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THE MONITORING OF LOCH LEVEN MACROPHYTES

DR A E BAILEY-WATTS

Plankton Ecology Project Group
78 Craighall Road
Edinburgh
EH6 4RQ

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FINAL REPORT TO THE NATURE CONSERVANCY COUNCIL ON THE MONITORING OF LOCH LEVEN MACROPHYTES (NCC/NERC CONTRACT NO. F3/03/73: ITE PROJECT NO. 497).

Dr. A.E. Bailey-Watts - Plankton Ecology Project Group

78 Craighall Road, Edinburgh. EH6 4RQ.

Introduction

This is the last of three annual accounts of studies on the macrophyte community of the shallow, eutrophic Loch Leven, Kinross, Scotland. First, it considers site and plant community features that have a special bearing upon the approaches adopted and, indeed, influenced the preliminary and exploratory character of the study as laid out in the project plan. Second, the methods employed are described. These methods fall into two main groups (a) those relating to assessments of plant distribution and abundance in the loch itself, and (b) those concerned with more remote surveillance by aerial photography. Third, the results obtained are presented, and, finally, the whole study is discussed, with especial emphasis on a proposed improvement of the methods; a programme for future work is suggested. While no general review of freshwater macrophyte work is attempted, some reference is made to a few publications, mainly those dealing specifically with Loch Leven.

The site and some general features of the macrophyte community

Aspects of the biology and ecology of a wide range of plant and animal communities in Loch Leven have been studied regularly since the mid-1960's. However, chemical analyses of the water were started by the Freshwater Fisheries Laboratory in the late 1950's and isolated biological and morphometric studies extend back as far as the early 1900's - commencing with that included in Murray & Pullar's outstanding general limnological contribution (1912). The results of much of the more recent work are summarised in a collection of papers presented at a Royal Society of Edinburgh/Stirling University sponsored symposium (R.S.E. 1974) on the Loch Leven International Biological Programme (1966-1972); since the start of that study, some 100 research papers have been published by the Loch Leven Research Group, which has also produced brief annual accounts of its work (Ann. Rep. Loch Leven Research Group 1972/73, 1974, 1975, 1976 and 1977).

Features of especial relevance to the present study are as follows. The loch (Figure 1) covers an area of 13.3 km^2 within an agriculturally rich catchment of some 10 times this size. Despite the presence of two areas ("kettle-holes" - Soons 1960) approximately 23 m deep, the mean depth of the loch is only 3.9 m (Smith 1974); areas where the total water depth is 3 m or less extend into the loch for more than 1½ km from the exposed north-east shore. Whereas the more organic sediments occur in areas deeper than 3 m, those in shallower waters usually consist of sand or muddy sand underlain by clay. The latter support a microflora of bacteria (Meadows & Anderson 1966) and epipsammic algae (Bailey-Watts 1973, 1974), with abundant invertebrate zoobenthos (Maitland & Hudspith 1974, Charles _et al_ 1974).

It is the areas where the depth of water does not exceed 3 m with which the present study is mainly concerned; these total some 6.7 km^2. However, the loch, as a whole, is of considerable importance in the general ecology of the higher plants, particularly in the direction and intensity of water movements (Smith 1974), the external loading, internal cycling and circulation of dissolved nutrients (Holden & Caines 1974) and the growth of planktonic algae (Bailey-Watts 1978). The influence on macrophytes of these features, through the impact on bed stability, underwater light penetration, nutrient concentrations and phytoplankton distribution have been recognised by Britton (1974) Jupp _et al_ (1974) and Jupp (1975) and Jupp & Spence (1977 a,b.). Jupp's work lays the foundation for subsequent studies, and was consulted at the outset of this programme. Of its main conclusions, those of most direct relevance to the strategies adopted here relate to the generally low abundance of plants; dense stands, consisting mainly of _Potamogeton filiformis_ Pers., occurred (e.g. 1972) only in very localised patches off the Grahamstone and North St. Serf's Island shores.

Preliminary field trials involving dragraking (described below) were carried out in September 1976, in order (a) to become familiar with the species of macrophytes present, (b) to gain a general impression of plant abundance and distribution, and (c) to determine the man-power and length of time that would be required for the sampling programme planned for the following years. It soon became evident that a considerable input - involving 3 persons over some 2 or 3 days - would be needed to achieve even a minimal, (and particularly unrewarding), coverage of the whole 0-3 m zone. These initial reconnaissances revealed that the description of patterns of macrophyte growth from work done 2 and 4 years previously by Britton and Jupp respectively (in Ann. Rep. Loch Leven Research Group for 1974 and 1976) remained relatively unchanged; plants were sparsely distributed (Plate 1 shows a small catch typical of much of the loch). Only in the Grahamstone and St. Serf's Island areas already noted were there stands of any significance (Plate 2); one of the problems of working in these areas results from propeller-fouling (Plate 3). Nevertheless, it was felt that surveillance of the shallower areas of Loch Leven as a whole should still be attempted.

One of the objectives of the project was to work towards establishing methods for detecting long-term changes in plant distribution and abundance. Vast areas are currently almost devoid of plants, but, as we have little information on long-term fluctuations except the knowledge that these are possible (charophytes, for example, had been much more abundant in Loch Leven earlier this century (West 1910)), it does seem necessary to maintain a cursory surveillance of even currently 'bare' areas. As a possible approach to this, aerial photography had been suggested in the course of discussions with the Nature Conservancy Warden for the Loch Leven NNR, at that time, Mr. Allan Allison.

Methods

FIELD SAMPLING - (a) BY TRANSECTS

This method was adopted to gain information on plant distribution over the whole zone. As explained in the interim reports, the sampling of plant material in the field was based on dragraking (Plate 4) along transects running at right angles to the shore. As Figure 1 shows, each transect is more or less perpendicular to the general run of the shoreline on the map (outline taken from Kirby 1974), rather than at exactly 90^0 to the actual shoreline at the point where the transect intersects. Minor deviations in directions were taken where these would enable particularly prominent landmarks to be followed for direction. General plant distribution was plotted by dragging the rake along 2 transects positioned at random within each of the 19 shoreline sectors indicated in Figure 1. Broad comparative assessments of plant abundance were made by determining the dry weight of the separate "catches" from contiguous sections of each transect; particularly bulky samples were subsampled by fresh weight in the field with the aid of a spring balance. In an attempt to maintain comparability between sections, but in the absence of an accurate method of measuring their actual length, they are defined by the distance covered by the boat during one or two minutes of 'uniform' running speed. Water depth was recorded at the beginning and end of each section (Plate 5). Data can be related to actual depth by taking account of temporal fluctuations in the water level of the loch (Table 1). Improvements to this method are discussed in a later section of this report.

FIELD SAMPLING - (b) BY QUADRATS

A pair of 2500 m^2 square sampling areas were marked out on the sediment approximately 150 m from each of the Grahamstone and St. Serf's shores (positions are shown in Figure 1). These areas were sampled repeatedly for information on seasonal fluctuations in the abundance of the dominant aquatic vascular plant -

Potamogeton filiformis. Shoot density and biomass dry weight were assessed from collections in randomly-placed quadrats within the 4 areas. Statistical analyses, for the various times of sampling, of the variation in plant density within and between sample areas, are described below. Glowa (in Ann. Rep. Loch Leven Research Group for 1977) describes associated work on benthic and epiphytic algae and water chemistry of these areas.

AERIAL PHOTOGRAPHY

Aerial photographic trials from between 1000 and 2000' altitude were done with an automatic "Robot" camera slung from the fuselage of a two-seater "Falke" motor-glider (Plates 6 & 7) owned by the Portmoak Gliding Club situated (extremely conveniently!) on the shores of Loch Leven. Trials have been made with the following film types: Monochrome (KODAK Tri-X 400ASA), colour (high-speed EKTACHROME 160 ASA, KODACHROME II ASA 25 and KODACOLOUR 400 ASA) and "false-colour" (KODAL EKTACHROME Infra-red - effectively 100 ASA with Wratten filter No. 12). The concluding section of this report comments on improvements that might be adopted in future work of this type.

Results

TRANSECT SAMPLING

Figure 1 indicates a typical distribution of sampling transects; these lines were followed during the survey of 8-10 August 1978. No sampling was made on this occasion from sector 7 (S.E. corner of the loch) or the West shores (sectors 14-19). Information relating also to the August 1978 work is presented in Appendix I to show the type of data recorded in the field: water depth, gross composition of plant catches etc. Extra botanical notes from this survey are shown in Table 2. The stand of *Eleocharis* referred to in Table 2 is shown in Plate 8; this stand is on part of the stony, rapidly shelving, south shore (contours close together in Figure 1). Figures 2 and 3 show the distribution of plant biomass (dry weight) with depth. Along transects sampled during the 1977 surveys. July data from around most of the shore (Figure 2) support the earlier findings (Jupp, Spence & Britton, 1974) that the Grahamstone and St. Serf's Island shores (sectors 3, 4 and 5), and, to a lesser extent, the broad N.E. shore (sectors 1 and 2) are the areas with most abundant plants. Figure 3, using May to September information, but from sector 2 only, shows that plant biomass is at its maximum in summer to early autumn.

These data result from a first attempt at a quantitative assessment of the plants present in the large area of Loch Leven sediment that lies beneath water of up to 3 m depth. The approach adopted can form the basis of a repeatable programme for future years' surveys. It improves significantly on previous attempts here at estimating plant abundance over such an extensive area. However, the method will still need to be improved if biomass estimates are to be related - as they ultimately need to be - to absolute areas of sediment and/or lengths of transects etc. Of particular importance will be the accurate fixing of the positions of the limits of the particular transects, and sections of these, adopted on separate sampling occasions. The potential for the further working of the existing data, pending later methodological improvements, is discussed in a later section of this report.

QUADRAT SAMPLING

Figure 1 shows the positions of the pairs of permanently established 50 m x 50 m sampling areas off the Grahamstone and St. Serf's Island shores. These areas were used in 1978 for assessing more precisely any seasonal fluctuations in the biomass ($g.m^{-2}$) and abundance ($no.m^{-2}$) of _Potamogeton filiformis_. The full data are presented in Appendix II.

In contrast to the transect-based data described above, plant number and biomass values obtained from quadrat samples allow an immediate more critical analysis. The statistical manipulations of these data are described, step-by-step, in the following paragraphs.

(a) preliminary examination of the data

In order to gain a first insight into the nature of the distribution of plants as estimated here, Table 3 presents, for each shore various quartile values for the sets of data - each of estimates from a sample of 8 quadrats. Values from both areas off these shores are presented for each sampling occasion and the information is for estimates by shoot numbers and dry weight. The spread of values (indicated by the interquartile ranges) reflect the heterogeneity in the variation of plant abundance in these areas on the different occasions of sampling. Means and variances of the untransformed data have also been calculated; the computer print-out of the results is lodged at I.T.E., Craighall Road. The high variance-to-mean ratios, obtained from these data indicate the marked skewness in the distribution of the values used; this, in turn, also reflects the patchiness of the plants in the loch. This further suggests the need for a transformation of the original values if a meaningful apportioning of the variation in plant numbers and weights within and between the sampling areas is to be achieved.

Validity of the analysis-of-variance approach to attaining this goal rests on the premise that the variability between, in our example, quadrats within areas, is the same for each area/sampling occasion combination. This prior assumption is considered for these data in the following section in relation to the function of the data transformation.

(b) Data transformation

The logarithms of the variances have been plotted against the logarithms of the corresponding means of the data for Grahamstone (Figure 4a, shoot numbers and 4b, biomass) and St. Serf's (Figure 5a, shoot numbers and 5b, biomass) shores.

These each show that as plant abundance increases, so does the variability; this confirms the interdependance of these two parameters, and a linear relationship is apparent. The slope of the line best followed (y:x = 2:1) indicates that by a logarithmic transformation the variance will be stabilised regardless of the mean.

(c) Analysis of variance (ANOVA) of the log-transformed data.

Since, in the original data (Appendix II) values of 0 occur, the actual transformation has been to log (x + 1) where x is a count of plants or weight estimate per quadrat.

The ANOVA calculates the contributions from the variation arising from separate sources to the total variation. In our examples, sources of variation arise between quadrats (i.e. "between quadrats within areas") and between areas. Table 4 shows summaries of these analyses of shoot number and biomass data for the areas off both shores. Computer prints-out of the full array of information (sum of squares, variance and mean square) calculated for the individual sets of 8 quadrat values are also lodged at I.T.E., Craighall Road.

For this exercise the occasion of sampling ("dates" in Table 4) has also been taken into account as a source of variance. These data have been obtained from 6 (in the case of the Grahamstone material) and 7 (for St. Serf's) sampling occasions. Thus there are 6 and 7 independant estimates of "within-area" (i.e. between-quadrats-within-area) components of variance, and within-plus between-area components of variance. These can be averaged to give a pooled estimate of each. By adding the 6 or 7 within-area sums of squares (Table 4) the within-area and sampling occasions sum of squares is obtained. Similarly the totalled 6 or 7 between-area sums of squares gives the between-area-within-sampling occasions sum of squares. The significance of these analysis to the planning of future surveys is discussed later.

Although the plants are distributed irregularly in these localities, and those off St. Serf's rather more than those off Grahamstone (compare the variances in Table 4), trends in the rise and decline in plant numbers in areas off the same shore are similar (Figure 6). Maximum abundance in each area is observed in July, although the plants off St. Serf's appear to increase towards these maxima rather earlier than those off the Grahamstone shore. The main period of growth in 1978 in terms of percentage increase, was in June, despite a very protracted winter which kept water temperatures below 10^{o}C until mid-May. Plate 4 gives an impression of the high densities of plants (10^2 to 10^3 $.m^{-2}$) in some patches. The major decline in numbers of Potamogeton filiformis seems to occur over September; as light and temperature at this time would appear still favourable for plant growth one can only conjecture that other factors have a significant effect. Of possible biological influences, those relating to the development of a Microcystis (blue-green alga) bloom in August, and grazing by wildfowl, are perhaps the most likely. Plate 9 is a close-hand photograph of Microcystis accumulating on the south-shore (see also aerial shots discussed in next section); the potential harm to the few emergent stands of e.g. Polygonum amphibium, Eleocharis palustris and Phragmites communis (Plates 8-10) as well as submerged species which are almost completely occluded (aerial photographs show this feature more plainly than ground photographs) is probably considerable - see e.g. Jupp & Spence (1977a)).

AERIAL PHOTOGRAPHY

A selection of plates (11-19) is used to illustrate the experience gained during the course of this study, albeit short. Colour plates were more useful than monochrome plates, which were mostly discarded. In spite of the fairly dull day on which trials were done, and the fact that a very slight surface wind ripple occurred, the results are disappointing. By chance, two of the many illustrations (lodged at the I.T.E. laboratory in Craighall Road, Edinburgh) form an overlapping pair suitable for stereo-viewing; however, these monochrome photographs also do not show the submerged stands of macrophytes as plainly as the colour photographs. During a day of most promising weather, even slight rippling of the water surface, particularly when combined with wrong camera orientation with reference to the sun, can also give poor results with colour (Plate 11).

If, however, one is fortunate enough to be able to mount a flight programme in calm, preferably bright, conditions, then the greater potential of this type of plant recording is realised. Plates 12-19 show various results with conventional colour and "false colour" film. Infra-red film has yet to be tried.

Conclusions - suggestions for future work

GENERAL

The work has indicated the potential of both 'ground' and 'air' surveys for assessing the general quantitative and qualitative characteristics of the macrophyte community at Loch Leven. Mid-summer maxima of the dominant species (*Potamogeton filiformis*) exceed 1000 shoots. m^{-2} or biomass estimates of 30 g dry wt. m^{-2} off the eastern position of the north shore between Grahamstone and St. Serf's; however, over the greater part of the 0-3 m zone (amounting to nearly 7 km^2) and for most of the year, total plant material does not exceed 0.1% of this value.

TRANSECT SAMPLING

It is thought that a programme of transect sampling carried out more frequently than once a year is unnecessary. A July or August survey is likely to result in maximum information on species types, distribution and peak densities.

The one serious short-coming of the system described above is the lack of accurate position-fixing; for this reason whilst e.g. a "2-minute section" is approximately equivalent to 100 m, how near it is to this distance is not known - hence, weight data here are for the present expressed per section. Discussions have been held recently with companies supplying portable position-fixing equipment suitable for such work. Accurate position-fixing would facilitate estimates of plant abundance per known and uniform length of transect and area of sediment. Data would then allow statistical analyses of the variation in plant biomass between and within different shore sections ($n = 19$ on the present plan), transects ($n = 2$ per section) and sectors (variable, ca .3-15, for different transects, depending on bottom topography). Moreover, such analyses could be done retrospectively on the data referred to in this report, after the previously timed boat runs have been calibrated in terms of distance.

QUADRAT SAMPLING

The variance analyses, presented above, of the quadrat data can be examined further with the view to the planning of future work of this type. However, it should be stressed at the outset, that considerations of this should take account of logistic and practical difficulties of the regular sampling on this exposed stretch of water; the resultant decisions can then be weighed against the requirements of numbers and positioning of sampling shores, areas and quadrats, as suggested from the statistical analyses. Nevertheless, an exploration of the relative efficiencies of different combinations of numbers of sample areas and quadrats, based on statistical theory, is instructive.

If k areas are selected at random the variance of the corresponding sample average will be:

$$\frac{\sigma_B^2}{k} + \frac{\sigma_W^2}{nk}$$

where σ_B^2 and σ_W^2 are the between and within area variances respectively, and n is the number of quadrats taken at random for each area; i.e.

the variance of the mean is the population variance divided by the sample size. The contribution to the error arising from between area variations varies inversely with the number of areas, whilst that arising from within area variations varies likewise with the total number of quadrats.

Using the values so far obtained of σ_B^2 and σ_W^2, or rather our estimates of them, we can calculate what is a likely sample variance of the mean ($\bar{x}$) to be expected for different values of n and k. The plots shown in Figures 7 (Grahamstone shoots A and biomass B), and 8 (St. Serf's) compare the relationships between s^2 and n for four values of k (1, 2, 3 and 4). As an example, consider the case for estimating shoot density off the Grahamstone shore; by taking 8 quadrats (n) per each of 4 areas (k), the estimated variance of the sample average (for log (no. of shoots + 1) is (values in Table 4) as follows:

$$\frac{0.0425}{4} + \frac{0.5271}{(4 \times 8)} = 0.027$$ (this value is marked on Figure 7a).

This estimated standard error of $\sqrt{0.027}$, or 0.16, is approximately 10% of the overall mean log (no. + 1) shoots. m^{-2} estimate, for the total of 84 estimates done on the Grahamstone shore areas during the summer - late autumn period. The value of exercises of this type, which attempt to predict the outcome of future samplings, may vary considerably; the so-called predictive statements (e.g. about s^2 given values of n and k) must therefore be judged with some caution. Statistical efficiencies as calculated from the plots in Figures 7 and 8 will only prove more-or-less true as long as the general characteristics of the plants' distribution remain as they have been found during the present study.

The indications are that, for both shores, there would be little to gain by taking more than the presently adopted number of 8, quadrats per area;

however the number of areas could be usefully increased to 4.

AERIAL PHOTOGRAPHY

Recent discussions on aerial photography have been held with the new Nature Conservancy Council warden for the Loch Leven N.N.R.; living very near the loch and thus being aware of day-to-day variations in weather, water clarity etc., he is ideally situated for arranging aerial photographic flights at short notice. Results of the few preliminary trials carried out during the last two summers indicate the tremendous potential of this approach. Improvements involving ground reference markers are needed; however, a planned series of runs along a system of "corridors" could result in an accurate vegetation map of the whole shallow zone.

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TABLE 1. Loch Leven water levels on the occasions of macrophyte sampling by transects mentioned in this Report. Survey datum - 106.87m A.S.L. - is that to which depth values on the contours in Figure 1 relate.

	Sampling date	Water level (m)	Relationship to datum (m)
1977	5-6 May	107.19	+ 0.32
	8-10 June	107.12	+ 0.25
	26-28 July	106.98	+ 0.11
	14-16 September	106.63	- 0.24
1978	8-9 August	107.02	+ 0.15

TABLE 2. Taxonomic notes on reference material collected during the survey done 8-9 August 1978.

Shore sector no. and transect	Section	Dominant species	Occasional species
9b.	OFF-SHORE	ELEOCHARIS PALUSTRIS (L.)	POTAMOGETON FILIFORMIS (Persoon)
12b		P. FILIFORMIS	CHARA FRAGILIS (Desvaux)
6c		P. FILIFORMIS	C. FRAGILIS
10a		P. FILIFORMIS	
6c		ELODEA CANADENSIS (Michx.)	
6a		NITELLA OPACA (Agardh.)	C. FRAGILIS
9b		C. FRAGILIS	
4b		N. OPACA	C. FRAGILIS

TABLE 3. Quartile information on quadrat data (not transformed) relating to plant abundance on different occasions of sampling off the Grahamstone and St. Serf's shores.

DATE	AREA	NO. OF QUADRATS	LOWER QUARTILE POINT	MEDIAN POINT	UPPER QUARTILE POINT	INTERQUARTILE RANGE
(a) Grahamstone - shoot No. m^{-2}						
24. 5.78	1	8	7.5	11	18	10.5
"	2	8	5.5	9.5	21	15.5
15. 6.78	1	8	22	76	284.5	242.5
"	2	8	100	115	178	78
6. 7.78	1	8	150	260	440	290
"	2	8	300	430	740	440
27. 7.78	1	8	600	670	840	240
"	2	8	540	960	1880	1340
11.10.78	1	8	90	260	470	380
"	2	8	0	0	250	250
1.11.78	1	8	0	0	10	10
"	2	8	0	0	40	40
(b) Grahamstone - shoot wt - $g.m^{-2}$						
24. 5.78	1	8	.16	.275	.56	.4
"	2	8	.125	.385	.6	.475
15. 6.78	1	8	.705	1.68	7.345	6.64
"	2	8	2.76	4.175	5.73	2.97
6. 7.78	1	8	1.58	3.395	7.395	5.815
"	2	8	5.335	7.725	20.355	15.02
27. 7.78	1	8	8.475	12.63	23.57	15.095
"	2	8	12.355	23.82	50.05	37.695
11.10.78	1	8	1.455	7.49	16.345	14.89
"	2	8	0	0	4.95	4.96
1.11.78	1	8	0	0	.055	.055
"	2	8	0	0	.395	.395
(c) St. Serf's - shoot No. m^{-2}						
23. 5.78	1	8	0	0	15	15
"	2	8	8	18	28	20
20. 6.78	1	8	490	1300	1480	990
"	2	8	0	0	490	490
6. 7. 78	1	8	20	900	1660	1640
"	2	7	0	240	1320	1320
3. 8.78	1	8	0	190	1260	1260
"	2	8	0	0	870	870
25. 8.78	1	8	380	1120	1480	1100
"	2	8	0	0	690	690
11.10.78	1	8	0	50	360	360
"	2	8	0	0	40	40
1.11.78	1	8	0	30	100	100
"	2	8	0	0	20	20
(d) St. Serf's - shoot wt - $g.m^{-2}$						
31. 5.78	1	8	0	0	.41	.41
"	2	8	.175	.485	.815	.64
20. 6.78	1	8	8.085	11.285	15.335	9.25
"	2	8	0	0	3.88	3.88

Table 3 (contd.)

DATE	AREA	NO. OF QUADRATS	LOWER QUARTILE POINT	MEDIAN POINT	UPPER QUARTILE POINT	INTERQUARTILE RANGE
6. 7.78	1	8	.16	17.495	25.055	24.895
"	2	8	.97	5.535	18.97	18
3. 8.78	1	8	0	1.615	9.075	9.075
"	2	8	0	0	3.055	3.955
25. 8.78	1	8	4.935	9.45	16.435	11.5
"	2	8	0	0	5.74	5.74
11.10.78	1	8	0	.275	5.64	5.64
"	2	8	0	0	.46	.46
1.11.78	1	8	0	.3	.675	.675
"	2	8	0	0	.065	.065

TABLE 4. Summary tables of results of ANOVA on data transformed to log (x+1).

GRAHAMSTONE SHORE

Shoot density (No. of shoots/sq m)

Source	df	Sum of squares	Mean square
Dates	5	63.130648	12.6263
Sample areas	6	5.205390	0.8676
Quadrats	84	44.272418	0.5271
Total	95	112.608456	0.5271

Variance of quadrats = 0.5271
Variance of sample areas = 0.0425 (i.e. $\frac{0.8676 - 0.5271}{8 \text{ (No. of quadrats)}}$)

Standing crop (Shoot dry weight/sq m)

Source	df	Sum of squares	Mean square
Dates	5	16.417704	3.2835
Sample areas	6	1.577257	0.2629
Quadrats	84	9.620985	0.1145
Total	95	27.615926	0.1145

Variance of quadrats = 0.1145
Variance of sample areas = 0.0185

ST. SERF'S ISLAND SHORE

Shoot density (No. of shoots/sq m)

Source	df	Sum of squares	Mean square
Dates	6	30.53788	5.0896
Sample areas	7	30.55712	4.3653
Quadrats	97	134.71182	1.3888
Total	110	195.80682	

Variance of quadrats = 1.3888
Variance of sample areas = 0.3758

Standing crop (Shoot dry weight/sq m)

Source	df	Sum of squares	Mean square
Dates	6	8.270101	1.3784
Sample areas	7	4.026911	0.5753
Quadrats	98	17.990676	0.1836
Total	111	30.287688	0.1836

Variance of quadrats = 0.1836
Variance of sample areas = 0.0490

FIGURES (1-8)

FIGURE 1 Map of Loch Leven showing contours for depths up to 3 metres, islands, inflows, outflow and various landmarks used in position-finding. The shore-line is divided into 19 sectors in each of which are marked two transects (4 in sectors 5 and 6 to the north and east of St. Serf's Island) along which macrophytes were collected. The random transects marked, refer to those used in the August 1978 survey. Solid squares off the Grahamstone and St. Serf's shores indicate the position of the 50 m x 50 m areas established for quadrat sampling.

Bailey-Watts (1979) ?

FIGURE 1

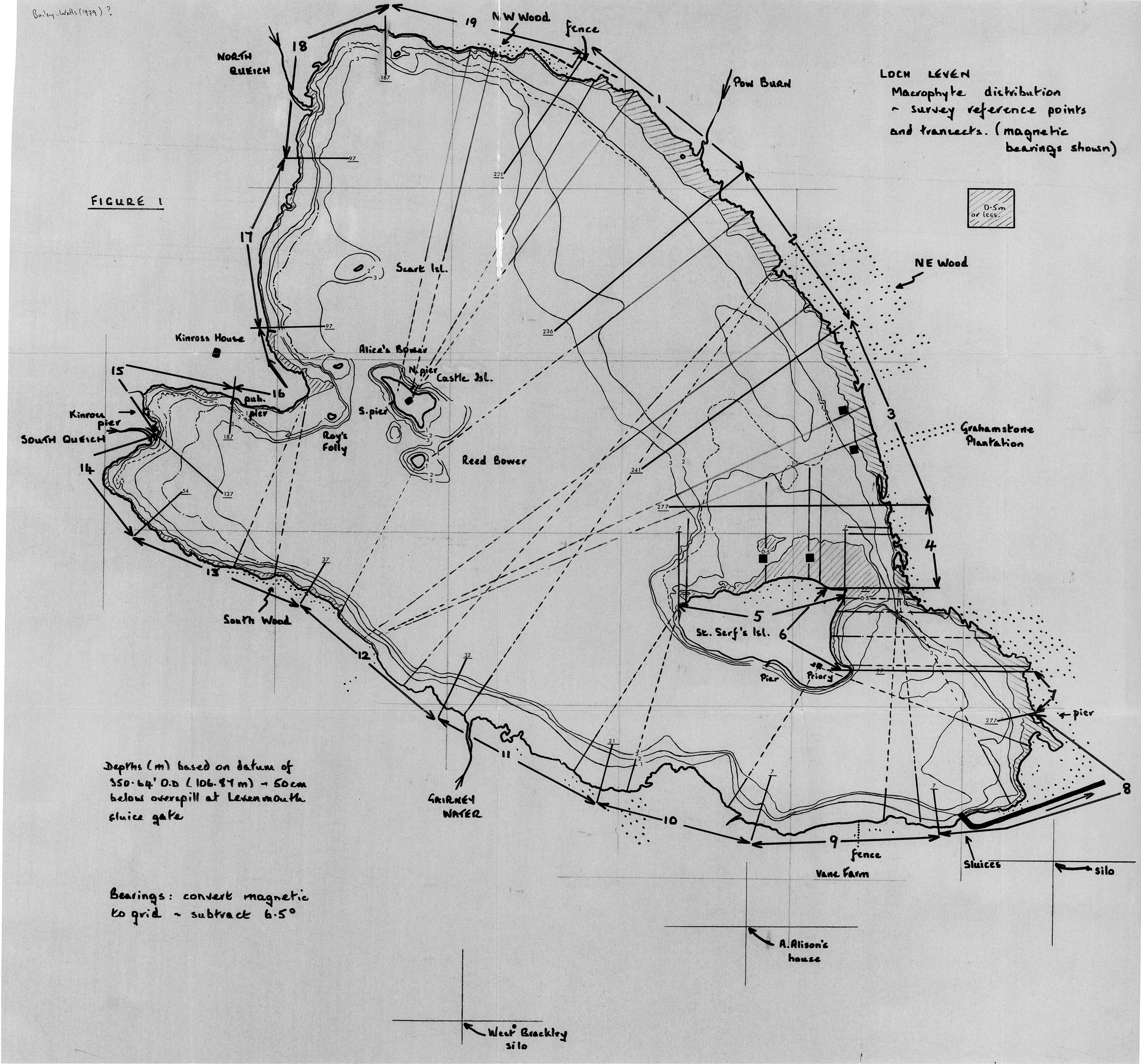


FIGURE 2. Results of July 1977 sampling based on transects; each graph shows bar charts of total dry-weight (g - left hand axis) of plant material taken in each of the contiguous sections - passing from shore (left) to open water (right); each section equivalent to 2 minutes' boat run in sectors 1, 2, 3, 6, 7 and 8, and one minute's run in the others. Water depth (m - right hand axis) indicated by continuous line.

FIGURE 2 Left hand axes - g dry wt. of plant material per section of transect (bar charts); right hand axes - metres water depth (line)

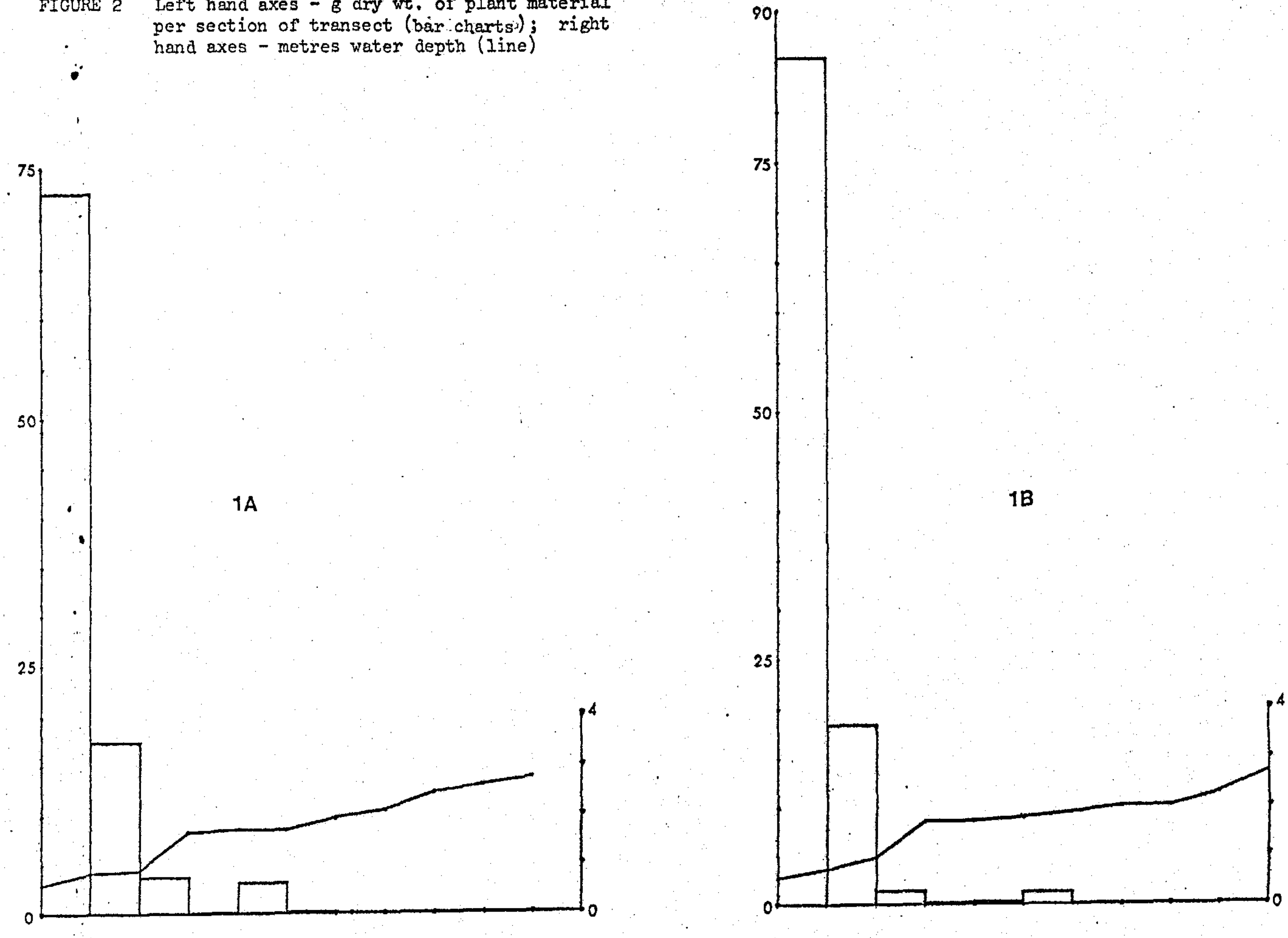


FIGURE 2 (continued)2

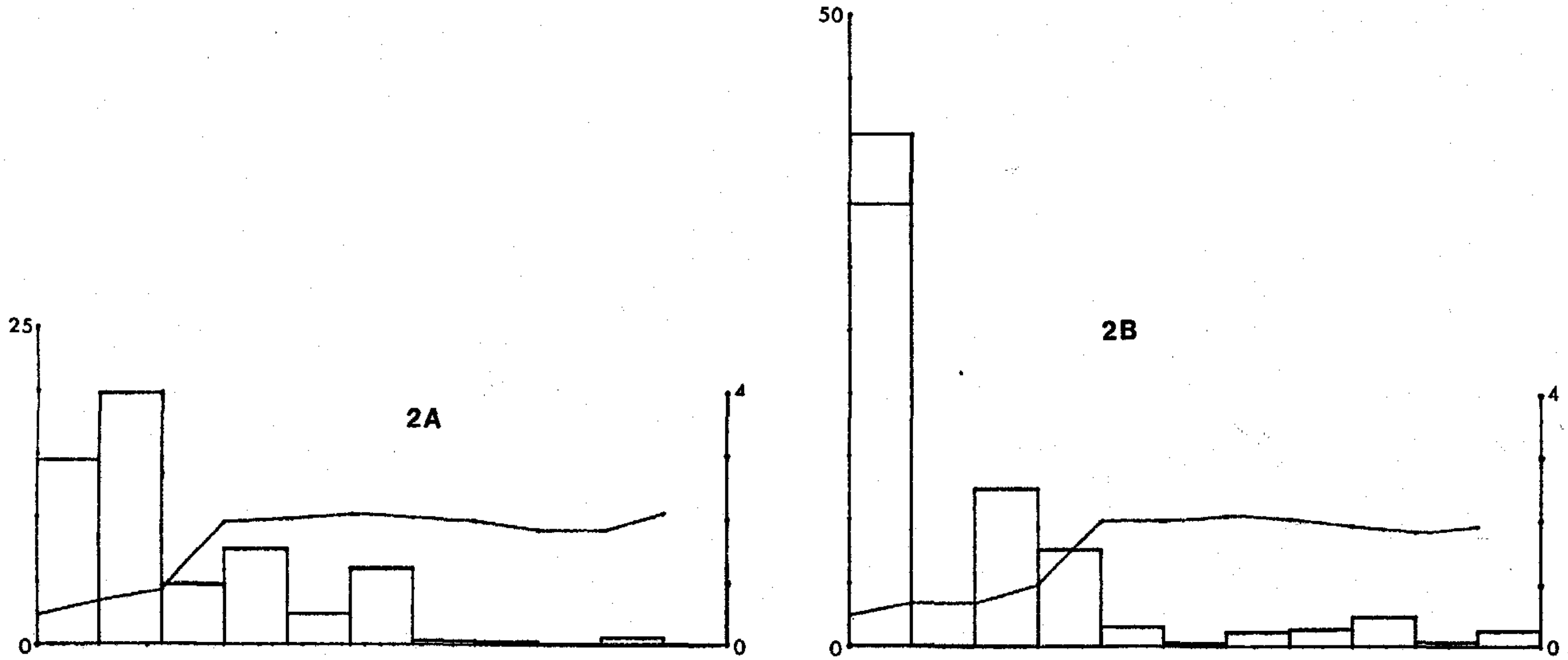


FIGURE 2A (continued)3

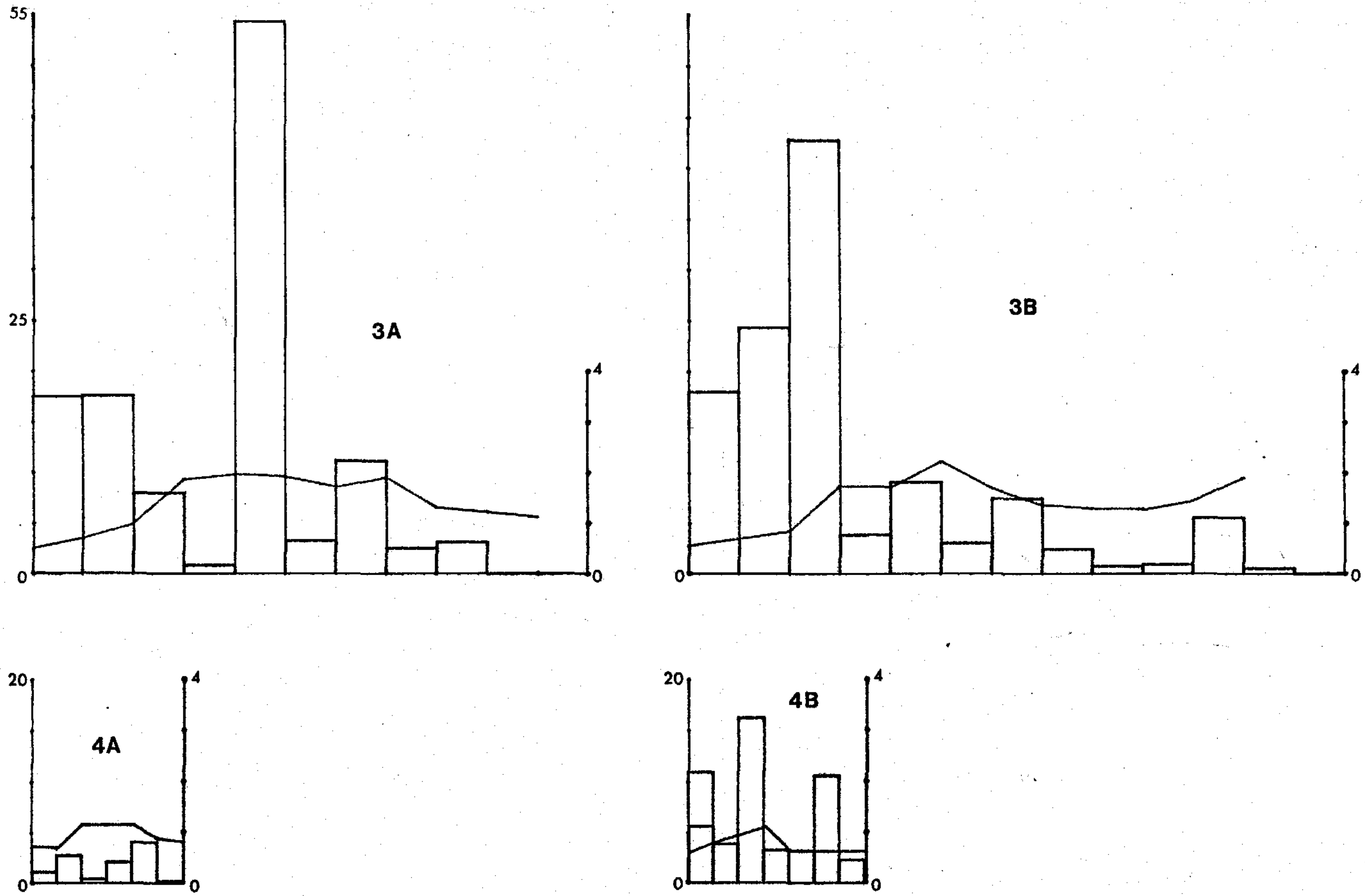


FIGURE 2 (continued)4

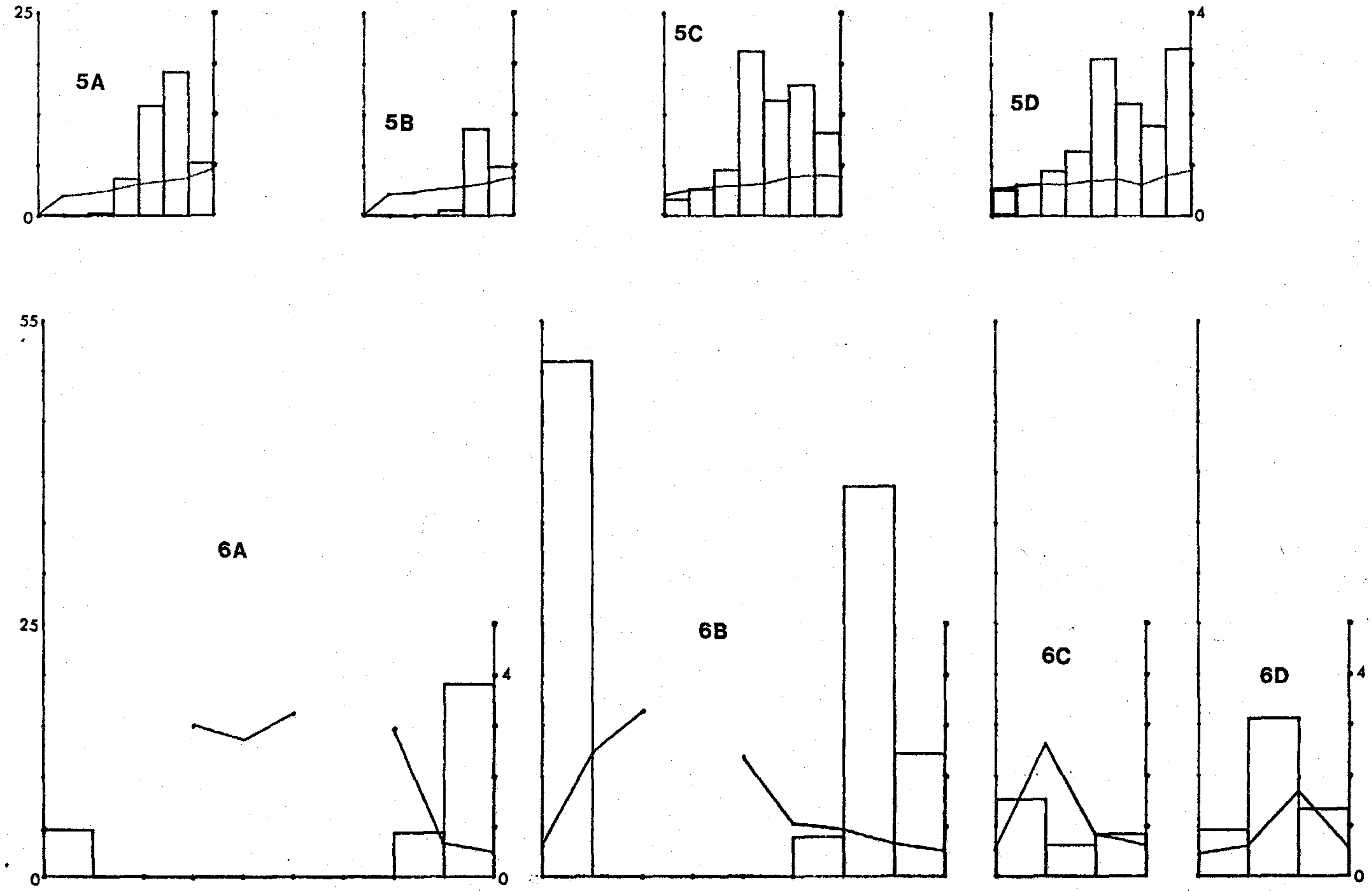
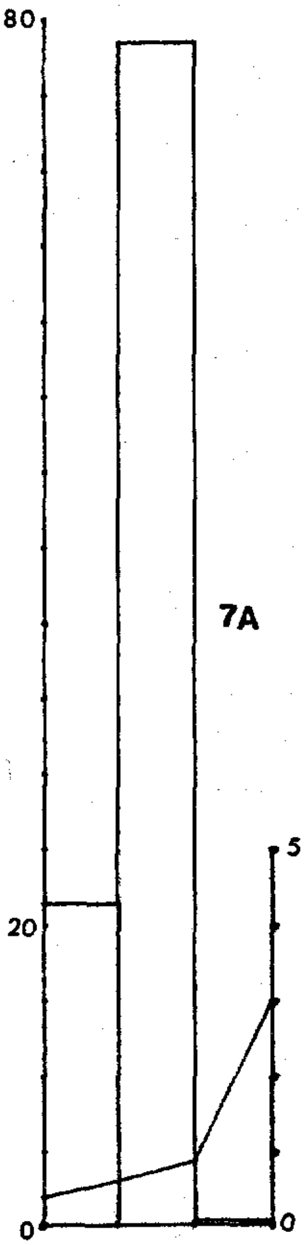
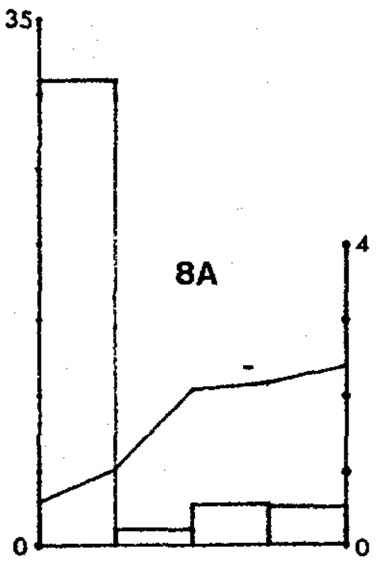


FIGURE 2 (continued)5





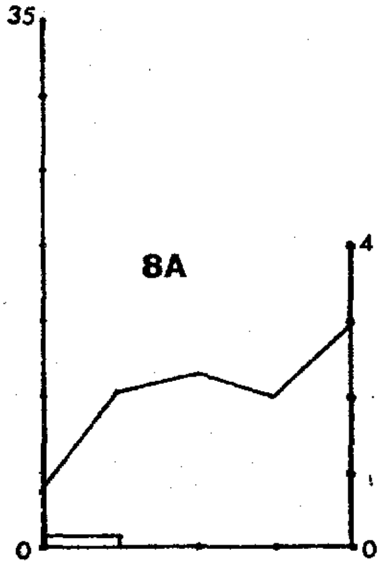


FIGURE 2 (continued)6

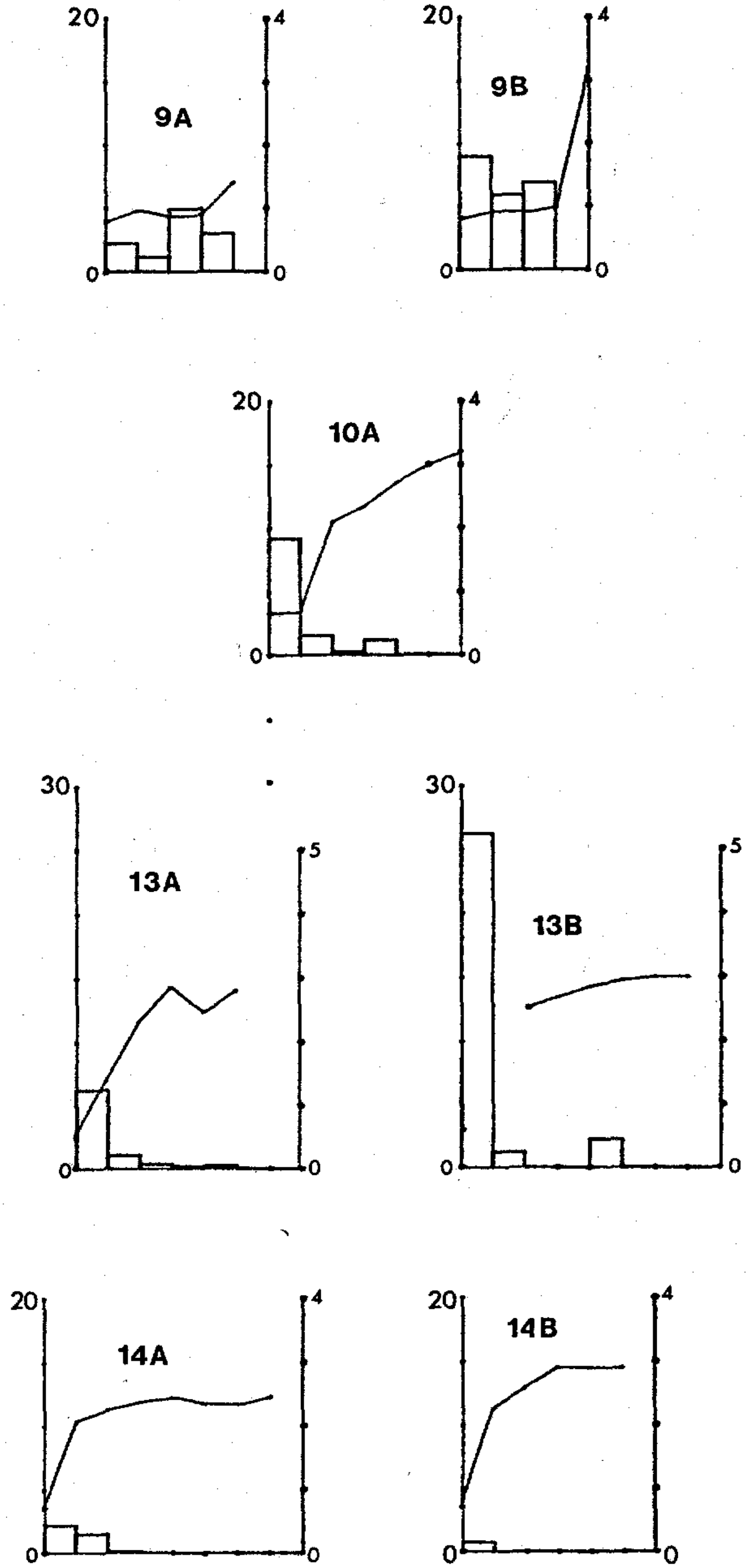


FIGURE 27 (continued)

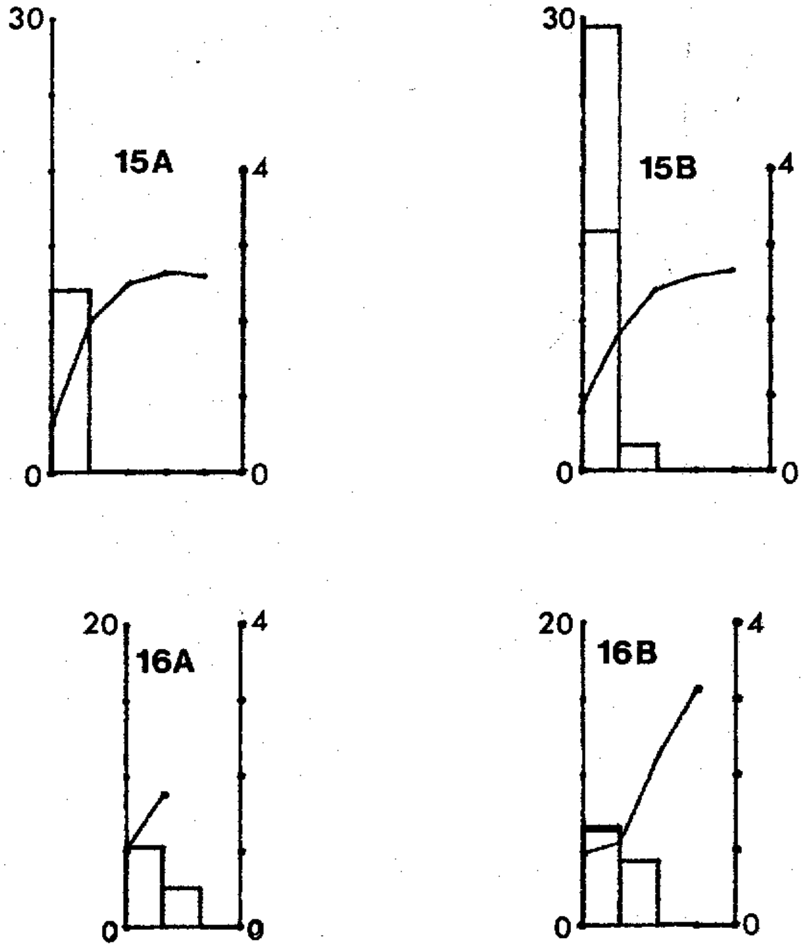


FIGURE 3. Results - expressed as described in Figure 2 - of sampling along pairs of transects within Sector 2 during 1977; 'A' transects to the left, 'B' to the right. Each section equivalent to 2 minutes' boat run.

FIGURE 3 Left hand axes - g dry wt. of plant material per section of transect (bar charts); right hand axes - metres water depth (line).

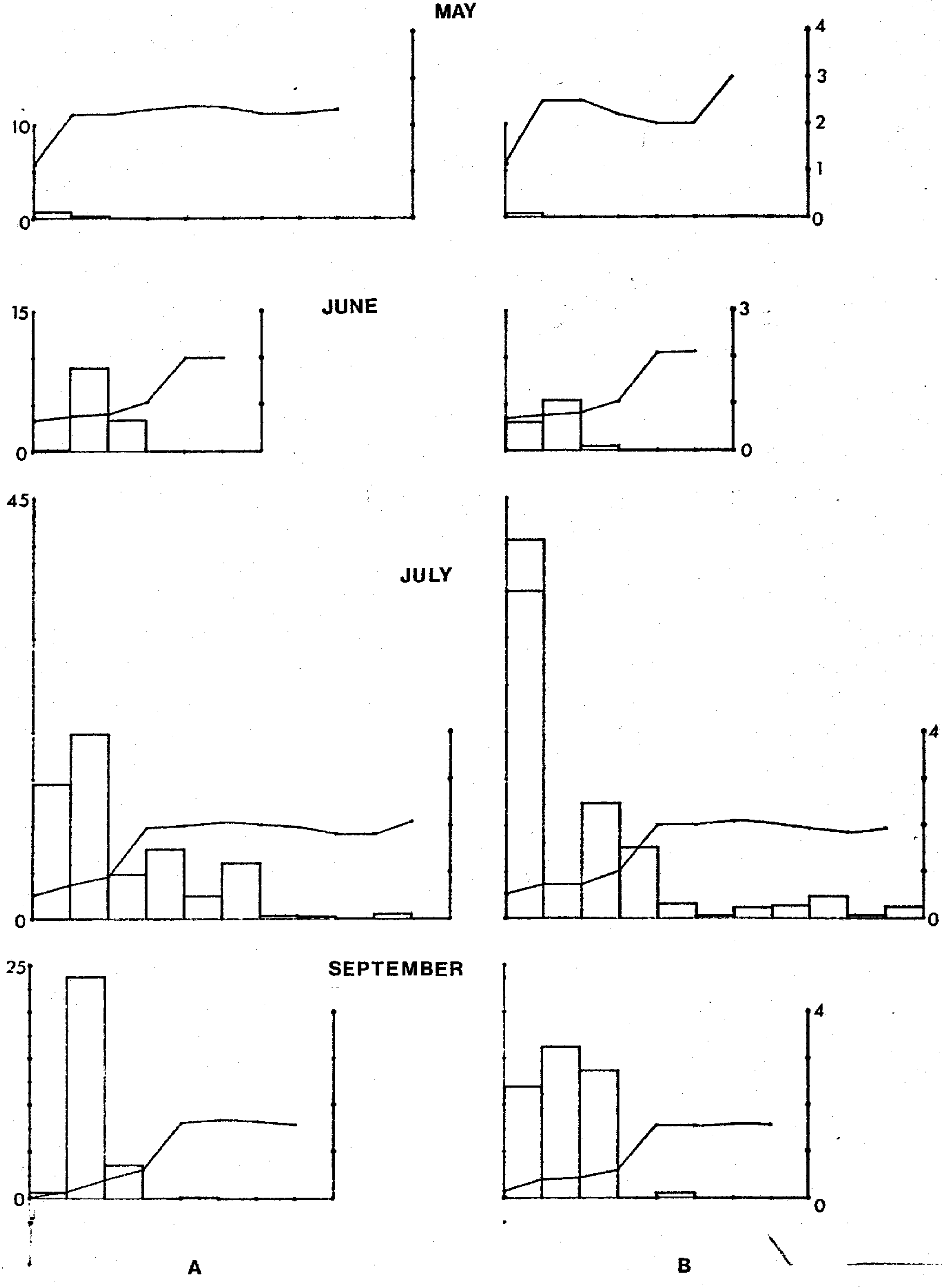


FIGURE 4. Relationship between log variance (y axis) and log mean (x axis) for shoot number (A) and weight (B) estimates of plant abundance off the Grahamstone shore, Loch Leven (1978).

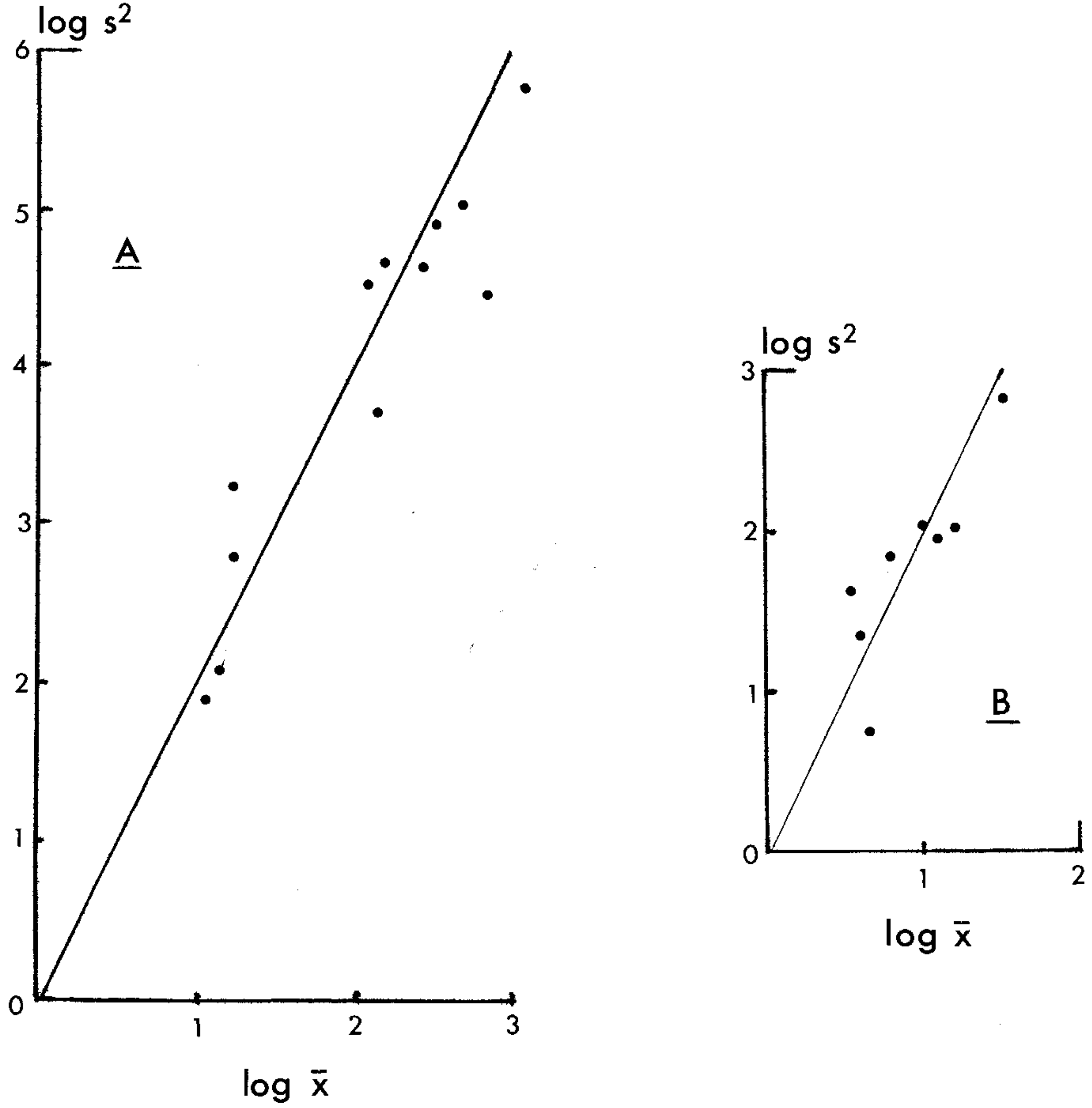

log s²
6
5
4
3
2
1
0
A
1
2
3
log x̄
log s²
3
2
1
0
B
1
2
log x̄

FIGURE 5. As Figure 4 for estimates of plant abundance off the St. Serf's Island shore, Loch Leven (1978).

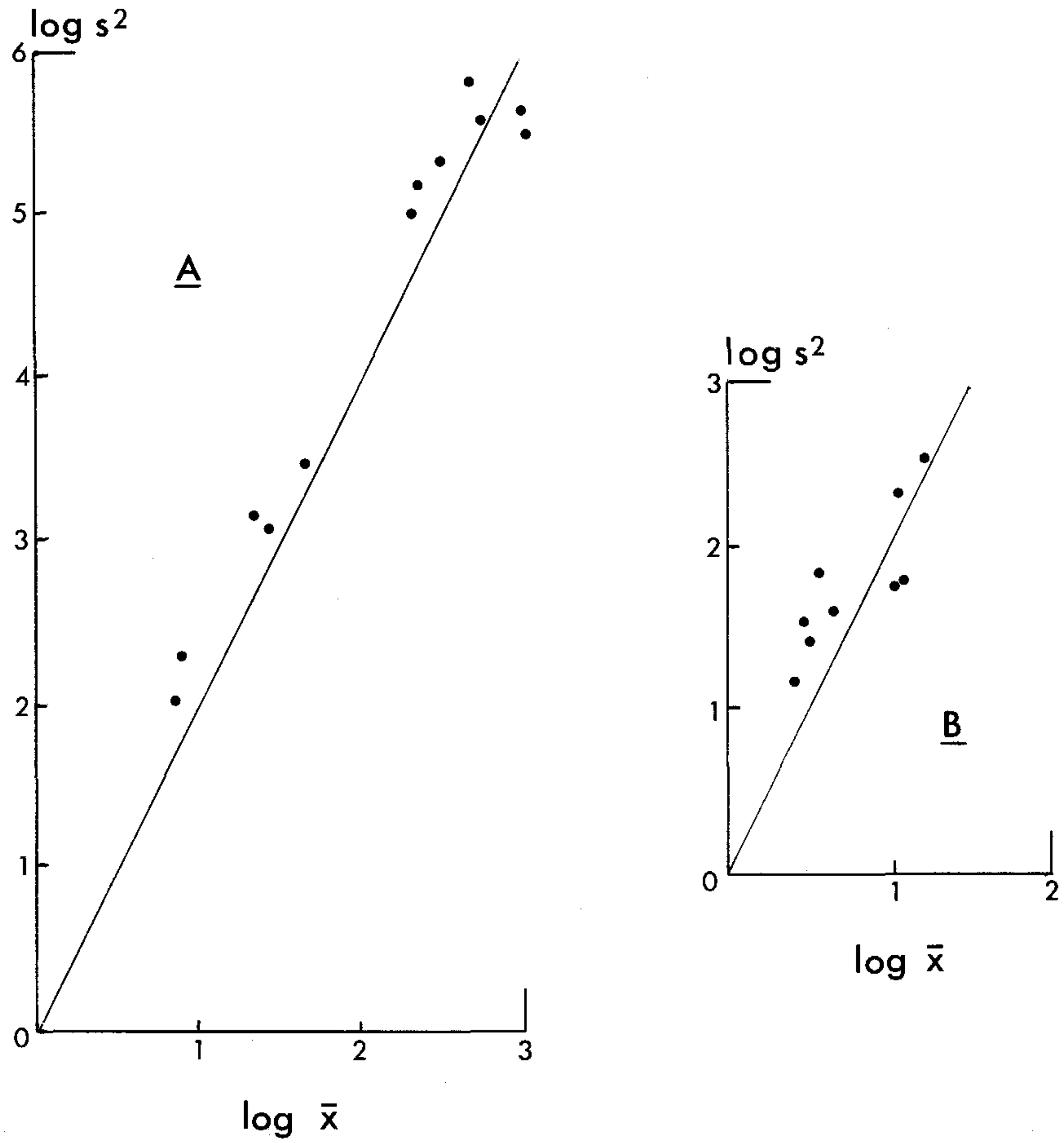
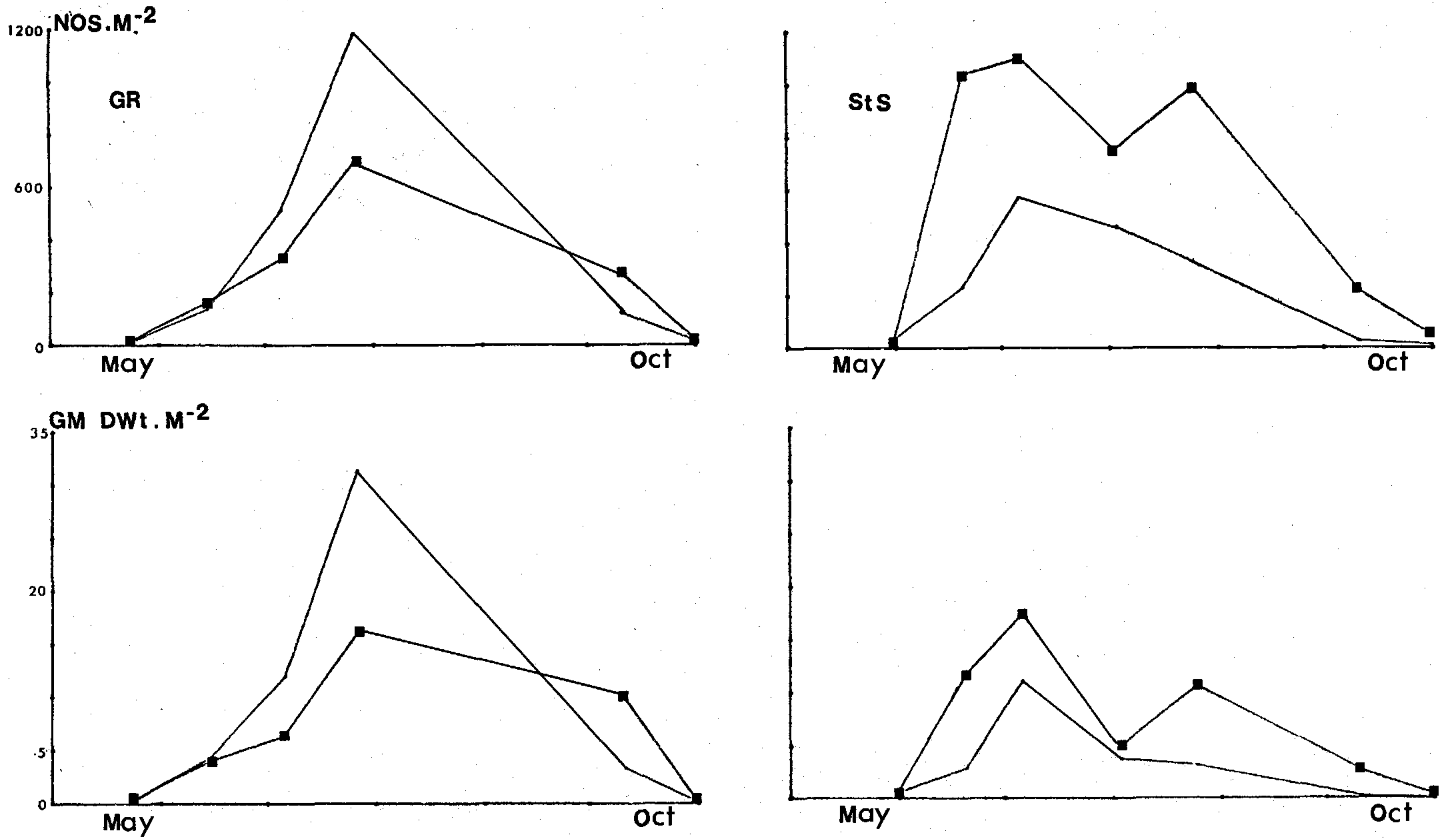

log s2
6
5
4
3
2
1
0
1
2
3
log x̄
A
log s2
3
2
1
0
1
2
log x̄
B

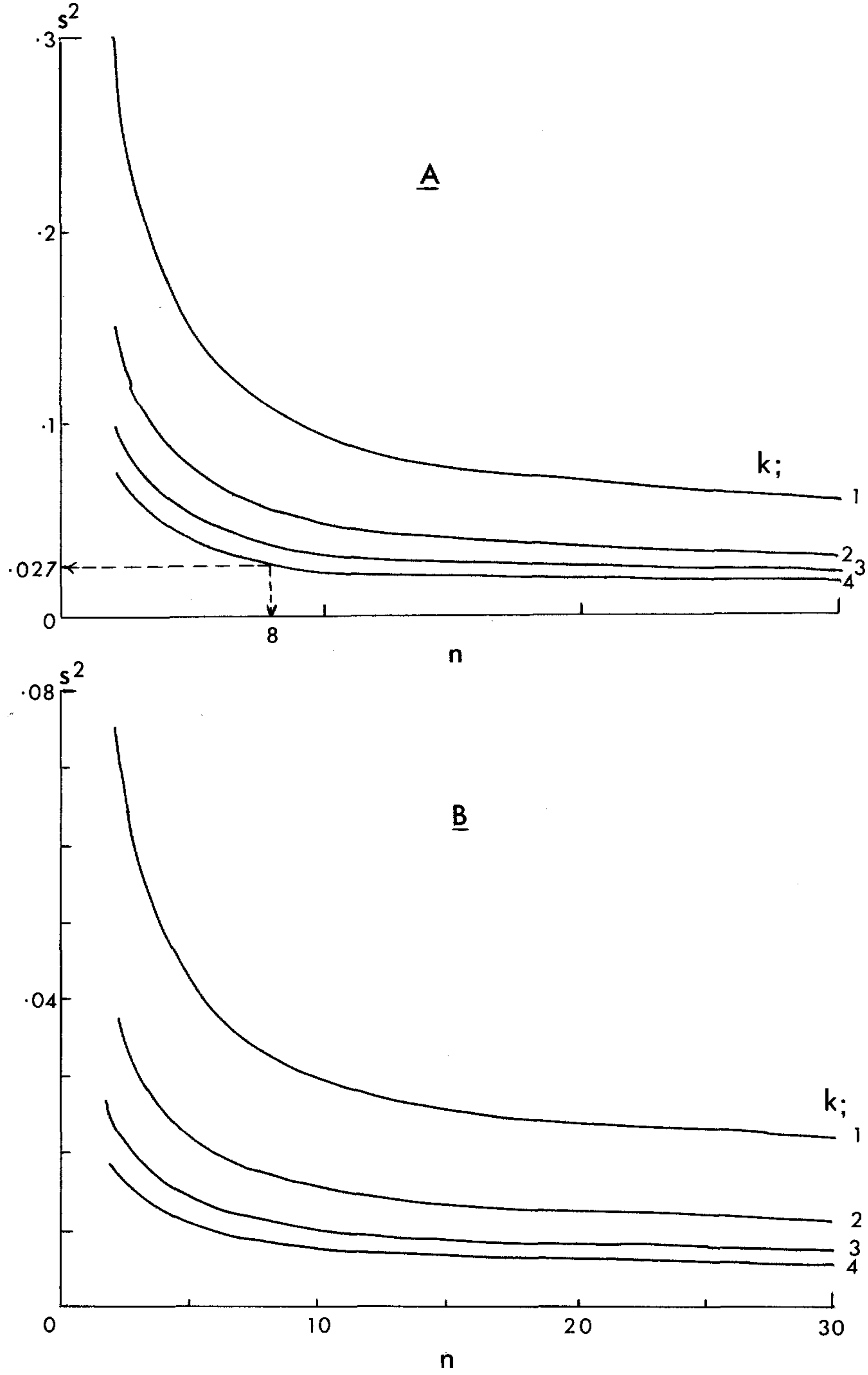
FIGURE 6. Results of quadrat sampling in the 50m x 50m areas off the Grahamstone (GR - left hand graphs) and St. Serf's Island (StS) shores from May to October 1978; upper graphs, nos. of plants m^{-2}, lower graphs, g. dry-weight $.m^{-2}$; plots linked by ■ refer to the westernmost area of each pair.

FIGURE 6



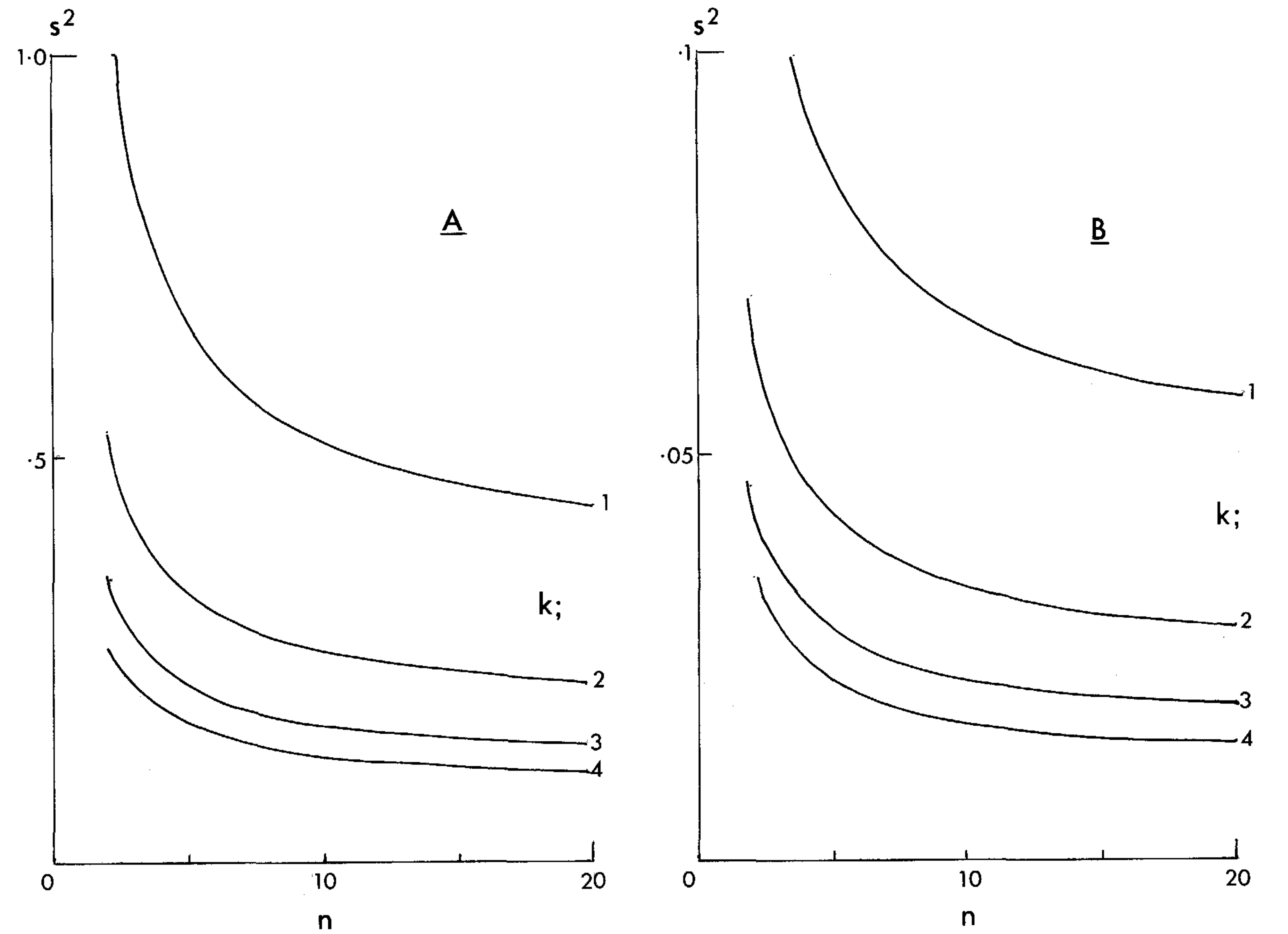
NOS.M.-2
1200
600
0
GR
May
Oct
StS
May
Oct
GM DWt.M-2
35
20
5
0
May
Oct
May
Oct

FIGURE 7. Plots, based on 1978 estimates of plant abundance off the Grahamstone shore, showing predicted values for sample variance of the mean (S^2 on y axes) for different quadrat (n)/area (k) number combinations (on x axes and plotted lines); (A) for shoot density $n.m^{-2}$ and (B) for shoot biomass g dry wt. m^{-2}. Predicted value of 0.27 for S^2, if 8 quadrats were taken from each of 4 areas, is indicated - see text for fuller explanation.



A
s²
·3
·2
·1
·027
0
8
n
k;
1
2
3
4
B
s²
·08
·04
0
10
20
30
n
k;
1
2
3
4

FIGURE 8. As Figure 7, but based on 1978 estimates of plant abundance off the St. Serf's shore.



A
B
s^2
1·0
·5
·1
·05
k;
1
2
3
4
0
10
20
n

APPENDIX I.

TABLE 1. Loch Leven macrophyte surveillance. Examples of information recorded in the field; data sheets from the survey made 8th-9th August 1978. Transects are those marked on the map in Figure 1. Column headed 'Dry weight (g)' would be filled in after the plant material drag-raked from each section of the transects had been dried at 80°C and weighed. Components of the catches: Characeae (C where a major constituent, c where a minor constitutent); _Potamogeton_ (P, p); _Cladophora_ (Cl, cl); _Enteromorpha_ (E, e)

SECTOR NO.	TRANSECT	BOAT RUNNING TIME PER SECTION	SECTION NO.	DEPTH AT START OF EACH SECTION (cm)	CONSTITUENTS OF 'CATCH'	TOTAL CATCH DRY WEIGHT (g)
1	a	1 min	1	90	Cl p	
			2	110	Cl C p	
			3	200	C cl	
			4	200	C cl	
			5	190	C cl	
			6	230	C Cl	
			7	240	C Cl	
			8	250	Cl	
			9	270	NONE	
			10	300+	NONE	
1	b	1min	1	70	Cl p	
			2	80	Cl p	
			3	95	Cl C	
			4	180	C Cl p	

TABLE 1 (continued) 2.

SECTOR NO.	TRANSECT	BOAT RUNNING TIME PER SECTION	SECTION NO.	DEPTH AT START OF EACH SECTION (cm)	CONSTITUENTS OF 'CATCH'	TOTAL CATCH DRY WEIGHT (g)
1	b	1min.	5	190	C CL P	
			6	170	C CL	
			7	190	CL C	
			8	198	CL	
			9	210	CL P C	
			10	245	CL	
			11	260	NONE	
			12	290	NONE	
2	a	1min.	1	60	C P CL	
			2	70	NONE	
			3	53	CL P	
			4	75	CL P	
			5	130	CL C	
			6	200	C CL	
			7	210	CL C	

TABLE 1. (continued) 3.

SECTOR NO.	TRANSECT	BOAT RUNNING TIME PER SECTION	SECTION NO.	DEPTH AT START OF EACH SECTION (cm)	CONSTITUENTS OF 'CATCH'	TOTAL CATCH DRY WEIGHT (g)
2	a	1min.	8	210	Cl	
			9	210	Cl c	
			10	220	NONE	
			11	220	Cl c	
			12	225	Cl	
			13	230	Cl	
			14	270	Cl	
			15	300+	NONE	
2	b	1min.	1	70	P Cl	
			2	70	P Cl c	
			3	80	P Cl c	
			4	185	NONE	
			5	240	Cl p	
			6	275	Cl	
			7	220	Cl C	

TABLE 1. (continued) 4.

SECTOR NO.	TRANSECT	BOAT RUNNING TIME PER SECTION	SECTION NO.	DEPTH AT START OF EACH SECTION (cm)	CONSTITUENTS OF 'CATCH'	TOTAL CATCH DRY WEIGHT (g)
2	b	1min.	8	180	C cl	
			9	175	C cl	
			10	170	C Cl	
			11	175	C cl	
			12	178	C Cl	
			13	197	C Cl	
			14	270	NONE	
			15	300+	NONE	
3	a	1min.	1	70	P cl	
			2	70	P cl c	
			3	200	C Cl	
			4	190	Cl C P	
			5	180	Cl c	
			6	220	Cl c	
			7	170	C cl	

TABLE 1.(continued) 5.

SECTOR NO.	TRANSECT	BOAT RUNNING TIME PER SECTION	SECTION NO.	DEPTH AT START OF EACH SECTION (cm)	CONSTITUENTS OF 'CATCH'	TOTAL CATCH DRY WEIGHT (g)
3	a	1min.	8	160	CL C	
			9	130	CL C	
			10	120	CL C	
			11	100	C CL P	
			12	98	C CL P.	
			13	110	CL c	
			14	130	CL	
			15	300+	NONE	
3	b	1min.	1	70	CL P c	
			2	100	CL C	
			3	150	CL C	
			4	165	CL C	
			5	170	CL c	
			6	170	CL C	
			7	170	CL c	

TABLE 1.(continued) 6.

SECTOR NO.	TRANSECT	BOAT RUNNING TIME PER SECTION	SECTION NO.	DEPTH AT START OF EACH SECTION (cm)	CONSTITUENTS OF 'CATCH'	TOTAL CATCH DRY WEIGHT (g)
3	b	1min.	8	122	C Cl	
			9	105	Cl C p	
			10	98	Cl C p	
			11	100	Cl C p	
			12	110	Cl C	
			13	115	C	
			14	170	Cl	
			15	300+	NONE	
4	a	1min.	1	70	Cl C p	
			2	125	C Cl e	
			3	65	C Cl p	
			4	65	NONE	
4	b	1min.	1	50	C Cl	
			2	150	C Cl	
			3	55	C cl p	

TABLE 1. (continued)

SECTOR NO.	TRANSECT	BOAT RUNNING TIME PER SECTION	SECTION NO.	DEPTH AT START OF EACH SECTION (cm)	CONSTITUENTS OF 'CATCH'	TOTAL CATCH DRY WEIGHT (g)
4	b	1min.	4	50	C Cl p	
			5	50	NONE	
5	a	1min.	1	50	C cl e	
			2	55	C cl p	
			3	65	C cl p	
			4	70	C cl p	
			5	85	C Cl P	
			6	95	C Cl	
			7	145	C Cl	
			8	150	NONE	
5	b	1min.	1	55	C Cl p	
			2	65	C P cl	
			3	70	C P Cl	
			4	80	C cl p	
			5	95	C cl p	

TABLE 1.(continued)

SECTOR NO.	TRANSECT	BOAT RUNNING TIME PER SECTION	SECTION NO.	DEPTH AT START OF EACH SECTION (cm)	CONSTITUENTS OF 'CATCH'	TOTAL CATCH DRY WEIGHT (g)
5	b	1min.	6	170	C Cl	
			7	195	Cl c	
			8	165	NONE	
5	c	1min.	1	65	Cl p	
			2	80	Cl p	
			3	70	Cl P C e	
			4	80	Cl P C e	
			5	75	Cl C P	
			6	90	Cl P C e	
			7	98	Cl P C	
			8	105	Cl P C	
			9	160	NONE	
5	d	1min.	1	70	Cl C	
			2	85	C cl	
			3	130	C Cl	

TABLE 1. (continued)

SECTOR NO.	TRANSECT	BOAT RUNNING TIME PER SECTION	SECTION NO.	DEPTH AT START OF EACH SECTION (cm)	CONSTITUENTS OF 'CATCH'	TOTAL CATCH DRY WEIGHT (g)
5	d	1min.	4	133	C cl	
			5	133	C Cl	
			6	120	C Cl	
			7	100	C Cl	
			8	125	C cl	
			9	160	C cl	
			10	162	C cl	
			11	165	C cl	
			12	165	C cl	
			13	165	NONE	
6	a	1min.	1	60	C Cl	
			2	90	C cl	
			3	150	C cl	
			4	300+	NONE	
			5	300+	C	

TABLE 1. (continued)

SECTOR NO.	TRANSECT	BOAT RUNNING TIME PER SECTION	SECTION NO.	DEPTH AT START OF EACH SECTION (cm)	CONSTITUENTS OF 'CATCH'	TOTAL CATCH DRY WEIGHT (g)
6	a	1min.	6	150	Cl p c	
			7	80	NONE	
6	b	1min.	1	50	Cl p c e	
			2	235	NONE	
			3	300+	NONE	
			4	300+	NONE	
			5	300+	Cl C	
			6	150	Cl C	
			7	120	Cl C p	
			8	105	Cl c	
			9	95	Cl C	
			10	80	P Cl c	
			11	65	NONE	
6	c	1min.	1	48	P cl	
			2	60	P cl	

TABLE 1.(continued) 11.

SECTOR NO.	TRANSECT	BOAT RUNNING TIME PER SECTION	SECTION NO.	DEPTH AT START OF EACH SECTION (cm)	CONSTITUENTS OF 'CATCH'	TOTAL CATCH DRY WEIGHT (g)
6	c	1min.	3	80	P Cl c	
			4	80	Cl C p	
			5	132	Cl C p	
			6	300+	NONE	
			7	300+	"	
			8	300+	"	
			9	300+	"	
			10	300+	"	
			11	300+	"	
			12	300+	"	
			13	250	C E	
			14	170	NONE	
6	d	1min.	1	50	P cl	
			2	65	P cl	
			3	80	P Cl	

TABLE 1.(continued)

SECTOR NO.	TRANSECT	BOAT RUNNING TIME PER SECTION	SECTION NO.	DEPTH AT START OF EACH SECTION (cm)	CONSTITUENTS OF 'CATCH'	TOTAL CATCH DRY WEIGHT (g)
6	d	1min.	4	122	CL c	
			5	300+	NONE	
8	a	1min.	1	60	"	
			2	223	"	
			3	210	"	
8	b	1min.	1	90	CL	
			2	140	CL	
			3	290	CL	
			4	270	CL	
9	a	1min.	1	70	P C	
			2	290	C	
			3	300+	NONE	
9	b	1min.	1	70	C	
			2	90	C	
			3	100	C	

TABLE 1.(continued)

SECTOR NO.	TRANSECT	BOAT RUNNING TIME PER SECTION	SECTION NO.	DEPTH AT START OF EACH SECTION (cm)	CONSTITUENTS OF 'CATCH'	TOTAL CATCH DRY WEIGHT (g)
9	b	1min.	4	300+	NONE	
			5	300+	"	
10	a	1min.	1	80	P	
			2	99	C	
			3	110	C	
			4	130	C	
			5	300+	NONE	
10	b	1min.	1	65	C P Cl	
			2	75	C Cl	
			3	300+	NONE	
			4	300+	"	
11	a	1min.	1	70	C P	
			2	75	C P	
			3	95	C	
			4	125	NONE	

TABLE 1. (continued)

SECTOR NO.	TRANSECT	BOAT RUNNING TIME PER SECTION	SECTION NO.	DEPTH AT START OF EACH SECTION (cm)	CONSTITUENTS OF 'CATCH'	TOTAL CATCH DRY WEIGHT (g)
11	a	1min.	5	300+	NONE	
11	b	1min.	1	60	C cl	
			2	300+	NONE	
12	a	1min.	1	65	Cl C	
			2	100	C	
			3	300+	NONE	
12	b	1min.	1	90	P cl	
			2	300+	NONE	
			3	300+	"	
13	a	1min.	1	80	P Cl C e	
			2	300+	NONE	
13	b	1min.	1	75	"	
			2	300+	"	

APPENDIX II - 1.

Standing crop (g SHOOT DRY WEIGHT m^{-2}) and shoot density (NO. SHOOTS. m^{-2}) of *Potamogeton filiformis* in eight (A-H) quadrats (Q) placed at random within each of two permanent 50m x 50m sampling areas off the Grahamstone (G1 and G2) and St. Serf's Island (S1 and S2) shores. Mean and standard deviation values are also given for these data before transformation (see Text).

Q	G1		G2		S1		S2	
	gm	No.	gm	No.	gm	No.	gm	No.
24.5.78								
A	0.11	5	0.07	6				
B	1.02	38	0.61	25				
C	0.15	12	0.45	21				
D	0.17	7	0.93	21				
E	0.41	12	0.59	13				
F	0.19	8	0.32	5				
G	0.71	24	0.03	2				
H	0.36	10	0.18	6				
Mean	0.39	14.5	0.40	12.4				
S.D.	0.32	11.1	0.31	8.9				
31.5.78								
A					0	0	0.76	20
B					0.48	18	0.05	5
C					0.34	12	0	0
D					1.21	39	0.50	18
E					0	0	0.87	36
F					0	0	1.84	112
G					0	0	0.30	11
H					0	0	0.47	18
Mean					0.25	8.6	0.60	27.5
S.D.					0.43	14.1	0.59	35.8

APPENDIX II (continued) 2.

15.6.78

Q	G1 gm	G1 No.	G2 gm	G2 No.	S1 gm	S1 No.	S2 gm	S2 No.
A	6.96	141	1.94	44				
B	1.80	104	4.60	156				
C	1.56	48	2.24	128				
D	13.11	388	6.86	100				
E	1.41	44	3.28	100				
F	7.73	596	4.23	200				
G	0	0	9.00	284				
H	0	0	4.12	104				
Mean	4.07	165.1	4.53	139.5				
S.D.	4.71	214.7	2.37	74.1				
					20.6.78			
A					13.60	1460	7.28	840
B					3.39	340	0	0
C					17.07	1480	0	0
D					1.11	160	0	0
E					26.37	1480	0	0
F					8.78	640	0	0
G					11.44	1560	16.18	860
H					11.13	1140	0.48	140
Mean					11.61	1032.5	2.99	230
S.D.					7.91	569.2	5.90	385.8

APPENDIX II (continued) 3.

6.7.78 | 6.7.78

Q	G1		G2		S1		S2	
	gm	No.	gm	No.	gm	No.	gm	No.
A	2.83	140	3.64	420	0	0	2.12	240
B	1.63	160	24.07	480	18.17	1080	0	0
C	1.53	180	8.28	440	0.32	40	0	0
D	3.96	360	7.17	340	0	0	28.61	1560
E	0.08	20	7.03	120	24.87	1740	8.95	640
F	6.57	340	27.90	1000	25.24	1580	1.94	220
G	26.28	940	2.19	260	53.43	3620	38.01	1320
H	8.22	520	16.64	1060	16.82	720	9.33	(?) N.B. n = 7
Mean	6.39	332.5	12.11	515.0	17.35	1097.5	11.13	568.6
S.D.	8.48	291.0	9.62	338.0	18.18	1235.1	14.40	636.2

27.7.78

Q	G1 gm	G1 No.	G2 gm	G2 No.
A	27.78	920	2.86	340
B	19.36	700	61.92	1340
C	11.53	940	16.28	560
D	6.50	580	16.46	580
E	6.11	420	8.43	520
F	33.64	760	38.18	1820
G	10.45	640	31.18	2380
H	13.73	620	77.01	1940
Mean	16.14	697.5	31.54	1185.0
S.D.	10.03	87.3	26.33	762.3

APPENDIX II (Continued) 4.

3.8.78					3.8.78			
Q	G1		G2		S1		S2	
	gm	No.	gm	No.	gm	No.	gm	No.
A					0.18	20	0	0
B					8.80	920	0	0
C					0	0	0	0
D					3.05	360	0	0
E					0	0	23.47	1900
F					0	0	0	0
G					17.56	3140	0	0
H					9.35	1600	6.11	1740
Mean					4.89	755.0	3.70	455.0
S.D.					6.47	1123.5	8.27	528.3
25.8.78*					25.8.78			
A					23.07	1940	0	0
B					11.21	1280	0	0
C					7.69	960	8.39	820
D					0	0	13.54	1180
E					3.29	60	3.09	560
F					14.58	1540	0	0
G					6.58	700	0	0
H					18.29	1420	0	0
Mean					10.59	987.5	3.13	320.0
S.D.					7.76	697.3	5.14	472.0

* Data for the Grahamstone shore - 25.8.78 - have still to be processed.

APPENDIX II (continued) 5.

11.10.78					11.10.78			
Q	G1		G2		S1		S2	
	gm	No.	gm	No.	gm	No.	gm	No.
A	13.46	560	0	0	0	0	0	0
B	0	0	0	0	0	0	0	0
C	2.91	180	0	0	0	0	0.52	20
D	0	0	17.8	300	8.18	920	0	0
E	29.85	500	0	0	0	0	0.71	60
F	19.23	340	1.66	200	0.55	100	0	0
G	5.71	180	8.26	500	3.10	240	0.40	100
H	9.27	440	0	0	9.03	480	0	0
Mean	10.05	275.0	3.45	125.0	2.61	217.5	0.20	22.5
S.D.	10.42	228.3	6.42	190.9	3.85	330.8	0.29	37.7
1.11.78					1.11.78			
A	0	0	0	0	0	0	0	0
B	0	0	0	0	0	0	0	0
C	0	0	0.50	40	0.60	60	0	0
D	0	0	0	0	0.74	120	0	0
E	0	0	0.31	60	0	0	0.04	20
F	0.31	120	0.48	40	0	0	0	0
G	0.11	20	0	0	0.61	80	0.11	20
H	0	0	0	0	1.16	120	0.09	20
Mean	0.05	17.5	0.16	17.5	0.39	47.5	0.03	7.5
S.D.	0.11	42.0	0.23	24.9	0.45	54.4	0.05	10.3

Plates

Legends to Plates referred to in this Report are listed on the next page. However only a few copies of the Report include the Plates; these are lodged with Dr C. Newbold (N.C.C. George House, Huntingdon), Mr A.J.P. Gore (I.T.E. Monks Wood Experimental Station, Abbots Ripton) and Dr. A.E. Bailey-Watts (I.T.E. Craighall Road, Edinburgh). Extra copies of Plates may be arranged through Dr Bailey-Watts who holds original transparencies and negatives.

Legends to Plates (all photographs by A.E. Bailey-Watts except where otherwise stated).

1. $<$ 0.5g dry weight 'catch' of *Potamogeton filiformis* from drag-rake section on western part of north-east shore.

2. A dense stand of *P. filiformis* in *ca* 60 cm waterdepth north of St Serf's Island (photograph by A. Allison).

3. Propeller of outboard engine choked with *Potamogeton* - South shore August 1978.

4. Double-headed rake used for sampling submerged plants; this illustration shows an especially large collection of *Potamogeton filiformis* plus *Cladophora* from the Grahamstone shore - September 1977. (photograph by L. May).

5. Measuring water depths between sections of sampling transects.

6. Two-seater 'Falke' motor glider.

7. Camera attachment to "Falke".

8. *Eleocharis palustris* stand on South shore August 1978.

9. *Microcystis* aggregations among *Polygonum* - August 1978.

10. *Phragmites communis* stand - east bay of St Serf's Island - August 1978.

11. Area north of St Serf's Island (July 1977): particularly dense stands of *Potamogeton*, *Chara* and *Cladophora* lower right with a flock of about one dozen Swans; glare from sun reflecting lower left. (1000' altitude) - July 1977.

12. Similar area to 11, more oblique, shot - (2000' altitude) - July 1977.

13. Patchy distribution of plants north of St Serf's Island - July 1977.

14. Shallows off north east shore - very slight accumulations of *Microcystis* - August 1978.

15. *Cladophora* beds off stony north shore of West bay near public pier - July 1977.

16. Floating aggregations of *Microcystis* top right and in small bay middle left - some submerged stands of *Potamogeton* visible. - August 1978.

17 and 18. Especially dense accumulations of *Microcystis* along south and north-east shores respectively - August 1978.

19. Section of south shore: 'false colour' photograph in which *Microcystis* aggregations show pink and terrestrial vegetation deep red.