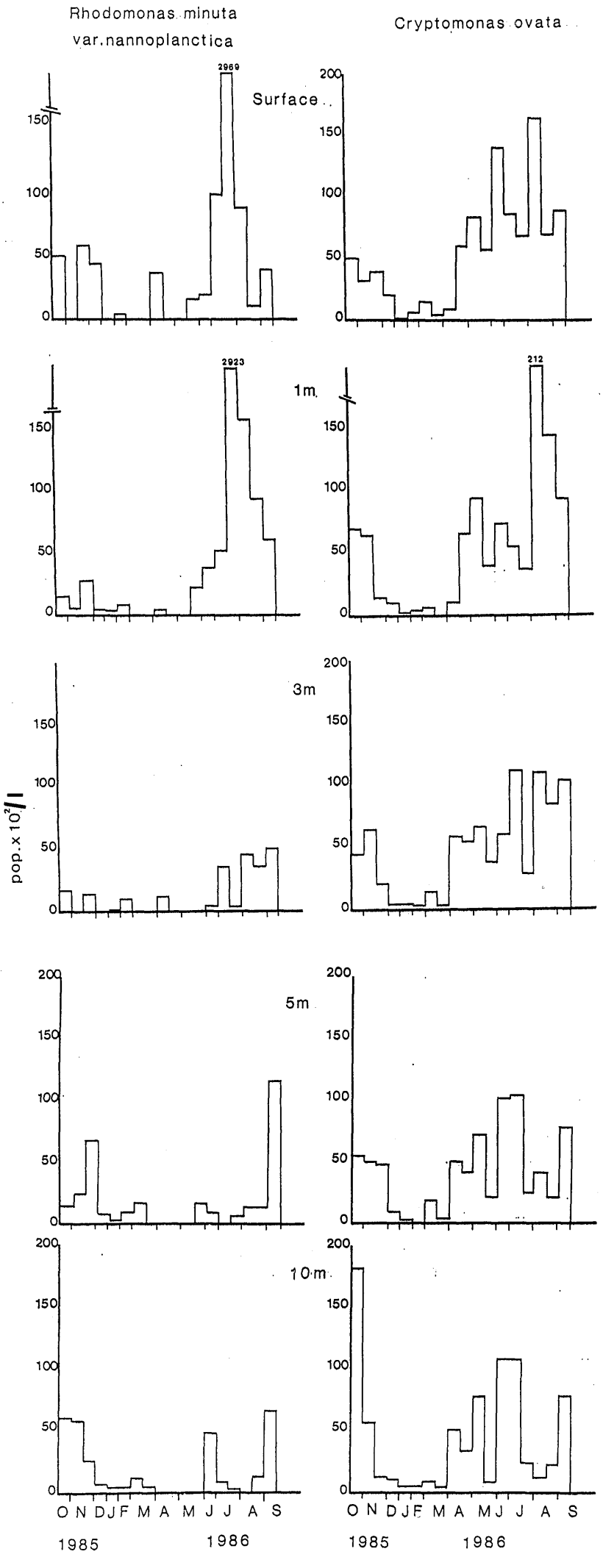
C. ovata was present through the whole duration of the study (Figure 19). Its frequency was 100% and 10% abundance in the phytoplankton.

The seasonal pattern showed an autumn, a spring and two summer peaks. The autumn population peak dropped to minimum winter levels. The spring registered a peak slightly higher than that in autumn and nearly confluent with the first summer peak in June.

Distribution was uniform with depth throughout the year except at the time of the late summer peak in August when C. ovata was mainly recorded from the upper 1m. In August, the phytoplankton biomass was mainly dominated by this species. September registered a more or less even distribution with depth and except the extraordinarily high level at the 10m in October, the autumn peak was the smallest.

C ovata was not recorded by Maulood, instead of this species, Peridinium, Ceratium and Fragilaria were registered

Figure 19: Seasonal patterns of Cryptomonas ovata and Rhodomonas minuta var. nannoplanctica at the surface 1, 3, 5 and 10m from October 1985 to September 1986. Populations expressed as number cells per litre.


Rhodomonas minuta
var.nannoplanctica
Cryptomonas ovata
Surface
1m
3m
5m
10m
2969
2923
212
pop.x 10²/l
0
50
100
150
200
O N D J F M A M J J A S
1985
1986

at the same summer months.

Rhodomonas minuta var. nannoplanctica

This species showed 17.5% in abundance and 74% frequency in the phytoplankton. The seasonal variation showed an autumn and larger mid summer peak (Figure 19).

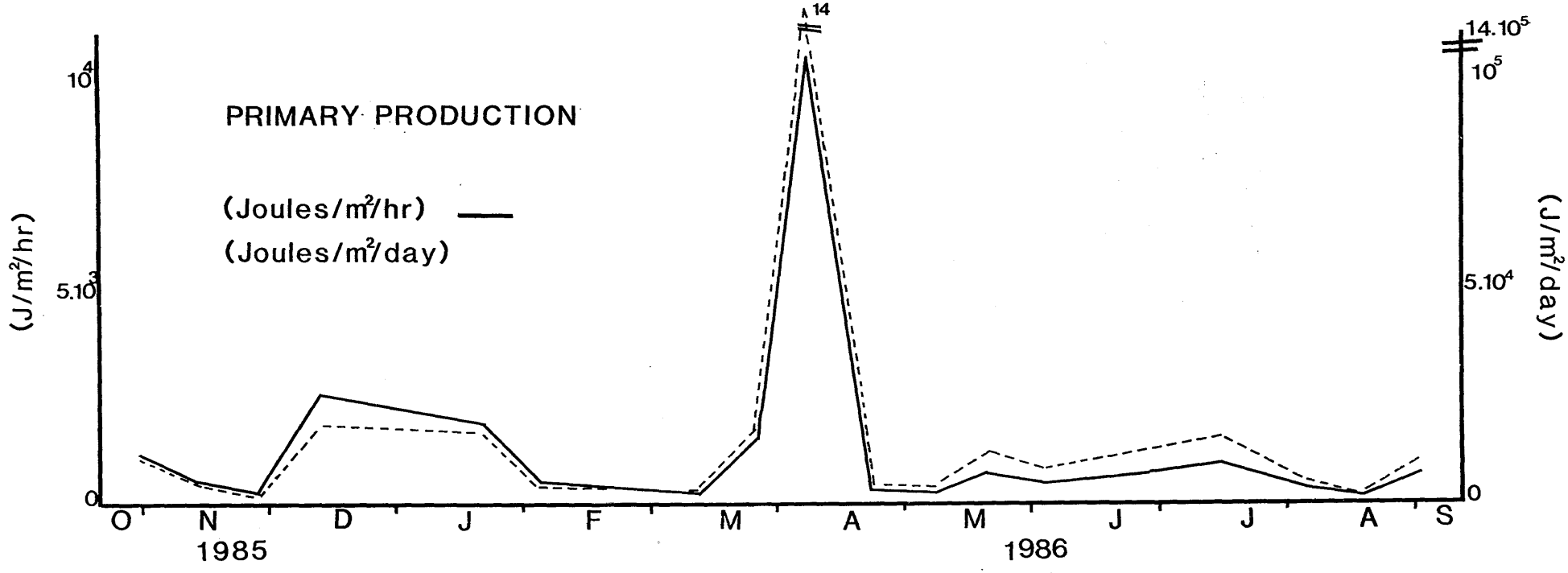
There was an apparent vertical stratification pattern of this specie, distributed in the epilimnetic region during the period of summer thermal stratification. The phytoplankton was greatly dominated by this species in the second part of July and shared similar populations than C. ovata levels through the rest of the year except in spring when it was almost absent, and in the autumnal peak where particularly low populations were registered in the middle waters.

This species was not recorded in Maulood's study.

3. 3. PRIMARY PRODUCTION

The seasonal pattern of the primary production determination in Loch Rusky, is presented in (Figure 20).

Figure 20: Seasonal changes in primary production from October 1985 to September 1986 expressed as joules per m^2 per day.


PRIMARY PRODUCTION
(Joules/m²/hr)
(Joules/m²/day)
(J/m²/hr)
(J/m²/day)
10⁴
5.10³
0
14
14.10⁵
10⁵
5.10⁴
0
O
N
D
J
F
M
A
M
J
J
A
S
1985
1986

The annual pattern showed one large distinct peak of productivity in spring and two small increases in mid summer and early winter.

The spring production peak, started slightly earlier in March than the spring increase in phytoplankton standing crop. The rise in production at this time was very rapid from less than 5 x 10^4 ($J/m^2/day$) in early March to 14.2 x 10^4 ($J/m^2/day$) by early April. Later in this same month the production declined to lower winter values coinciding with a decrease in population numbers.

The primary production was generally low during the rest of spring and summer months, with only small peaks over 1 x 10^4 ($J/m^2/day$) in May and July. At this time the production rate did not correspond to biomass pattern as measured by cell numbers which showed several peaks in spring and a mid summer peak in July. In August there was a pronounced drop in production, just prior to recovery to previous production values in the early autumn.

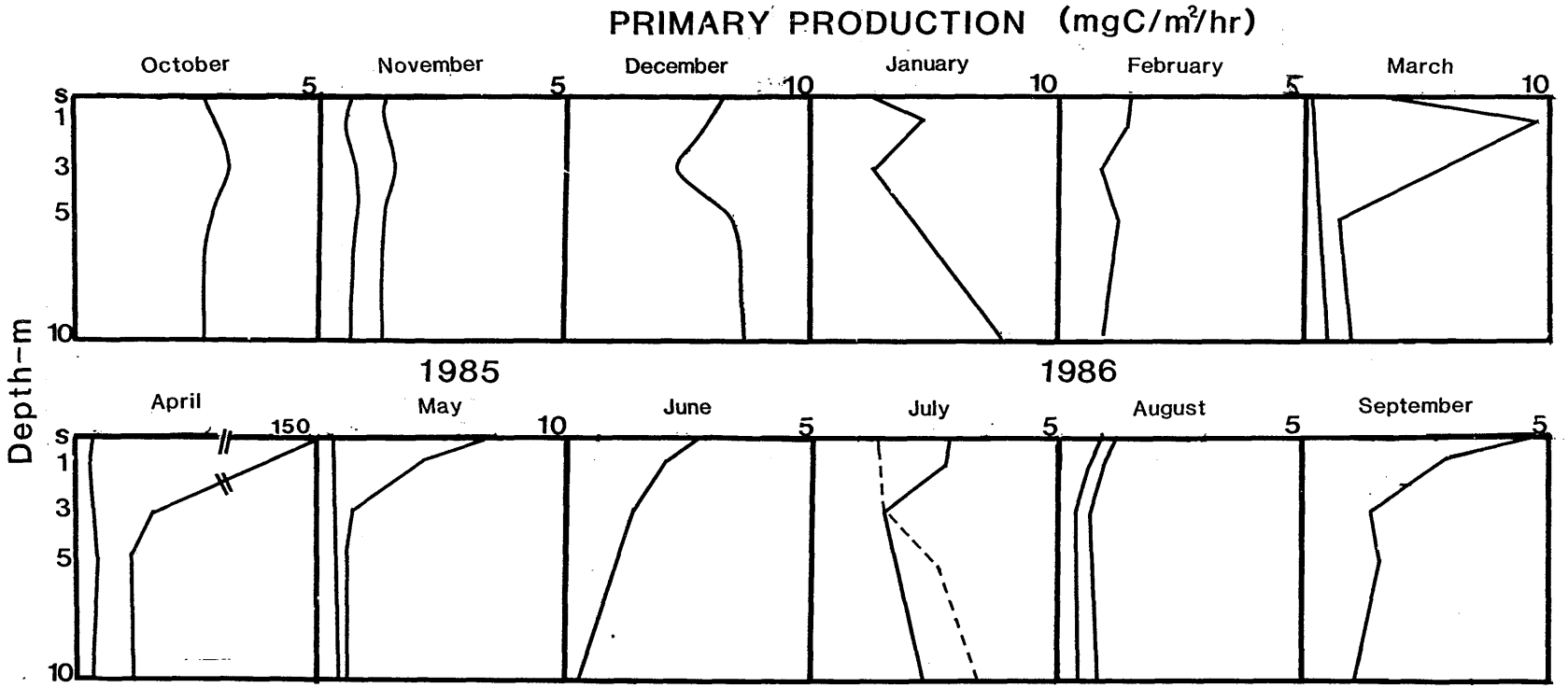
The winter production peak was confined to December and January and occurred approximately a month later than the autumnal algal bloom dominated by Cyanobacteria. At this station a production around 2 x 10^4 ($j/m^2/day$) was reached under the annual shortest daily light regime.

The profile with depth of the primary production is presented in (Figure 21). The production was mainly confined to the upper 5m for most of the period under study. The average of maximum depth light penetration was established at the 4m, calculated from occasional light readings taken in situ during the period of study. (see page 32).

The seasonal production profile with depth (figure 21) showed approximately homogeneous values throughout the water column, during autumn and winter, except in December and January which presented a higher maximum at the bottom 5m. The spring peak showed a vertical distribution with maximum production at the surface and gradual decrease with depth through the euphotic zone. By June the production extended into deeper waters.

During the period of stratification, mainly in July, the epilimnion showed uniform production and the maximum was reached in the bottom 4m. The previous profile observed during mixing water conditions was established again during August and September.

Figure 21: Vertical distribution of primary production from October 1985 to September 1986 expressed as miligrams of carbon per m^2 per hour.


PRIMARY PRODUCTION (mgC/m²/hr)
October
November
December
January
February
March
1985
1986
April
May
June
July
August
September
Depth-m
S
1
3
5
10
5
5
10
10
5
10
150
10
5
5
5
5

3.4. ZOOPLANKTON COMMUNITY

SEASONAL CHANGES IN BIOMASS

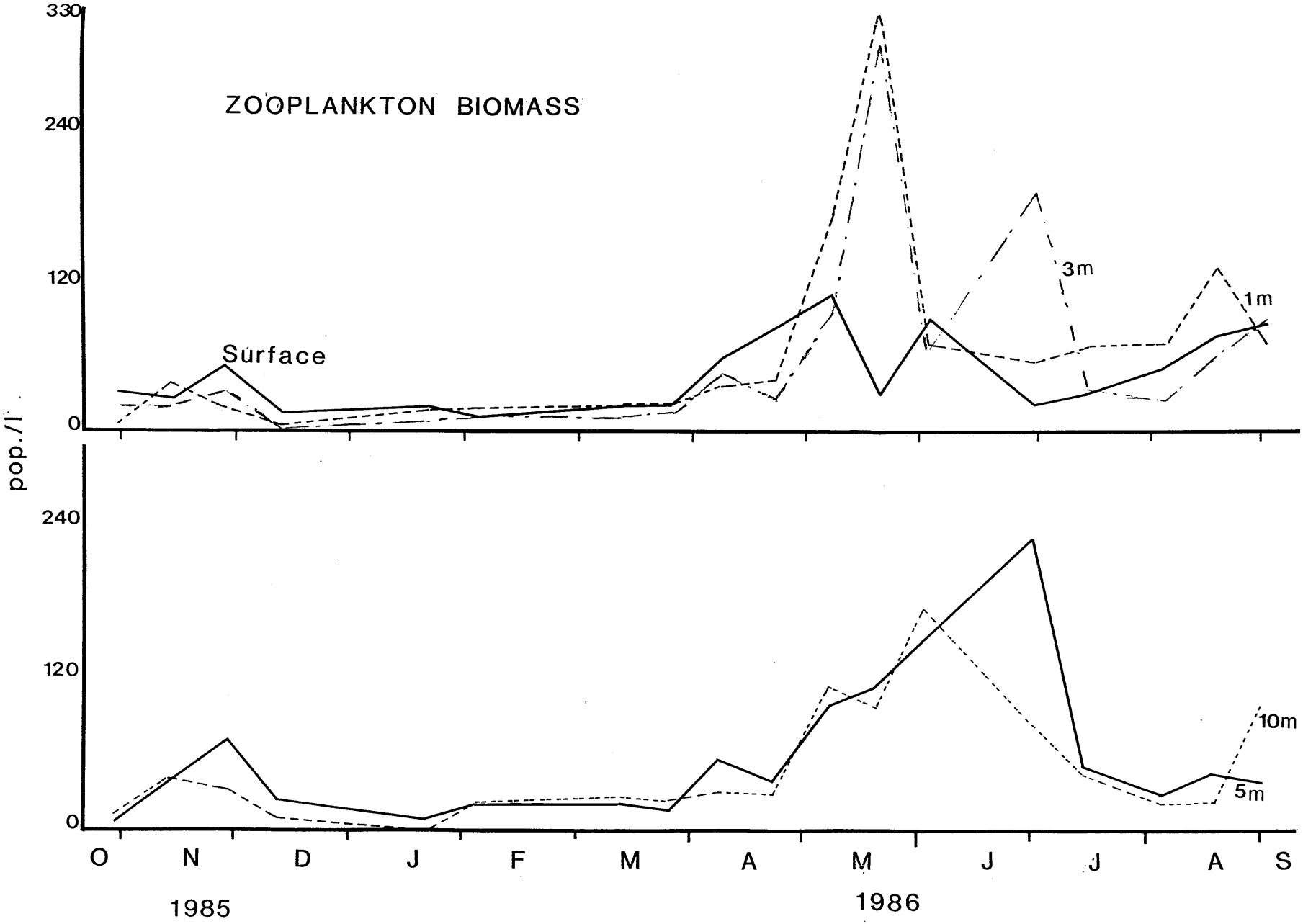
For the major part of the year, the seasonal changes of zooplankton biomass were similar to those for the phytoplankton (Figure 22).

The maximum biomass of 330 ind/l was recorded during spring, in May and the minimum of 6 ind/l in winter. The low winter biomass was followed by a spring-summer peak from April to the middle of July and then a decrease until a second smaller peak of around 120 ind/l from mid August onwards. A late autumn peak of 60 ind/l was recorded in November before a decline to winter population levels.

In contrast to the seasonal phytoplankton biomass pattern (Figure 13), the zooplankton did not attain high levels of biomass in the middle of summer.

The vertical distribution of zooplankton was particularly irregular during the high spring-summer density seasons and was more or less uniform in the remainder of the year.

Figure 22: Seasonal changes in zooplankton biomass at the surface 1, 3, 5 and 10m from October 1985 to September 1986. Biomass expressed as number individuals per litre.


ZOOPLANKTON BIOMASS
330
240
120
0
pop./l
Surface
3m
1m
240
120
0
10m
5m
O
N
D
J
F
M
A
M
J
J
A
S
1985
1986

During the spring-summer peak, the surface water continued with a low and more or less constant zooplankton biomass, except for a spring increase in early May. The community at the 1m depth was comprised of a large monospecific peak in the late May and the highest biomass during summer stratification which consisted of such groups as Cladocera and Copedoda. The 3m depth followed approximately the same pattern as the shallower depth during mixing water conditions in the spring and shared with 5m a second monospecific biomass peak in the early July when thermal stratification confined the distribution of zooplankton species to mainly beneath the epilimnion. The bottom 5m columns of water registered a gradual biomass increase from May to July. The September peak was most well defined at the 10m depth.

SEASONAL CHANGES OF THE MAJOR GROUPS

Rotifers were the most common zooplanktonic group throughout the whole period of study (Figure 23) and also the best represented in number of species (Table III). The highest representation in the plankton was reached in spring, a month later than the spring phytoplankton increase. The dominance of this group was retained

Figure 23: Seasonal changes of the major zooplankton groups at the surface 1, 3, 5 and 10m from October 1985 to September 1986.

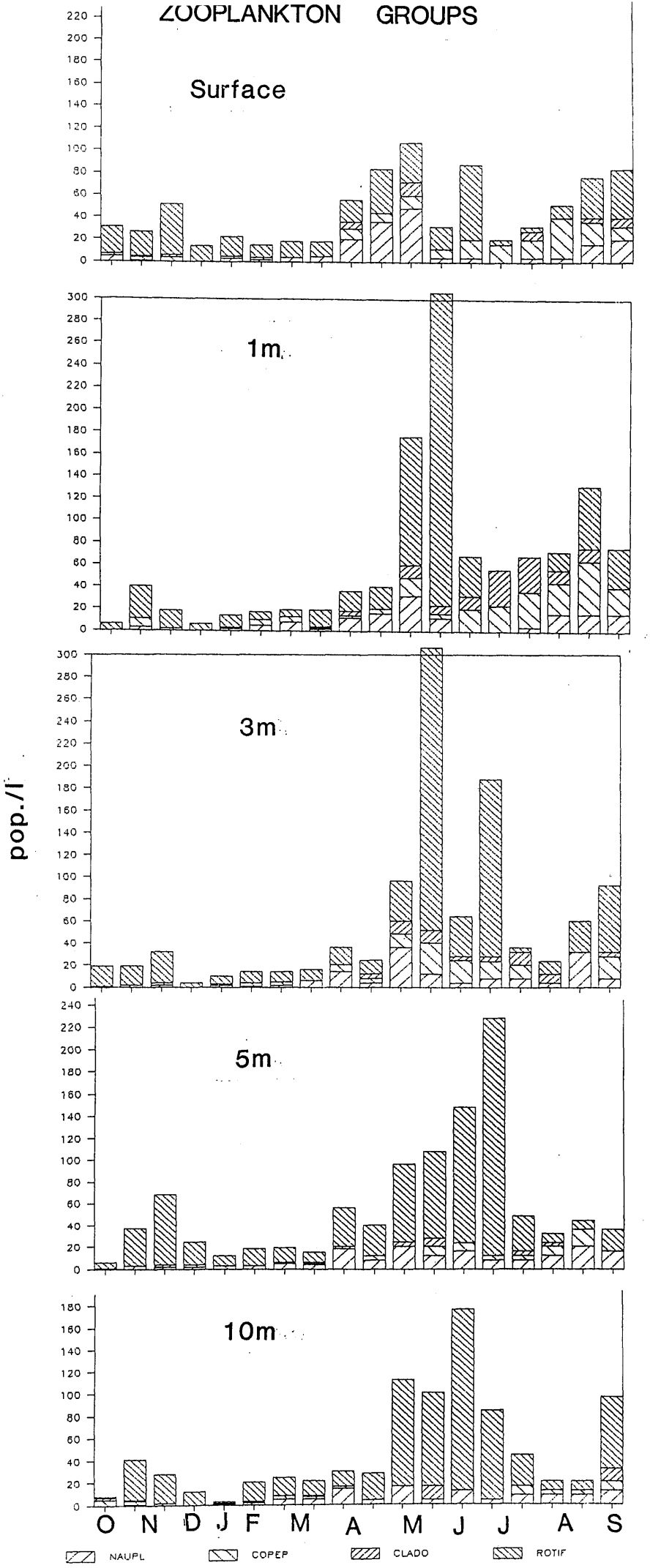

ZOOPLANKTON GROUPS
Surface
1m
3m
5m
10m
pop./l
O N D J F M A M J J A S
NAUPL
COPEP
CLADO
ROTIF

Table III. Species composition of the zooplankton.

TABLE III

- SPECIES COMPOSITION OF ZOOPLANKTON -

ORDER CLADOCERA	OCCURRENCE	REL. ABUNDANCE
Daphnia hyalina Leydig	+	..
Daphnia longispina Muller	-	-
CLASS ROTIFERA		
Ascomorpha ecaudis Perty	-	...
Asplanchna Priodonta	-	.
Brachionus angularis Gosse	-	.
Euchlanis dilatata Ehrb.	-	.
Filinia longiseta Ehrb.	++	..
Kellicottia longispina Kellicott	+	.
Keratella cochlearis Gosse	++	..
Keratella quadrata Muller	-	.
Polyarthra remata Skorikov	+++	...
Trichocerca similis Wierzejski	-	-
Trichocerca spp.	+	...
ORDER COPEPODA		
Cyclops sp.	-	.
Diaptomomus gracilis Sars.	++	..
Nauplius	+++	...

Occurrence :		Rel. Abundance :	
[100 - 75%]	+++	[25 - 10%]	...
] 75 - 50%]	++	]10 - 5%]	..
] 50 - 25%]	+	] 5 - 1%]	.
under 25%	-	under 1%	-

throughout the year, except in summer. The vertical distribution was uniform during autumn and winter and irregular during spring. The summer registered a higher occurrence in the hypolimnion.

Copepoda was mainly represented by Diaptomus gracilis occurring in abundance in the zooplankton in the surface waters from April to late summer. Cyclops sp., solely appeared in low numbers when D. gracilis was absent in the beginning of August. The Copepoda nauplii stage showed two seasons prior to those observed for adults and was present at all the depths during the whole year. There was no direct evidence in this study of the number of generations of Copepods, but it is presumable that the two nauplii peaks lead to two generations of adults populations.

Cladocera were the minor group in the zooplankton community, mainly represented by Daphnia hyalina which only occurred in significant numbers in the epilimnion in July. Cladocera and Copepoda were important in the zooplankton when replacing Rotifera in the summer succession.

ZOOPLANKTON SPECIES

A total of 15 species were identified from the

zooplankton during the period of this study (Table III). Of this total 11 belonged to Rotifera, 2 to Cladocera and 2 to Copepoda. Only 5 species (Polyarthra remata, Keratella cochlealis, Filinia longiseta, Trichocerca sp and Diaptomus gracilis), occurred in sufficient numbers to permit the determination of the seasonal pattern.

Rotifera

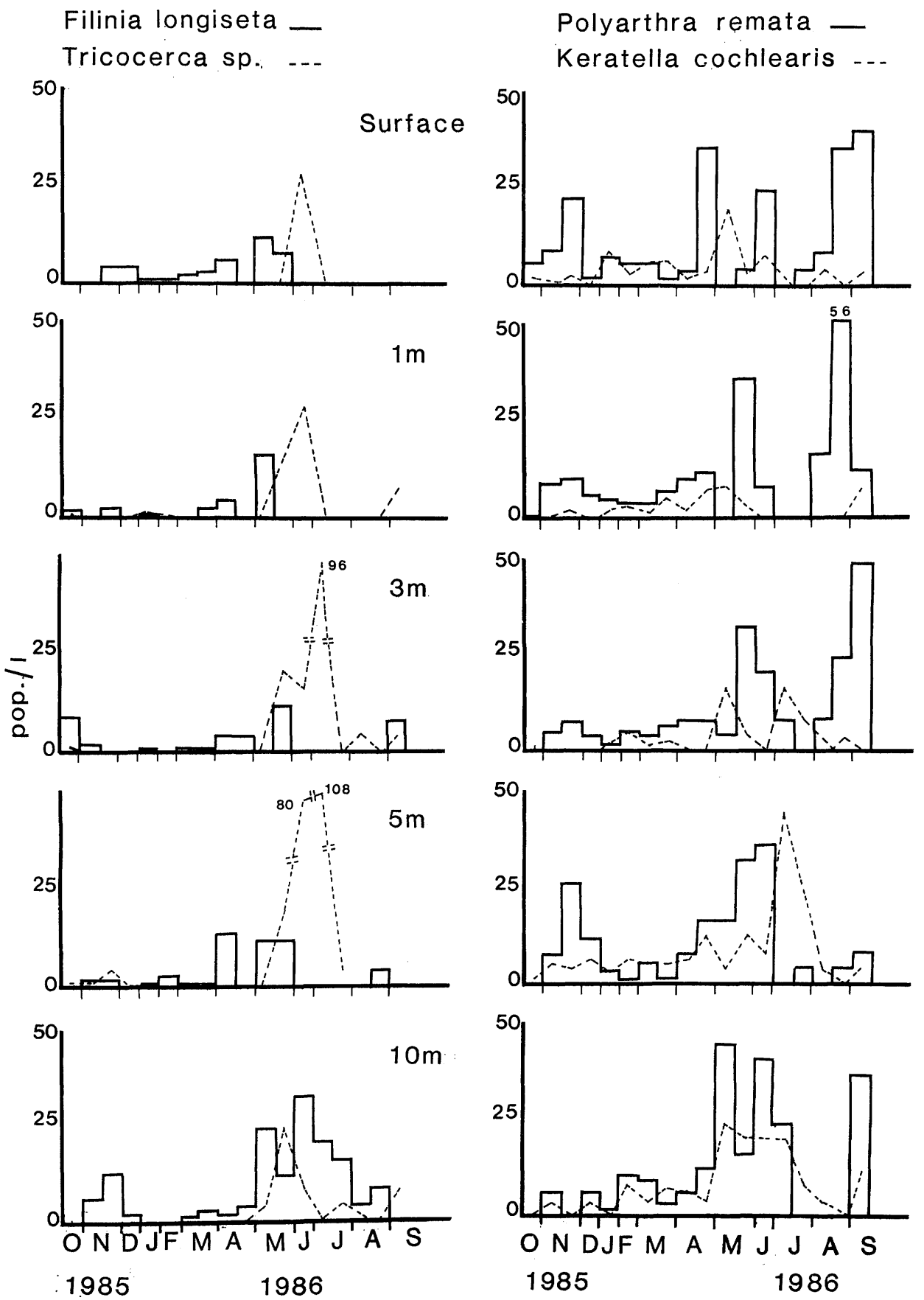
Polyarthra remata

This was the most common of the zooplankton species in Loch Rusky, over the period of sampling occurring on 84% of occasions and reaching up to 20% abundance. Its seasonal pattern shows three distinct peaks (figure 24). The first peak occurred mainly in the bottom 3m from April to July. In contrast, the late summer peak in August and September was concentrated mainly in the epilimnion, although in September high population numbers were also recorded at 10m. In late autumn a third peak was shown more or less evenly distributed throughout the water column and thereafter low population levels remained during the winter.

Keratella cochlearis

K. cochlearis was present through the entire study

Figure 24: Seasonal pattern of Polyarthra remata, Keratella cochlearis, Kellicottia longispina, and Trichocerca sp. at the surface, 1,3,5 and 10m from October 1985 to September 1986. Populations are expressed as number individuals per litre.


Filinia longiseta
Tricocerca sp.
Polyarthra remata
Keratella cochlearis
Surface
1m
3m
5m
10m
ind./l
50
25
0
96
80
108
56
O N D J F M A M J J A S
1985
1986

period at all depths except for brief periods in summer and autumn at 1m and 3m respectively (Figure 24). Its occurrence was 72% and represented up to 9% of the total numbers of zooplankton (Table III). Maximum population levels were attained during the late spring and the early summer. The vertical seasonal pattern showed uniformity under mixing water conditions but under stagnation in summer K. cochlearis was confined to the bottom 3m of the water column. There was a uniform increase in number through September and constant population levels remained during autumn and winter.

Filinia longiseta

This species showed 53% occurrence and 6% relative frequency (Table III). There was a distinct vertical seasonal pattern with greater presence and longer population levels at the 10m depth. This species was present in small numbers during autumn and winter. The population levels rose from April to May throughout all depths but thereafter became exclusively restricted to the hypolimnion until September. The highest population was reached in June. September registered a small increase in the bottom 3m and there was no clear autumn peak except at 10m.

Trichocerca sp

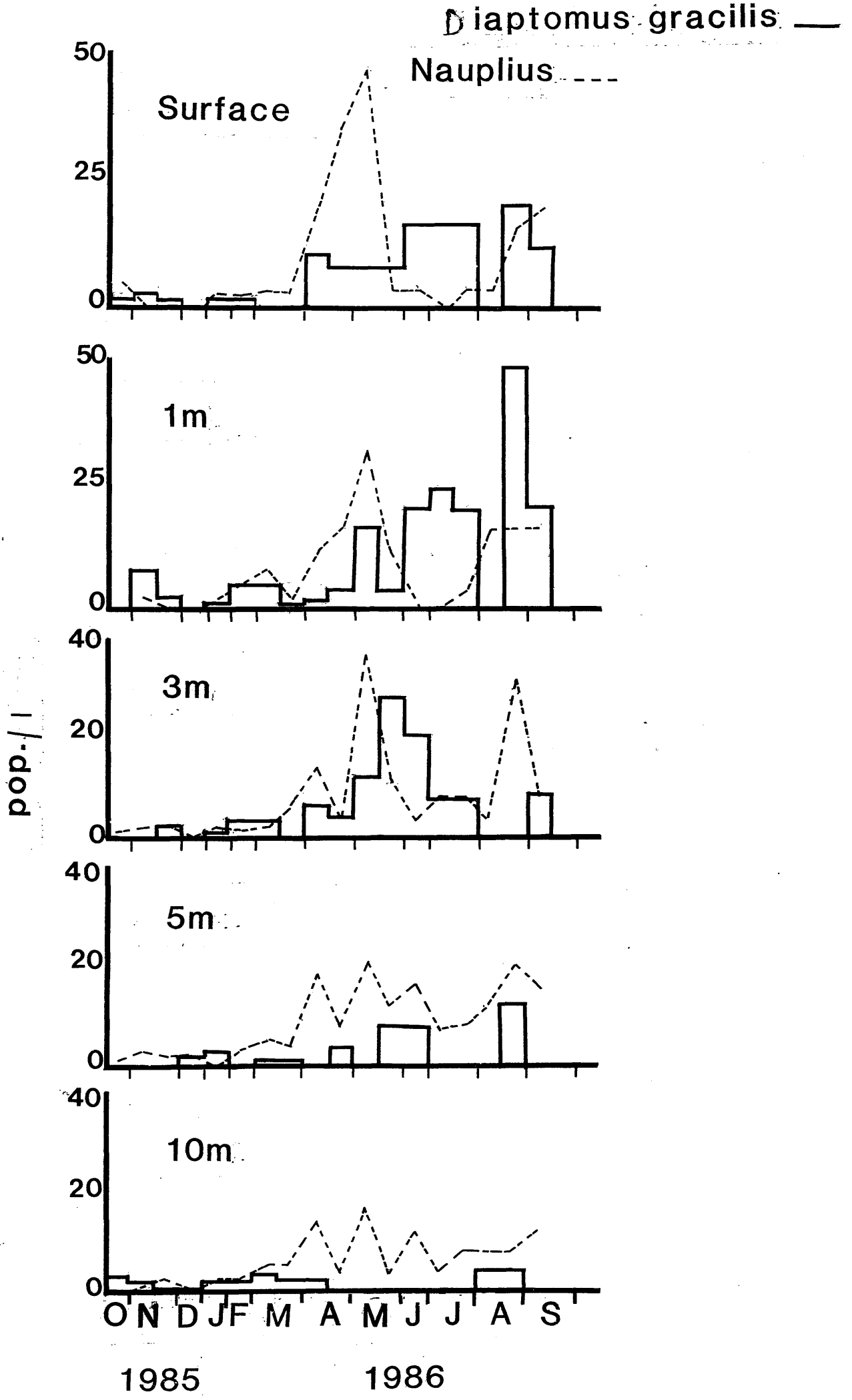
This was an infrequent species in the zooplankton but was characterised by a rapid developement under high temperatures in early summer (Fig. 24). There was a single seasonal peak from May to July. The highest biomass was reached in July and was mainly concentrated in the middle depth. The population rapidly declined in the same month and disappeared completely from the epilimnion with very low levels remaining in the hypolimnion during summer. There was a small irregular increase in September and almost total absence thereafter.

Copepoda

Diaptomus gracilis

The various nauplii stages were bulked together in this study. There were high occurrence (87%) and abundance (15%) nauplii levels throughout the whole year. The seasonal pattern showed two peaks, one in spring and the other in summer (Figure 25). The spring increase was larger in number and immediately prior to D. gracilis adults peak. After this spring maximum nauplii population declined

Figure 24: Seasonal pattern of Polyarthra remata, Keratella cochlearis, Kellicottia longispina, and Trichocerca sp. at the surface, 1,3,5 and 10m from October 1985 to September 1986. Populations are expressed as number individuals per litre.


Diaptomus gracilis
Nauplius
Surface
1m
3m
5m
10m
50
25
0
40
20
pop./l
O N D J F M A M J J A S
1985
1986

throughout the summer, until a second peak in the late August. The numbers fell rapidly during autumn and winter, starting to recover again from January onwards. Seasonal differences were found in the vertical distribution. The nauplii populations recorded higher values in the upper region during the spring, but were confined to the metalimnion in the summer. During the remaining seasons distribution was uniform throughout the water column.

Population of D.gracilis adult was higher over the late spring and summer months than at other times (Figure 25). The seasonal pattern showed a gradual increased peak from April to July followed by a steep decline and a second larger peak in the late August. D. gracilis was distributed in the epilimnion during thermal stratification and in the upper well oxygenated water, in the late summer.

Other plankton specimens

There were also recorded in this study two unidentified planktonic organisms named by Protozoa 1 and Protozoa 2 (Table II). There was not enough evidence in this study for complete identification, although some morphological characteristics suggest them to be Protozoa.

Protozoa - 1 :was a spherical cell with uniform size (approx. 300um)and distribution of ciliates over the smooth superficie. A nucleus was apparent in a parental position. The cell content was filled with evenly distributed dark granules.

It showed a high occurrence of 75% throughout the whole year, reaching a single maximum population in November and again throughout the whole summer months at 5m. During the rest of the year remained low levels evenly distributed in the water column.

Protozoa - 2 : was smaller than Protozoa 1 between 130 - 180 um; spherical shape with cilia exclusively presented in a cluster at the anterior end of the cell. The cell contained a nucleus situated at the anterior end with 3 - 4 ciliates. It showed lower abundance than Protozoa 1 for the whole period with a single seasonal occurrence during autumn - winter in the surface waters.

3. 5 DIVERSITY

The diversity of species in both phytoplankton and zooplankton communities was calculated together using the

Shannon-Weaver index (1963). This index was devised to determine the amount of information (structural complexity) of an assemblage of objects and it has been widely applied to the structure of ecological communities (Pielou, 1966). The index relates two components: richness of species and equitability or relative abundance of species. An increase in the number of species and/or a tendency toward a more equal distribution of individuals among species can result in higher values of the diversity. The index is expressed in units of bits called bits per individual per litre.

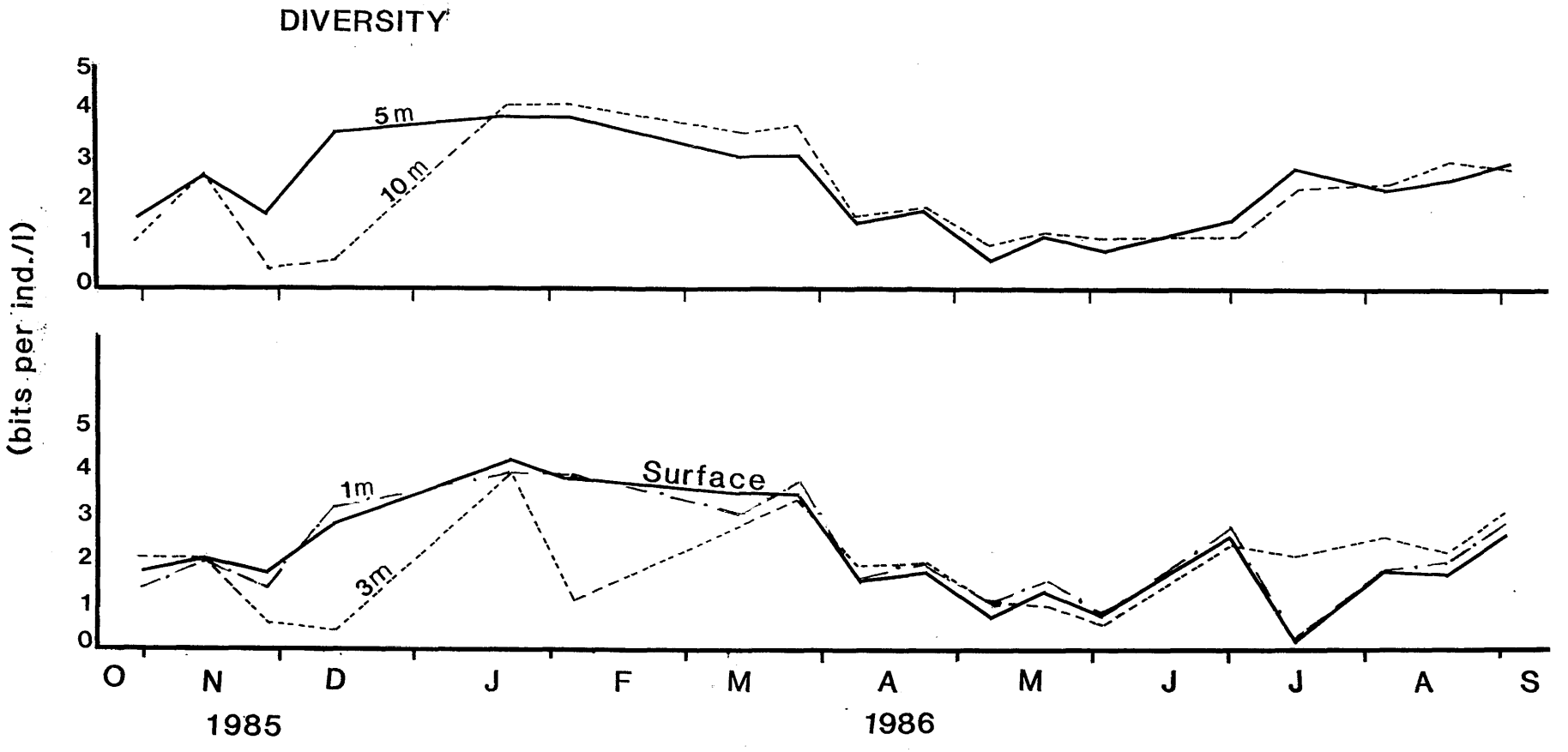
Seasonal diversity changes

The diversity found in relation to depth and time for the plankton species of Loch Rusky is shown in (fig. 26).

The minimum diversity for the whole period occurred at the stations and times where a small number of specific species dominated the plankton biomass. Thus diversity below 2 was registered during the diatoms spring bloom, from April to June. Afterwards, values arose to about 3 during the summer, except in the epilimnion where it dropped to the annual minimum, below 0.5 as a result of a single dominance in abundance of nanoplanktonic species.

Through September, the diversity reached 3 throughout

Figure 26: Seasonal changes in diversity of the plankton community from October 1985 to September 1986, expressed as bits of species per litre.


DIVERSITY
(bits per ind./l)
5
4
3
2
1
0
5m
10m
Surface
1m
3m
O
N
D
J
F
M
A
M
J
J
A
S
1985
1986

the whole water column and declined to about 2 during early autumn. From late November to early December a selective vertical decrease below 1, took place at the 3 and 10m. coinciding with an occasional Cyanobacteria bloom which occurred mainly in these depths.

The maximum annual diversity about 4, was reached throughout all the depths except 3m, during the winter. This coincided with the minimum plankton biomass but with the highest richness of species in both zooplankton and phytoplankton communities.

DISCUSSION

4. DISCUSSION

4. 1. DISCUSSION:- PHYSICO-CHEMICAL PARAMETERS.

Temperature - Oxygen :

Loch Rusky is a second order monomictic lake (Hutchinson, 1957), with thermal stratification occurring through the summer months. Dissolved oxygen concentrations were at nearly saturation levels throughout the period of isothermal conditions and declined to the minimum in the hypolimnion after several weeks of thermal stratification.

The rate of oxygen depletion depends on the total amount of oxygen present, in relation to depth and amount of sinking decaying organic matter originating in the epilimnion (Golterman, 1975). In a nutrient poor lake such as Loch Rusky, the amount of organic matter sinking is very limited and oxygen depletion would occur only when the volume of the epilimnion is large in comparation with the hypolimnion.

The oxygen depletion in the hypolimnion is due to decomposition processes and animal respiration. There is not always a constant ratio between CO_2 produced and oxygen

consumed, however heterotrophic and anaerobic processes may occur (Golterman, 1975). The oxygen depletion leads to a decrease in redox-potential, and the production of CO_2 lead to a reduction of pH. An absolute disappearance of oxygen from overlying water was not detected during sampling period, although it is likely that during the summer, the levels at the maximum depth of 15m dropped below the minimum recorded (21% at 11m).

The rise in temperature through the spring and summer reduced the capacity of the water to dissolve oxygen, and algal production produced supersaturated levels in the upper layers. Mixing conditions due to wind induced turbulance and the shallowness of Loch Rusky afforded isothermal and uniform oxygen saturation levels throughout the water column for most of the year.

It is likely that the occasional periods of ice-cover during the winter produced a slight oxygen vertical stratification with supersaturation levels under the ice supported by algal production (Welch, 1952).

Light

Light penetration in Loch Rusky is characteristic of a dystrophic lake as greater penetration is recorded in the

red wave band than in the blue which is rapidly absorbed in the upper waters by dissolved and suspended compounds (Hutchinson, 1957; Talling, 1962). The high content of coloured materials in the Loch determined a shallow effective illumination zone which depended of seasonal variations but never extended below 4m. Light penetration was largely restricted by non-living particulate matter and detritus, after autumn overturn.

Light was directly related to phytoplankton growth and temperature, constituing the limiting factor for algal developement during winter, whereas increasing in day length and solar elevation promoted the outburst in spring (Lund, 1965).

During summer there was no evidence of light inhibition on algal growth in the upper waters as a result of a rapid light filtration by particulate suspended material and reduction of radiation by cloud cover, although this was not directly measured.

Alkalinity and pH :

pH in this study paralleled biological activity and was closely related to alkalinity since both are involved in

the carbonate water equilibrium (Mackereth, 1978). To a large extent increase in alkalinity is associated with increase in pH. During periods of low primary productivity pH levels were generally reduced and high pH in periods of maximum photosynthesis, as a result of a depletion of free carbon dioxide and a shift in the carbonate system towards bicarbonate.

The influence of rainfall and inflow rates were an important factor in the determination of pH and alkalinity in Loch Rusky (Welch, 1952). Seasons of high rainfall (autumn-winter) lead to a lowering of the pH whereas alkalinity arose to the seasonal maximum. This alkalinity increase could be related to the artificial addition of soda lime to the main inflow (see page 84).

During December - January likely ice-cover on the loch produced a temporary winter stagnation where hydrogen ion and alkalinity concentration increased progressively with depth to a certain level after which a form of stability occurs resembling that of the summer stagnation period although with slightly more acid levels (Welch, 1952).

The slight hypolimnetic increase in alkalinity during summer could be caused by products of decomposition process (Hutchinson, 1957) and respiration. The epilimnetic pH

increase in summer seems, in part be related to the phytoplankton activity, however primary production showed low levels during summer. The episodic inputs of atmospheric acides (Cl, SO_2, NO_3) caused short-terms drops in water pH, especially during the seasons of heavy rains (autumn-winter) and the first phases of snow melt (Feb-March).

Nutrients

The seasonal distribution of nutrients in lake water can be ascribed to many different factors both internal and external to the body of water (Hutchinson 1957). External sources of supply are of considerable importance both from natural and artificial sources. The most important natural source of silicate and phosphate is from the erosion of rock mineral (Golterman 1975), whereas rainfall supplies large quantities of inorganic nitrogen compounds (Allen et al, 1968), sulphate and chloride. The seasonal variation in the rate of the stream inflow was also important as an influence on external supply. The winter rise in all nutrients is associated with the annual mixing cycle (Hutchinson, 1957). Nevertheless nutrient release to the overlying water from the sediment is negligible because of the high oxygen saturation (Mortimer, 1941). The high rainfall and inflow rates in autumn and winter together with low biological activity contributed to this increase nutrient into the lake. These factors were graduallly reversed through spring until the next autumn overturn. The nutrients affected by the lowering of redox-potential in the

hypolimnion, were partially renewal in the bottom during summer stratification.

Orthophosphate :

Phosphate distribution was greatly influenced by biological activity within the lake. When this decreased, orthophosphate concentrations increased.

During thermal stratification the orthophosphate levels showed small variation with depth, although a small increase in phosphate occurred in the hypolimnion when oxygen levels fell to the minimum in the later phases of stagnation. This is in major part due to decomposition of sinking plankton and liberation of phosphate from sediment by reduction (Hutchinson, 1957). The phosphate distribution is determined by behaviour of other substances such as iron which was not measured in this study (Mortimer, 1941).

The annual maximum of phosphate nutrient in the surface waters could be caused by increasing in the surface runoff at the time of higher rainfall and autumnal leaf fall. Occasional influxes of phosphate from the Letter Burn characterised the period between the two phytoplankton spring peaks, and these were important in the maintenance of the algal succession.

Silicate :

The seasonal pattern of silicate was similar to that for phosphate and nitrate. The seasonal depletion of silicate in the water was primarily the result of diatom productivity and growth (Hutchinson, 1957, Lund 1965). Otherwise the lowest silicate concentrations recorded in the epilimnion at the time of minimum diatom populations, is likely to be related to the large development of littoral vegetation communities (e.g. equisetum) in the early summer (Hutchinson, 1957). Silicate generally increased with decreasing oxygen saturation in the hypolimnion. This seems more the result of mineralization of diatoms frustules sedimented since the previous stratification than the product of the release of chemically bound silicate from the sediment (Golterman, 1975). The rate of inflow was important as external supply of this element from the catchment area.

Nitrate and ammonia :

The proportions of each nitrogen compound is related to oxygen concentrations, with high oxygen levels favouring nitrate and very low levels ammonia (Mortimer, 1941-42). Nitrification is a source of nitrate within a lake. This

can take place in freshwater and mud whenever oxygen is present. Nitrification appears to proceed most rapidly in winter and is sensitive to low pH (Hutchinson, 1957). Surface runoff and acid rainfall could both be also important sources of nitrate to a lake system (Golterman, 1975).

Maximal amounts of nitrate were present in the loch at the end of winter. When mixing conditions, high rainfall and increase in pH took place. The general rise of nitrate through the autumn overturn had an exception in December when particularly low nitrate concentrations appeared throughout the water column. The slight decrease in oxygen and pH was unlikely to be sufficient to explain this decline by reduction of nitrate, particularly since ammonia, was not detectable and the denitrifying bacteria that liberate molecular nitrogen were not measured in this study.

During spring algal growth, nitrate was depleted from the water by algal assimilation (Golterman, 1975). In the early summer, it showed a minimum in the middle waters. Nitrate was presumably removed from the epilimnion by assimilation and at the bottom by reduction to ammonia, where a peak of this latter was registered. This increase in ammonia occurred when oxygen concentrations were high (70%) but declining (Mortimer, 1941-42), whereas when the

oxygen levels reduced further to the minimum (20% or less), an increase of nitrate and absence of ammonia occurred throughout the column water and particularly in the hypolimnion. This could be associated with nitrification process in the free water and mud by decomposition of larger falling plankton and faeces, which could represent an important source of nitrogen compound in small lakes (Hutchinson, 1957).

The rapid increase in ammonia through the autumn overturn seems to be insufficient to explain reduction of nitrate in the upper waters, when both nitrogen forms reached more or less the same concentration. The adsorption onto falling seston during the later phase of stagnation and later liberation to the circulating water during the early autumn is not supported by any evidence (Hutchinson, 1957) and it seems likely that external unmeasured supplies of rainfall and surface run off were involved.

Sulphate and chloride :

Rainfall is the major source of chloride to a lake system (Hutchinson, 1957), however chloride levels in Loch Rusky were minimal during the high rainfall seasons. Seasonal changes influenced by thermal stratification, oxygen depletion and biological activity were not recorded

for this nutrient. Wind direction borne salts, evaporated from the sea and deposited in the study area was not monitored in this study and presumably was a factor influencing the seasonal pattern.

Sulphate concentrations normally declined with decreasing oxygen levels. Rainfall is the prime source of sulphate to most lake systems (Hutchinson, 1957). The seasonal pattern of sulphate generally supported these contentions.

Organic matter :

Dissolved organic matter can be an approximate measure of material of the allochthonous origin consisting mainly of extractives organic acids from soils or peaty materials (Hutchinson, 1957). The yellow or brown colouring matter is important as a screen of penetrating light in the loch, particularly since absorption is in the blue end of the spectrum, important wavelengths absorbed by Chlorophylls. The main factor influencing the organic matter was the surface runoff and this was closely related with rainfall seasons. The autumn-winter high rainfall recorded high organic matter in the loch and burn, and both declined through spring-summer.

Comparation physical-chemical parameters with the previous study of the loch: Maulood 1972-73.

The general comparation of the physical-chemical parameters registered on the loch during this study and those reported by Maulood in 1972-73 showed very few differences and the environmental conditions remained more or less constant. Phosphate and pH are the only important factors which showed significant changes. The slight quantitative differences found in the other parameters are assumed to be within of natural annual variation (e.g. annual differences in rainfall and supply of nutrients by the inflow).

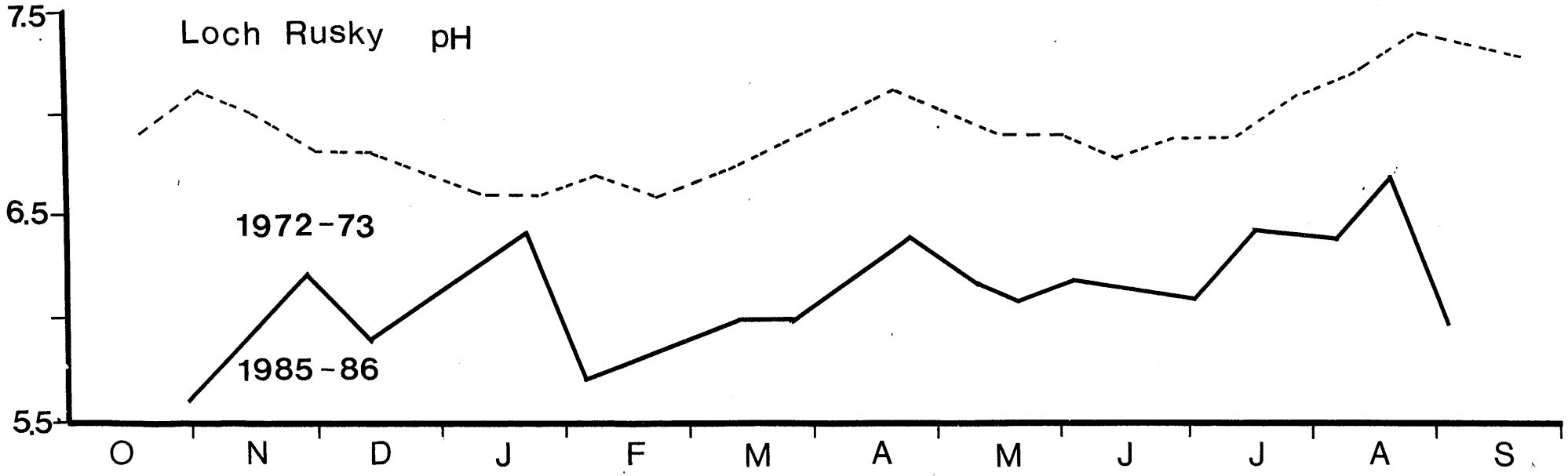
The differences found in phosphate concentrations were likely due to a short term artificial fertilization programme in the Loch in progress at the time of Maulood's study. During 1972-74 the Forestry Commission spread rock phosphate on the newly planted woodland, and much of this was washed through the Letter Burn into Loch Rusky (Mr. McKenzie, personal communication).

The decrease in pH has a different cause. The pH has decreased by one pH unit during the twelve years between the two periods of study, the range changing from 6.6 - 7.8 to

5.6 - 6.9 (fig. 27). The changes for the main inflow were smaller from 5.4 - 7.5 to 5.6 - 6.75, presumably due to the artificial addition of soda lime to the stream. The loch was periodically buffered with 50Kg of soda lime every 4 - 5 months by the Angling club to improve pH conditions for the fish stock. The treatment was reported not to be completely satisfactory and so it has been replaced by depositing rock limestone in the bed of the feeder stream (Loch Rusky Angling Club, personal communication).

This rise in water acidification in Loch Rusky has several possible causes. It seems to be related to the general increase in acid rain in West Scotland (Watt Committee, 1983) and change in land acification by the growth and development over the past twenty years of the softwood forest around the loch (Leivestad et al.,1976) which at the present covers 87% of the whole catchment area. The deposition of conifer leaves on the water surface have also disturbed the insect larvae development and fish resources (personal communication Angling Club). The geological characteristics of the rocks where the loch itself lies possibly contributes to this acidification process (Leivestad et al., 1976, Sutcliffe, 1983).

Figure 27: Seasonal decrease of pH in Loch Rusky from Maulood's study in 1972-73 to the present in 1985-86.


Loch Rusky pH
7.5
6.5
5.5
1972-73
1985-86
O
N
D
J
F
M
A
M
J
J
A
S

4.2 DISCUSSION - SEASONAL SUCCESSION, PLANKTON DIVERSITY AND PRIMARY PRODUCTION.

Plankton seasonal succession

The annual periocity of phytoplankton in temperate zones is primarily controlled by seasonal changes in water temperatures and incident light levels (Hutchinson, 1967). During winter months, light energy is the main limiting factor for growth of algae and should enable nutrient levels to increase over this period (Moss, 1980). These nutrient then decline in spring when growth in phytoplankton populations takes place under increasing temperatures and insolation levels.

Diatoms *Asterionella formosa* and *Melosira italica* dominated the spring phytoplankton increase in Loch Rusky. This early start was presumably due to the ability of these two species to grow under conditions of weak light and low temperatures which are less suitable for other algae (Lund, 1965). The faster rate of increase of *M.italica* (Lund, 1954) lead to it forming the first spring peak in April wheras *A.formosa* augmented its population gradually until its maximum in late June. The different optimal temperature conditions for each species influenced on the rate of

division (Lund 1950, 1954) and therefore these successional peaks. M.italica attained its maximum after a slight increase in winter temperatures from 4.5°C to 6°C and A.formosa at about 11°C.

The small number of cell per colony found throughout spring - summer in both species
was likely determined by the rate of division and silicate supply (Lund, 1949, Gardiner, 1940-41).

The diatoms populations were sustained by high nutrient levels (especially silicate); increasing light and temperature levels, and continued suspension in the photic zone by water turbulance in spring. The end of the period of growth by June was presumably set by the depletion of silicate to under 0.5mg/l (Pearsal, 1932, Lund, 1950). The onset of water stratification resulted in more rapid sinking by the diatoms (Lund, 1954, 1963; Reynolds, 1973), was shown in the loch by an apparent higher concentration of this group in the deeper water.

The restoration of small populations of both species at the time of the autumn overturn related turbulance to the resuspension from the bottom, sedimented M.italica filaments (Lund, 1954) and the growth of suspended A. formosa cells under the increase of circulating nutrients in the

tropogenic zone (Lund, 1949; Blanton, 1973).

Depletion in nitrate and particularly phosphate concentrations, were correlated with the spring algal increase but is unlikely that they reached limiting growth levels for diatoms.

The general depletion in nutrients in Loch Rusky to minimum annual levels and the establishment of thermal stratification favoured the algal succession from Diatoms to flagellates (Cryptomonas ovata and Rhodomonas minuta) during the summer months (Moss, 1969). The more efficient utilization of nutrients by nannoplankton in a poor environment is due to the high surface to volume ratio (Finderegg, 1966) and to greater activity to avoid sinking by maintaining a position in the euphotic zone (Reynolds, 1976).

The nannoplanktonic populations of C.ovata and R.minuta remained in low numbers during the period of highest zooplankton biomass increase from May to early July. It is likely they were grazed by zooplankton (e.g. Rotifers) more extensively than net plankton (e.g. diatoms) (Lund, 1964; Edmonson, 1965).

R.minuta and C.ovata registered consecutive pulses of

maximum populations, occurring in the upper water during early and late summer respectively. The small size and fast division rate of these species made possible a very rapid cell increase in numbers, to reach the maximum annual biomass. This rapid cell increase, together with the influence of specific environmental conditions (such as, higher light-temperature and deprivation in nutrients) during summer, seemed to lead to a reduction in the content of chlorophyll *a* per cell (Jensen, Sakshaug 1973). Therefore discrepancies arose at this time between biomass results obtained by standing crop and total Chlorophyll *a* (see results page 49).

The occurrence in late summer of an increase in colonial cellulose walled algae, such as Cyanobacteria *Chroccocus dispersus* and the green algae *Quadrigula closterioides* was apparently related to a lack of predation from zooplankton grazing (Allan, 1976). These algae however did not attain great importance in the biomass.

Through the autumn overturn the algal population continued growing under decreasing light and temperature conditions, at the time when nutrient levels began to increase. Under autumnal full circulation, silicate levels (above 0.5 mg/l) were not reached before November, by which time it is likely that low light levels limit growth for

diatoms (Lund, 1965).

C.ovata and R.minuta continued to dominate the phytoplankton in the early autumn, whereas an occassional monospecific bloom of Cyanobacteria preceded the minimum winter algae populations. This autumnal Blue-green algae peak in Loch Rusky might be determined by special chemical conditions, possibly involving the accumulation of specific organic compounds such as vitamins (Hutchinson, 1967, Pearsall, 1932) at the time of maximum organic matter input in the Loch, although organic micronutrients were not measured in this study. The defenitive causes are unknown in part due to the inability to identify the specific Blue-green algae (see results page for description).

The reduction of light penetration by non-living materials at this time, seemed to be more important than that caused by the massive blue-algae growth, which was mainly concentrated at the deeper waters.

The seasonal changes of zooplankton for most of the year were similar to those for the phytoplankton in the loch. Rotifers was the most diverse and abundant zooplankton group in Loch Rusky for most of the year. Nevertheless, it could be possible that during the study, Copepoda and Cladocera populations had been quantitively

underestimated due to the method used for the collection and counting of plankton samples, which was mostly adapted for small organisms such as algae and rotifers (Edmonson and Winberg, 1971) (see material and methods Page 5). The periods of major error would coincide with those to high phytoplankton biomass (spring-summer), when reduced water samples (250ml) were considered; however, the seasonal distribution of relative abundance between the three main zooplankton groups seemed to be consistent throughout the whole study.

Over all temperatures, Rotifers have the fastest rate of increase of any zoolankton (Allan, 1976) and this would enable this group to respond to its population numbers quickly to increasing phytoplankton biomass, as was observed in the loch at the time of spring and autumn peaks.

There were strong similarities between the seasonal variations of Rotifers (mainly P. remata) and phytoplankton (mainly the flagellate C. ovata) (Edmonson, 1965), although from this study it is not possible to ascertain whether rotifers feed on exclusively nanoplankton or whether diatoms and supplementary sources (e.g. bacteria, detritus) were also involved (Lund, 1965).

During mixing water conditions the vertical

distribution of total zooplankton was uniform. Under thermal stratification in summer, Copepoda and Cladocera developed their largest populations in the epilimnion, whereas Rotifera population numbers were small and distributed mainly in the deeper waters. It seems likely that thermal and chemical gradients determined the position of the zooplankton under these conditions (Hutchinson, 1967). The higher filtering rate and greater food range of Copepoda and Cladocera (Allan, 1976) convey a relative disadvantage to Rotifers during this time.

The general low occurrence of Cladocera, mainly represented by Daphnia hyalina throughout the period of study, could be related to its high sensitivity to vertebrate predation (Stenson, 1972) and the continuous programme of stocking the loch with fish. The reduction in the consumption of Daphnia by trout during summer (Thorpe, 1974) could contribute to the increase of this species in the zooplankton at this time.

Developmental stages nauplius of the Copepods were first apparent in February and were continually present until autumn. This early start to the breeding season seems necessary to compete with faster reproducing zooplankton groups such as rotifers or cladocera. The two annual increases in nauplius numbers, generally preceded those of

the adults. The adult population in summer apparently produced a second brood, smaller than that in spring, followed by the subsequent peak of nauplii in late summer. The low autumnal populations of D.gracilis seems the result from a high mortality of nauplii in this later peak, which is presumably related to the higher feeding rate of Salmo trutta under summer-autumn temperatures in the loch (Brown, 1957) and higher flood loses through the out-flow by autumn.

Some of the variations in both phytoplankton and zooplankton biomass are explained by interactions between the two communities, especially during the spring and autumn when the population numbers were high. Through the summer, physical and chemical factors were also involved in establishing succession patterns. During this time zooplankton populations were relatively low, since phytoplankton, the primary food sources, were high in number. This could be partly explained by the dominence of Copepoda and Cladocera at this season. An investigations into the nature and rate of grazing by zooplankton was not attempted in this study, but it is presumed that the higher filtration rate and larger particle size acceptibility of the larger zooplankters (Allan, 1976, Edmonson, 1965) were compensated by low population numbers. Nevertheless, phytoplankton populations throughout the whole period of study seemed to be

sufficient to support zooplankton requirements.

The interactions between zooplankton and phytoplankton might determine the site of the specific populations (e.g. nanoplankton), but there was not a completely direct relationship due to supplementary sources of food of the zoplankton (Lund, 1965) and the direct influence of temperature on zooplankton reproductive cycles (Edmonson, 1965).

The effect of parasitism (e.g. Bacteria and fungi) on phytoplankton populations were not attempted in this study but it may be of importance to explain the steep reduction of A. formosa in middle April in the loch (Lund, 1950; Canter & Lund, 1948).

Diversity

The diversity of the phytoplankton communities measured in this study by the Shannon-Weaver Index was widely influenced in time and depth by the relative abundance of a few dominant species (Sager & Hasler, 1969). The high seasons of phytoplankton standing crop were coincident therefore with decreasing values in the diversity index, mainly due to the dominence in the plankton of a few species. This was apparent during summer, when there was a

stratification in diversity between the epilimnion and hypolimnion with higher values in the latter. The large abundance of an almost single-species-culture in the upper water and the equitability of the different represented groups in the bottom accounted in the index for this distribution.

The coexistence of a relatively large number of species under more limiting conditions in summer (Hutchinson, 1967) seems to be the result of a non-uniform environment under stratificate water (Moss, 1972). The unpredictable planktonic environment favoured the rapid changes in abundance of species, which was well reflected by the Shannon-Weaver index (Tramer, 1969; Margalef, 1968).

The richness of species (about 30 species), together with the positive effect of their equitability contributed to the high winter index. The phytoplankton was represented by a larger range of species of diatoms than later in spring, as well as species of chlorophyta (e.g. desmids).

The index is apparently insensitive to rare species (Sager and Hasler, 1969). The zooplankton could be approached in this study, as rare species due to their low relative abundance when it is considered together with the diversity of phytoplankton.

The range of diversity (between 0.5 - 4) found for Loch Rusky is similar to that showed in Loch Awe (1.5 - 4 in 1976) and slightly greater than that to the South Basin of Loch Lomond (1.5-3 in 1970-72) (R.Tippett, personal communication).

The phytoplankton diversity seems to be lower in spring than during late summer and autumn for these three lochs. This seems to related to the common dominance of diatoms in the phytoplankton after the winter. The general high diversity during the late summer is the result of a more complex environment determinated by thermal stratification in all of these lochs, which make possible the co-existence of a relatively large number of groups. The high winter diversity of the plankton in Loch Rusky was particularly different from other lochs.

Primary production

The seasonal variations of primary production only correspond with that of phytoplankton biomass in autumn and early April. During April increasing algal populations (mainly composed of diatoms) were followed by a very striking production peak. Afterwards, low primary production prevailed when light and phytoplankton biomass

were increasing. The observed results may be accounted for several environmental and technical factors. It is likely that the problems with the malfunction of the scintillation counter, particularly from May onwards, may have introduced some unknown degree of unreliability in the results (see Page 111).

Through the summer months the general depletion in nutrients and increasing algal respiration under conditions of high temperatures may be limiting factors on the primary production (Waite & Duthie, 1974, Morris, 1980). The rapid rise in the standing crop of the nanoplankton in the epilimnion corresponded with the very low summer production peak. This is in contrast to the higher turnover rates and productivity normally recorded for this phytoplankton group (Findenegg, 1965; Kristiansen, 1971; Lund, 1961).

It seems unlikely that heterotrophic growth was carried out by the nanoplanctonic species C.ovata and R.minuta (Rodhe, 1962). A possible differential source of error could be introduced in the primary production method during the process of filtration of labelled samples, due to the greater susceptibility to damage and loss of fixed carbon in naked flagellates (such as R.minuta) (Arthur & Rigler, 1967). This is in agreement with the slightly higher variance calculated for filtration in the routine

Carbon-14 method used in this study to measure plankton productivity (see mat. and meth. page 26) and with the increase of production resulted in the hypolimnion, where a larger diverse net phytoplankton groups were represented (e.g. Diatoms, Cyanobacteria).

The quantitative error introduced by both filtration and scintillation counting stages is unknown, nevertheless it is unlikely that it could completely account for the observed primary production results.

The primary production peak during the winter months (Dec-Jan) did not correspond with the standing crop recorded at this time, but increases in pH and oxygen values in the upper waters during these months correborated the rise in productivity. The parallel increase in production observed with depth in winter in both, dark and light bottles, could be the result of a high heterotrophic carbon fixation produced in the dark beneath the euphotic zone.

Comparative study of plankton succession with the previous work: Maulood, 1972-1973.

The plankton succession for the main diatoms species (A. formosa, T. fenestrata and M. italica) in the two studies remained similarily characterized in time and space,

CONCLUSIONS

CONCLUSIONS

The seasonal environmental parameters and phytoplankton succession patterns were fairly consistant through the time since Maulood's previous study in 1972-73. The reduction in pH through this period is a further problem which should be considered in the maintenance of the fish stock and freshwater life in the Loch and to be noted in future studies.

The seasonal variations of the phytoplankton community in Loch Rusky, were mainly controlled by nutrient, temperature, and insolation levels and water turbulence. Decreasing insolation through late autumn caused a parallel decline in phytoplankton numbers. In spring both light and plankton began again to increase at a time when nutrient levels were already high. The phytoplankton community dominated by the diatoms Asterionella formosa and Melosira italica, was strikingly affected by silicate concentrations and water turbulence. Through summer under depleted nutrient levels and water stratification, the composition of the community rapidly shifted from diatoms to nanoplanktonic species such as Cryptomonas ovata and Rhodomonas minuta. These are more efficient at absorbing nutrients because of the high surface to volume ratio and actively able to resist sinking, so that they rapidly reached a rapid maximum

biomass.

The start of the autumn overturn in September and associated turbulence and nutrient supply, lead to an increase in numbers of both cryptomonads and diatom groups. The late autumnal succession of Cyanobacteria appeared to be related to heterotrophic conditions, especially influenced by maximum seasonal input of organic matter in the loch.

The seasonal zooplankton pattern displayed marked variations in relation to phytoplankton composition and concentration. The general dominance of rotifers through most of the year was related to their faster rate of reproduction compared with Cladocera and Copepoda. The seasonal pattern of growth presents evidence of a feeding relationship between Polyarthra remata and Cryptomonas ovata. The seasonal variations of rotifers were also determinated by temperature and possible suplementary food sources.

The primary production of the phytoplankton showed low correlation with standing crop, being higher during winter and spring than in summer. It is likely that the disfunction of the Carbon-14 scintillation counts since April masked the results over this period. Loss of carbon fixed by rupture of flagellates cells (R minuta) during

filtration in summer would also help account for this discrepancy. Primary production was presumably controlled by light as the limiting factor in winter while depleted nutrient concentrations were important in summer. The general data obtained on productivity in this study characterized Loch Rusky as oligotrophic, in contrast to Maulood's assertion that the Loch showed a shift to eutrophic conditions. This conclusion was perhaps influenced by the short term addition at that time of artificial fertilization in the Loch and its catchment.

APPENDIX

APPENDIX I

METHOD FOR THE ESTIMATION OF SOLUBLE REACTIVE PHOSPHATE

In acid solution phosphate and molybdate - molybdo - phosphoric acid which is then reduced to molybdenum blue complex.

REAGENTS

a) Sulphuric acid 14% v/v.

b) Amonium molybdate solution.

Dissolve 30g (NH) Mo O .4H) in 800 ml warm distilled water, cool and make up to 1 litre.

c) Ascorbic Acid solution

Dissolve 5.4g of ascorbic acid in water and make up to 100ml. This solution does not keep well and should be freshly prepared every time.

d) Potassium Antimonyl tartrate solution

Dissolve 0.68g of KSbo.C H O in water and make up to 200ml

e) Butan - 1 -ol

f) Working reagent

Prepare immediately before use from reagents (a), (b), (c), (d) in the following proportions:

WORKING REAGENT

(a) 5: 100ml Sulphuric acid 14%)

(b) 2: 40ml Ammonium molybdate

(c) 2: 40ml Absorbic acid

(d) 1: 20ml Potassium antimonyl tartrate 200ml

PROCEDURE

Measure 200m (l) of sample into a 250ml separating funnel. Add 20ml of the freshly prepared working reagent (f) to the sample and mix. Allow to stand for 10 minutes.

Add 29ml of Butan -1-Ol to the flask and shake for 1 minute. Allow to stand until *the layers have separated. Run off the aqueous layer and run the solvent layer into the 10ml measuring cylinder. Maake up the volume to 10ml with methylated spirits, pour into a 4cm cuvette and read the acsorbance at 690mm against a blank prepared from distilled water.

*Discard the aqueous layer.

STRONG ACID SALTS (SULPHATE, CHLORIDE, NITRATE)

All cations exchanged for H ions. Effluent consist of solution of free acids corresponding to salts originally present and in equivalent concentration. Titrating to pH4.5 excludes weak acids.

1. Cation exchange material.
2. N/100 potassium hydroxide solution. Make up when required from a stock of N strength.
3. B.D.H. 4.5 indicator.

Pass approximately 100cc sample through the column, discarding the first 20cc of efflent and collecting the remainder suitable aliquot of efflent (say 25cc) pippetted into 100cc conical flask, 2 drops of indicator added and the solution titrated to pH 4.5 with N/100 potassium hydroxide. The colour change is from orange to grey; blue indicates the titration has gone to far.

If "x"cc of N/100 potash are consumed in titration of "y"cc of effluent, then the concentration of strong acid salts is 10x/y meq/l.

SULPHATE AND NITRATE Silver part of exchange column removes chloride as insoluble silver halide. Soluble silver sulphate and silver nitrate pass through to H half and finally emerge as sulphuric and nitric acids. Pass 100cc of sample through column discarding the first 20cc of effluent. The remainder is collected and a suitable aliquot is titrated in exactly the same way as for total strong acids. The difference between results for total strong acids and sulphate and nitrate gives the concentration of chloride in meq/l.

SILICATE

N.B. In acid solution silicic acid + molybdate - yellow heteropoly (molybdosilicic) acids which are then reduced to silicomdybdenum blues.

1. Acid ammonium molybdate. Shake 2g ammonium molybdate with about 70cc water, add 6cc conc. HCL and dilute to 100cc. store in polythene bottle.
2. Oxalic acid. 10g of oxalic acid dehydrate (C O h. H O) to 100c water.
3. Sulphuric acid, 25% v/v.
4. Metol sulphate solution - 3g sodium sulphite (anhyd.) 5g metol, to 250cc water, filter (No.1 peper) and store in dark bottle.

5. Reducing agent. mix 100cc metol sulphite with 60cc oxalic acid and add while cooling 120cc sulphuric acid.

Dilute to 300cc. PRepare afresh fortnightly.

USE PLASTIC WARE

Pipette 20cc sample into 50cc graduated stoppered flask. Add cc of acid molbdate reagent and mix. After 10mins. add 15cc reducing agent from a measuring cylinder and make up to 50cc with water. Allow to stand 3 hours. Transfer sample to 4-cm, cell and read extinctionat 812 mu against a similarly prepared blank.

NITRATE

*1. Phenoldisulphonic acid
2. Magnesium sulphate: 10% Solution of crystalline $M_{g}SO_{4}$ $7H_{2}O$ w/v
3. Sodium hydroxide, appro. 40% solution.
4. Red litmus paper.

METHOD

Evaporate 100cc sample to dryness in 200cc flask. To the residue add 2cc phenoldisulphonic acid. Revolve flask to

wet residue completely with acid and allow to stand for 10 minutes. Wash acid to bottom of flask with not more than 80cc water, and add 2cc magnesium ulphate and a small piece of litmus paper. Add sodium hydroxide, until the litmus paper just stays blue when the solution is mixed. A precipitate of magnesium hydroxide forms which carries with it any organic colouration of the water. Transfer to 100ml vol. flask and make volume up to 100ml exactly, mix and centrifuge at least 50cc to remove the precipitate. Measure the yellow colour which develops on the spectrophotometer at 410mu.

COD. (PERMANGANATE OXIDATION OF ORGANIC MATTER)

1.* N/80 Potassium permanganate. Make up when required from a stock solution of N/10 (3.161g KMnO/1.

2. N/80 (approx.) sodium thiosulphate.

3. Potassium iodide, 5% solution.

4. Starch solution.

5. Sulphuric Acid, 25% v/v.

METHOD

To 100cc sample in a 250cc flask add 10ml permanganate solution and 10cc H_2SO_4. (For control use distilled water).

Place flasks in a boiling water bath for 30 mins, cool the flasks, add 1cc iodide solution, shake, and titrate the iodine produced with thiosulphate solution from a burette, using a starch solution for the end point.

If "a" is number of cc of thiosulphate equivalent to 10cc N/80 permanganate (control) and "b" is cothiosulphate used in titration of sample, then the amount of oxygen absorbed by the sample is 10 (a-b) amg O_2/1.

AMMONIA

N.B. Ammonia reacts with phenol and hypochlorite in alkalive sol'n to form indophenol blue, catalyzed by nitroprusside. Proportional to amount of ammonia present.

REAGENTS

1. Phenol - alcohol solution: 10g reagent grade Phenol in 100cc 95% alcohol and 5% Prpanol.

2. Sodium nitroprusside: 1g sodium nitroprusside in 200cc water. Store in amber bottle for not more than one month.

3. Alkaline solution: 100g trosodium citrate and 5g sodium hydroxide made up to 500cc with water.

4. Sodium hypochlorite: Commercial grade.

5. Oxidising solution: 100cc solution 3 and 25cc solution 4. This is stable for less than 1 day.

METHOD

To 50cc sample, add 2cc phenol solution, 2cc sodium nitroprusside, and 5cc oxidising reagent, successively, mixing thoroughly after each addition. Let mixture stand for 1hr at room temperature (20-27°C). Absorbance unchanged for at least 24 hours. Measure absorbance at 640mu in 4cm cuvette. Then use calibration curve.

ALKALINITY (BICARBONATE). (weak acid salt)

1. N/100 hydrochloric acid. Make up when required, from stock solution of N HCL.
2. B.D.H. 4.5 indicator.

METHOD

Pippette 100cc sample into conical flask, add 5 drops of

indicator and run in standard acid from 10cc burette with continuous shaking until the end point is reached. The colour change is from blue to grey (almost colourless). Yellow or red indicates the titration has gone too far.

N/100 acid contains 0.01meq of acid in each ml, so each cc of acid used in titration corresponds to 0.01 meq bicarbonate ion in 100cc sample, or 0.1 meq/l of sample. If v ml acid used in titration, the concentration of bicarbonate in sample is 0.1 × v meq/l.

Loch Rusky.

Elevation	445 feet 135.6 metres
Length	0.5 miles 800 metres
Breadth	MAX 0.4 miles, MEAN 0.3 miles 640 metres, 480 metres
Depth	44 feet 13.2 metres
Volume	14 545 $\times 10^6 m^3$
Loch Area	0.074 sq. miles 192,000 m^2
Total Catchment Area	1.16 sq. miles 3 Km^2
Total Drainage Forest Area	1 sq. mile 2.675 Km^2
Area Catchment into inflow	1,590,000 m^2 1.59 Km^2
Area Catchment into the Loch	1,375,000 m^2 1.375 Km^2

Table I. Temperature- Oxigen Profile for Loch Rusky.

	29.10.85		13.11.85		27.11.85		12.12.85		21.1.86		4.2.86		12.3.86		25.3.86		8.4.86	
	T°C	O %	T°C	O %	T°C	O %	TC	O %	T°C	O %	T°C	O %	T°C	O %	T°C	O %	T°C	O %
SURFACE	10	96	5.5	96	4.0	100	4.0	92	4.5	120	4.0	92	4.5	100	6.0	96	6.5	96
1 m	9.5	94	5.5	90	4.0	98	4.0	92	4.5	112	3.5	92	4.5	98	6.0	96	6.5	96
2 m	9.5	94	5.5	92	4.0	96	4.0	92	4.5	110	3.5	92	4.5	98	6.0	95	6.5	96
3 m	9.25	94	5.5	96	4.0	94	4.0	94	4.5	106	3.5	92	4.5	98	5.5	95	6.5	96
4 m	9.25	92	5.5	94	4.0	94	4.0	93	4.5	106	3.5	92	4.5	92	5.5	95	6.5	96
5 m	9.25	96	5.5	94	4.0	92	4.0	92	4.5	106	3.5	92	4.5	92	5.5	95	6.5	96
6 m	9.25	96	5.5	94	4.0	92	4.0	92	4.5	106	3.5	94	4.5	92	5.5	95	6.5	96
7 m	9.25	98	5.5	97	4.0	92	4.0	92	4.5	106	3.5	94	4.5	92	5.5	95	6.5	96
8 m	9.0	97	5.5	96	4.0	92	4.0	92	4.5	106	3.5	94	4.5	92	5.5	95	6.5	96
9 m	9.0	97	5.5	98	4.0	92	4.0	92	4.5	105	3.5	94	4.5	92	5.5	94	6.5	96
10m	9.0	96	5.5	97	4.0	93	4.0	92	4.5	104	3.5	94	4.5	92	5.5	92	6.5	96
11m	9.0	–	5.5	97	4.0	92	4.0	92	4.5	104	3.5	94	4.5	92	5.5	96	6.5	96
12m	–	–	5.5	–	4.0	92	4.0	92	4.5	104	3.5	94	4.5	92	5.5	95	6.5	96

TableI (cont). Temperature-Oxigen Profile for Loch Rusky.

	23.4.86		8.5.86		20.5.86		3.6.86		1.7.86		15.7.86		5.8.86		19.8.86		2.9.86	
	T C	O %	T C	O%	T C	O %	T C	O %	T C	O %	T C	O %	T C	O%	T C	O%	T C	O%
SURFACE	6.5	104	9.0	90	10	135	12.5	127	20.0	127	17.0	129	16.0	116	15.0	135	12.5	132
1 m	7.0	104	9.0	86	10	135	12.5	127	20.0	126	17.0	125	15.0	101	15.0	135	12.5	129
2 m	7.0	104	9.0	83	10	133	12.5	127	20.0	114	17.0	125	15.0	104	15.0	124	12.5	129
3 m	7.0	102	9.0	85	10	135	13.0	129	18.0	110	17.0	118	15.0	101	15.0	116	12.5	129
4 m	7.0	102	9.0	84	10	135	13.0	121	17.0	106	17.0	107	15.0	93	15.0	133	12.5	129
5 m	7.0	102	9.0	84	10	133	12.5	120	15.0	93	16.0	89	14.5	92	15.0	104	12.5	128
6 m	7.0	102	9.0	84	10	135	12.5	115	15.0	93	15.0	75	14.0	91	14.0	95	12.5	128
7 m	7.0	101	9.0	83	10	135	12.0	110	14.0	91	14.0	71	14.0	85	14.0	91	12.5	127
8 m	7.0	101	9.0	83	10	135	11.5	111	13.0	89	13.0	71	14.0	61	13.5	66	12.5	125
9 m	7.0	101	9.0	83	10	133	11.5	111	12.5	86	12.5	71	12.0	39	13.0	55	12.5	122
10m	7.0	101	9.0	83	10	134	11.0	111	12.0	85	12.0	70	12.0	29	12.5	29	12.5	118
11m	7.0	98	9.0	81	10	134	11.0	92	12.0	83	12.0	68	11.0	24	12.0	21	12.5	113
12m	7.0	98	9.0	77	10	134	11.0	91	12.0	81	12.0	64	11.0	–	11.5	–	12.5	–
13m	7.0	98	9.0	72	–	–	11.0	83	11.5	71	11.5	59	–	–	–	–	–	–
14m	7.0	98	9.0	72	–	–	–	–	11.0	68	11.5	57	–	–	–	–	–	–
15m	7.0	98	9.0	72	–	–	–	–	11.0	–	11.5	–	–	–	–	–	–	–

APPENDIX II (Cont'd)

Table II. Water Chemistry of Loch Rusky.

		29.10.85	13.11.85	27.11.85	12.12.85	21.1.86
ALKALINITY (meq/l)	S	0.226	0.220	0.234	0.184	0.170
	1m	0.206	0.232	0.184	0.186	0.164
	3m	0.230	0.226	0.224	0.188	0.156
	5m	0.232	0.230	0.228	0.194	0.162
	10m	0.242	0.310	0.238	0.200	0.160
AMMONIA (µg/l)	S	140	—	35	—	—
	1	135	—	40	—	—
	3	125	—	45	—	Trace
	5	120	—	50	—	—
	10	120	—	50	—	—
C.O.D (mgO_2/l)	S	16.48	18.06	16.20	15.74	13.70
	1	14.88	15.56	17.44	16.68	13.86
	3	14.88	18.06	17.70	16.52	14.90
	5	15.00	18.86	17.90	15.82	13.94
	10	15.40	18.52	17.54	15.82	12.70
NITRATE (µg/l)	S	140	190	155	60	225
	1	140	170	120	15	210
	3	140	250	125	55	220
	5	160	165	165	55	175
	10	105	155	160	40	175
PHOSPHATE (µg/l)	S	0.85	0.85	3.75	1.40	0.90
	1	0.80	0.90	1.25	1.20	0.75
	3	1.00	0.80	1.15	1.05	1.10
	5	0.85	1.00	1.50	0.85	1.00
	10	0.90	0.95	1.40	1.10	0.95
STRONG ACID (meq/l)	S	0.520	0.552	0.560	0.500	0.612
	1	0.632	0.484	0.540	0.524	0.584
	3	0.504	0.452	0.496	0.492	0.596
	5	0.520	0.472	0.588	0.476	0.588
	10	0.640	0.492	0.560	0.480	0.572
SULPHATE + NITRATE (meq/l)	S	0.40	0.248	0.324	0.276	0.252
	1	0.40	0.328	0.340	0.288	0.240
	3	0.44	0.300	0.352	0.284	0.256
	5	0.24	0.320	0.364	0.276	0.260
	10	0.32	0.296	0.348	0.280	0.256
CHLORIDE (meq/l)	S	0.120	0.304	0.236	0.224	0.360
	1	0.368	0.156	0.200	0.236	0.344
	3	0.064	0.152	0.144	0.208	0.340
	5	0.280	0.152	0.224	0.200	0.328
	10	0.320	0.196	0.212	0.200	0.316
SILICATE (mgSil/l)	S	0.22	3.70	3.52	3.42	5.28
	1	0.22	3.74	3.54	3.12	6.72
	3	0.22	3.70	3.62	3.42	6.00
	5	0.24	3.64	3.76	3.28	4.96
	10	0.24	3.75	3.82	3,46	5.60

Table II (Cont.). Water Chemistry of Loch Rusky.

		4.2.86	12.3.86	25.3.86	8.4.86
ALKALINITY (meq/l)	S	0.170	0.190	0.172	0.206
	1	0.163	0.194	0.190	0.194
	3	0.164	0.182	0.176	0.186
	5	0.159	0.168	0.166	0.196
	10	0.148	0.184	0.170	0.184
	IF	0.341	0.212	0.222	0.700
AMMONIA (µg/l)	S	-	-	30.00	-
	1	Trace	Trace	15.00	-
	3	-	"	35.00	-
	5	-	"	20.00	-
	10	Trace	"	25.00	-
	IF	Trace	"	-	-
C.O.D (mgO_2/l)	S	11.98	11.20	10.15	8.69
	1	11.98	12.94	10.21	8.79
	3	12.12	12.58	10.56	8.88
	5	12.04	12.50	9.44	8.73
	10	12.36	12.46	10.09	8.71
	IF	9.26	14.76	6.97	7.60
NITRATE (µg/l)	S	175.00	205.00	140.00	185.00
	1	198.5	225.00	240.00	180.00
	3	233.5	230.00	235.00	165.00
	5	230	265.00	165.00	220.00
	10	228.5	225.00	250.00	210.00
	IF	180	265.00	215.00	120.00
PHOSPHATE (µg/l)	S	0.745	0.80	0.45	0.40
	1	1.05	0.95	0.45	0.30
	3	1.375	0.75	0.45	0.30
	5	1.16	0.65	0.50	0.35
	10	1.60	0.80	0.45	0.35
	IF	2.15	0.30	-	0.60
STRONG ACID (meq/l)	S	0.764	0.740	0.728	0.680
	1	0.724	0.668	0.700	0.693
	3	0.676	0.668	0.672	0.686
	5	0.760	0.560	0.608	0.680
	10	0.700	0.668	0.680	0.646
	IF	0.518	0.692	0.656	0.673
SULPHATE + NITRATE (meq/l)	S	0.300	0.256	0.304	0.240
	1	0.296	0.256	0.260	0.253
	3	0.292	0.240	0.244	0.260
	5	0.296	0.248	0.236	0.246
	10	0.288	0.252	0.252	0.253
	IF	0.312	0.248	0.260	0.220
CHLORIDE (meq/l)	S	0.464	0.484	0.424	0.440
	1	0.428	0.412	0.440	0.440
	3	0.384	0.428	0.428	0.426
	5	0.464	0.312	0.372	0.434
	10	0.412	0.416	0.428	0.393
	IF	0.206	0.444	0.396	0.453
SILICATE (mg/l)	S	3.62	3.04	2.60	2.88
	1	4.14	3.36	2.00	3.56
	3	4.32	2.40	3.52	3.32
	5	3.18	3.56	1.56	3.84
	10	4.34	3.84	2.04	2.68
	IF	4.92	3.96	4.80	4.44

TableII(cont.b.). Water Chemistry of Loch Rusky.

		23.4.86	8.5.86	20.5.86	3.6.86	1.7.86
ALKALINITY (meq/l)	S	0.058	0.126	0.120	0.166	0.158
	1	0.050	0.120	0.128	0.160	0.158
	3	0.062	0.130	0.124	0.158	0.148
	5	0.060	0.120	0.124	0.176	0.148
	10	0.056	0.144	0.116	0.162	0.156
	IF	0.100	0.136	0.170	0.338	0.720
AMMONIA (µg/l)	S	–	–	–	Trace	95
	1	–	–	–	–	100
	3	–	–	–	Trace	95
	5	–	–	–	–	100
	10	–	–	–	–	90
	IF	–	–	–	–	55
C.O.D (meq/l)	S	7.06	8.49	15.40	8.59	8.786
	1	8.46	8.51	7.87	8.61	8.946
	3	8.51	8.75	8.72	8.66	8.590
	5	–	8.79	8.35	8.77	8.590
	10	8.05	8.77	8.80	8.45	8.574
	IF	8.36	9.54	8.27	8.45	10.146
NITRATE (µg/l)	S	190	130	170	125	100
	1	125	160	170	120	115
	3	180	165	185	80	95
	5	185	160	185	125	90
	10	120	175	170	160	70
	IF	105	125	110	60	110
PHOSPHATE (µg/l)	S	0.35	0.40	0.30	0.45	0.30
	1	0.25	0.45	0.20	0.40	0.25
	3	0.20	0.45	0.15	0.40	0.35
	5	0.10	0.45	0.25	0.45	0.30
	10	0.35	0.40	0.30	0.40	0.25
	IF	0.40	1.80	0.35	0.75	1.40
STRONG ACID (meq/l)	S	0.675	0.76	0.68	0.691	0.649
	1	0.744	0.71	0.71	0.681	0.697
	3	0.700	0.69	0.66	0.671	0.686
	5	0.710	0.69	0.72	0.713	0.657
	10	0.625	0.66	0.68	0.668	0.718
	IF	0.784	0.63	0.62	0.610	0.703
SULPHATE + NITRATE (meq/l)	S	0.250	0.26	0.30	0.290	0.240
	1	0.250	0.24	0.27	0.246	0.250
	3	0.255	0.25	0.26	0.229	0.285
	5	0.260	0.23	0.23	0.249	0.251
	10	0.225	0.25	0.28	0.246	0.258
	IF	0.250	0.25	0.24	0.257	0.330
CHLORIDE (meq/l)	S	0.425	0.50	0.38	0.401	0.409
	1	0.494	0.47	0.44	0.435	0.447
	3	0.445	0.44	0.40	0.442	0.401
	5	0.450	0.46	0.49	0.464	0.406
	10	0.400	0.41	0.40	0.422	0.460
	IF	0.534	0.38	0.38	0.353	0.373
SILICATE (mg/l)	S	1.80	1.96	1.60	0.82	0.08
	1	2.16	2.12	1.54	0.90	0.10
	3	2.16	1.78	1.32	0.88	0.10
	5	2.92	1.90	1.54	0.90	0.20
	10	1.80	2.32	1.66	1.36	0.10
	IF	3.72	2.84	2.22	2.52	4.48

Table II (cont.d). Water Chemistry of Loch Rusky.

		15.7.86	5.8.86	19.8.86	2.9.86
ALKALINITY (meq/l)	S	0.164	0.190	0.186	0.204
	1	0.178	0.172	0.202	0.210
	3	0.166	0.174	0.220	0.222
	5	0.190	0.182	0.202	0.208
	10	0.182	0.190	0.200	0.204
	IF	0.802	0.454	0.366	0.870
AMMONIA (ng/l)	S	Trace	–	–	–
	1	25	–	–	Trace
	3	–	–	–	–
	5	–	–	–	–
	10	55	30	35	–
	IF	–	–	Trace	–
C.O.D (meq/l)	S	8.39	7.82	7.95	10.29
	1	8.64	8.24	8.00	12.54
	3	8.47	7.63	8.51	10.42
	5	8.25	7.88	7.55	10.10
	10	8.50	7.76	8.36	10.56
	IF	5.95	8.22	8.78	11.28
NITRATE (ng/l)	S	90	110	95	80
	1	85	100	80	95
	3	65	110	90	60
	5	100	120	100	90
	10	90	145	130	85
	IF	35	100	80	50
PHOSPHATE (ng/l)	S	0.20	0.30	0.15	0.20
	1	0.25	0.20	0.20	–
	3	0.25	0.25	0.10	–
	5	0.30	0.30	0.15	0.30
	10	0.35	0.40	0.40	0.25
	IF	1.20	0.85	0.40	0.40
STRONG ACID (meq/l)	S	0.666	0.70	0.808	0.573
	1	0.695	0.73	0.944	0.740
	3	0.700	0.67	0.824	0.653
	5	0.678	0.70	0.920	0.780
	10	0.692	0.72	0.880	0.700
	IF	0.618	0.67	0.720	0.606
SULPHATE + NITRATE (meq/l)	S	0.328	0.31	0.376	0.326
	1	0.263	0.30	0.336	0.313
	3	0.405	0.35	0.304	0.293
	5	0.266	0.36	0.320	0.320
	10	0.281	0.32	0.344	0.373
	IF	0.256	0.36	0.432	0.306
CHLORIDE (meq/l)	S	0.338	0.39	0.432	0.247
	1	0.432	0.43	0.608	0.427
	3	0.295	0.32	0.520	0.360
	5	0.412	0.34	0.600	0.460
	10	0.411	0.40	0.536	0.327
	IF	0.362	0.31	0.288	0.300
SILICATE (ng/l)	S	0.12	0.20	0.36	0.42
	1	0.16	0.24	0.40	0.42
	3	0.12	0.26	0.36	0.42
	5	0.22	0.26	0.54	0.36
	10	0.78	0.54	0.78	0.40
	IF	4.16	2.06	2.88	2.

APPENDIX II (Cont'd)

Table III. pH - Profile for Loch Rusky.

	29.10.85	13.11.85	27.11.85	12.12.85	21.1.86	4.2.86	12.3.86	25.3.86	8.4.86.
	pH	pH	pH	pH	pH	pH	pH	pH	pH
SURFACE	5.7	5.8	6.1	5.9	6.8	5.75	6.2	6.9	6.4
1 m	5.6	5.9	6.2	5.9	6.4	5.7	6.0	6.0	6.2
3 m	5.6	5.8	6.1	6.0	6.35	5.8	6.0	5.75	6.1
5 m	5.6	5.8	6.1	5.8	6.3	5.75	5.9	5.8	6.1
10 m	5.6	5.8	6.1	5.8	6.25	5.7	5.9	5.65	6.0
IF	-	-	-	-	-	5.8	5.6	5.8	6.4

Table III. (Cont'd) pH - Profile for Loch Rusky.

	23.4.86	8.5.86	20.5.86	3.6.86	1.7.86	15.7.86	5.8.86	19.8.86	2.9.86
	pH	pH	pH	pH	pH	pH	pH	pH	pH
SURFACE	6.35	6.4	6.1	6.05	6.15	6.50	6.50	6.8	5.7
1 m	6.40	6.2	6.1	6.20	6.10	6.45	6.40	6.75	6.0
3 m	6.30	6.1	6.15	6.20	6.05	6.30	6.30	6.65	6.15
5 m	6.30	6.1	6.2	6.20	5.90	5.90	6.25	6.50	6.15
10 m	6.25	6.0	6.2	6.05	5.75	5.65	5.80	6.10	6.10
IF	6.20	6.0	6.1	6.30	6.50	6.75	6.50	6.50	6.50

APPENDIX III

Table IV Light penetration (µenst..)

	29.10.85	13.11.85	20.5.86	3.6.86.	1.7.86
Surface	700	250	180	380	700
1m	15	9	17	49	150
2m	2.5	1.1	5	14	50
3m	0.25	0.2	1.7	3.5	14
4m	0.05	-	0.5	0.95	2.5
5m	-	-	0.2	0.30	0.45
6m	-	-	0.1	0.15	0.10
7m	-	-	0.05	-	0.05
8m	-	-	0.025	-	-

APPENDIX IV

Table V Total production of energy in water column.

	($J/m^2/hr$)	($J/m^2/day$)	Light hours per day
29.10.85	1.183	10.971	9hr.30 min.
13.11.85	573	4.721	8hr.25 min.
27.11.85	304	2.242	7hr.36 min.
12.12.85	2660	18.704	7hr.03 min.
21.01.86	1985	17.029	8hr.58 min.
04.02.86	486	4.522	9hr.30 min.
12.03.86	309	3.498	11hr.33 min.
25.03.86	1476	19.535	13hr.23 min.
08.04.86	10.593	141.841	13hr.39 min.
23.04.86	338	5.239	15hr.47 min.
08.05.86	283	4.390	15hr.52 min.
20.05.86	767	13.247	17hr.27 min.
03.06.86	535	9.192	17hr.16 min.
01.07.86	807	13.977	17hr.31 min.
15.07.86	955	16.257	17hr.03 min.
05.08.86	328	5.400	16hr.48 min.
19.08.86	172	2.626	15hr.30 min.
02.09.86	746	10.043	13hr.47 min.

APPENDIX V

Table VI Chlorophyll a (mg/litre).

Date	Surface	1m	10m
08.05.86	2.732	3.786	3.606
20.05.86	2.737	2.677	2.223
03.06.86	6.2455	6.0065	5.7665
01.07.86	2.975	2.856	2.142
15.07.86	1.9040	0.7735	-
05.08.86	4.1055	4.2840	1.0115
19.08.86	4.8195	4.8195	1.3685
02.09.86	5.5335	3.0345	2.5585

APPENDIX V (Cont'd)

Table VII Total Biomass of phytoplankton (ind or colonies/l)

Date	Surface	1m	3m	5m	10m
29.10.85	11.444	9.649	7.471	7.983	25.341
13.11.85	5.008	9.558	9.236	10.323	15.682
27.11.85	49.730	28.107	93.254	40.732	177.987
12.12.85	10.574	5.678	87.768	6.032	46.590
21.01.86	4.149	4.528	4.503	3.640	4.606
04.02.86	4.163	4.289	34.362	4.380	5.217
12.03.86	4.818	4.622	5.012	8.727	5.864
25.03.86	7.634	5.016	5.767	5.528	8.978
08.04.86	152.061	98.362	106.399	160.649	159.446
23.04.86	22.165	20.664	17.648	18.625	19.261
08.05.86	107.282	113.534	92.981	118.087	125.729
20.05.86	62.696	90.769	84.408	72.175	70.823
03.06.86	155.077	130.029	150.889	142.307	145.851
01.07.86	29.294	22.383	25.867	45.635	40.869
15.07.86	2308.876	301.174	9.256	10.728	5.690
0.5.08.86	31.820	49.374	28.743	14.712	6.233
19.08.86	16.449	40.176	30.531	12.099	7.863
02.09.86	20.044	31.715	30.325	31.301	20.727
TOTAL	1,003.262	968.627	824.419	713.663	892.759

APPENDIX VI

Diatoms (nº Cells colony.)

	1985				1986														
	Oct	Nov		Dec	Jan	Feb	March		April		May		June	July		Aug		Sept
Date	29	13	27	12	21	4	12	25	8	23	8	20	3	1	15	5	19	2
Asterionella formosa	7	9	9	6	7	7	8	8	-	-	5	7	8	6	5	7	7	10
T. fenestrata	5	6	6	5	3	3	4	7	-	-	8		8	8	4	8	8	11
T. flocculosa	-	2	2	2	2	1	1	1	-	-	16		2	2		2	8	
Melosira italica	17	21	18	18	12	15	20	20	-	-				11	12		18	33

	Average cells/colony autumn - winter	Average spring - summer
Asterionella formosa	8	6
T .fenestrata	5	8
T. flocculosa	2	2
Mel. italica	18	14

*. September number/per colony was not considered in the average.

APPENDIX VII

Table VIII Total zooplankton biomass (ind/l)

Date	Surface	1m	3m	5m	10m
29.10.85	31	6	19	6	8
13.11.85	26	40	19	37	41
27.11.85	52	18	32	68	28
12.12.85	14	6	4	24	12
21.01.86	22	14	10	12	3
04.02.86	15	17	14	18	20
12.03.86	18	19	14	19	24
25.03.86	18	19	16	15	31
08.04.86	56	36	46	56	30
23.04.86	84	40	24	40	28
08.05.86	108	176	96	96	112
20.05.86	32	336	304	108	100
03.06.86	88	68	64	148	176
01.07.86	20	56	188	228	84
15.07.86	32	68	36	48	44
05.08.86	52	72	24	32	20
19.08.86	76	132	60	44	20
02.09.86	84	76	92	36	96
TOTAL	828	1199	1062	1035	867

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