BROADS RESTORATION PROJECT
FIRST YEAR REPORT - 1990

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BIOMANIPULATION AND RESTORATION OF THE NORFOLK BROADS

SECTION ONE

THE WHOLE BROAD ISOLATION EXPERIMENTS - ALDERFEN BROAD

Alderfen Broad, isolated from its effluent-rich inflow in 1979, subsequently showed a recovery of large crops of submerged plants in the early 1980s. No sediment was removed from the Broad, nor were plantings made. The plants then declined in the mid 1980s and there were co-incidental increases in spring of diatoms and in summer of blue-green algae. The size and extent of the algal growths was not likely to be great enough to outcompete the plants for resources such as light. In the late 1980s the algal crops declined and the plant crops began to increase again. The attached paper, which has just been published, summarises the situation until summer 1989. The plant crop in August/September 1989 was 11.4±S.D.17.7 gd.w m^{-2} (n=51) and there was a further increase to very dense growths in 1990 (53.9±S.D.55.0 gd.w m^{-2} (n=55). There has thus been a major resurgence of plants and the probability that an innate cycle exists is increased.

It is still not clear, however, what drives the cycle. Zooplankton communities are not closely correlated with the cycle though overall the grazer potential is high and the water remains clear throughout the growing season of zooplankton and potentiallly of algae. It is likely that a low fish stock allows this sitaution though stocks are not regularly monitored in this Broad. There is an abundance of phosphate, much of which appears to emerge from the sediments, and because of the isolation of the broad from its catchment, a very low load of nitrogen. The attached paper suggests that nitrogen supply may be linked with the plant and algal cycles in the Broad but there is also the possibility of a plant-driven cycle in which the large crops of plants at the height of their growth alter the conditions at the sediment surface so as to inhibit their own regeneration. Clearly they create anaerobic and possibly sulphide-rich conditions in the surface sediments as a result of decomposition. It is possible that once these conditions are created, a period of reoxidation of the sediment surface is needed before the plants can again regenerate from seed. Such a process might be expected also in other plant-beds, but may take place annually over winter. In Alderfen Broad the complete lack of flow though of water may inhibit the process and extend it over three or so years.

Alderfen Broad remains as a particularly interesting isolation experiment, demonstrating that sediment removal is not inherently necessary for plant regeneration and that sediment-plant interactions are nonetheless likely to be important. An investigation of the plant cycle would constitute a major project in itself and it is a matter of regret that there is time only for a minimal monitoring of the experiment.

SECTION TWO

THE WHOLE BROAD ISOLATION EXPERIMENTS - COCKSHOOT BROAD

Cockshoot Broad was isolated in 1982 with the removal of sediment from all but the western edge and the Dyke which formerly connected the Broad with the river. Improvement in water quality followed isolation with rapid colonisation of the Dyke by plants and a slow recolonization until 1984/85 of the main basin. The Dyke community has continued to flourish but after 1985 the plant population, which was sparse in the main Broad, declined as chlorophyll a levels in the phytoplankton coincidentally increased and water turbidity also increased.

Examination of past data showed that zooplankton grazing had been extensive in the early years with large populations of *Daphnia* of large body size initially present. Large Cladocera in substantial numbers persisted among the plants of the dyke and experiments in dialysis bags in 1989 showed that grazing was the reason why the water remained clear in the dyke. This maintains a very favourable light climate for plant growth.

In the main Broad, however, the *Daphnia* populations became progressively smaller from 1982 onwards and their body sizes decreased. These changes were progressive until 1988 and are symptomatic of increasing predation by young coarse fish. Experimental fishing in 1986 showed a good recruitment of two year old (born in 1984) fish which was repeated in subsequent years, but few fish older than those born in 1984. It appeared that the disturbance of the engineering operations involved in sediment removal and damming of the Broad had scared fish back to the river. With its very shallow water the Broad probably had very few fish in its former state. Low initial fish predation had thus allowed the prolific *Daphnia* development after isolation. However, with but a few breeding pairs, coarse fish stocks can rapidly recover and remove the *Daphnia* in the absence of refuges for it. In the open water of the main Broad, with few refuges available from plants in the early years, *Daphnia* numbers were progressively reduced and the larger individuals, which graze most efficiently, preferentially eliminated.

In the Dyke, however, rapid initial plant establishment had provided refuges early and had allowed the coexistence of fish predator and cladoceran prey which much work elsewhere in Broadland has shown to be crucial for maintenance of a permanent plant community. The reason why the plants established much more rapidly in the Dyke seems to be that the Dyke affords physical shelter from the prevailing wind. Coot grazing was important in restricting growth of water lilies planted in the main basin and with wind and wave disturbance undoubtedly contributed to delayed colonization of the main basin. With the sheltered nature of the Dyke, however, equal if not greater attention from coots did not prevent prolific growth being established very quickly.

In 1988, the decision was made to remove fish from the Broad and this was done in early 1989. There was a dramatic improvement in the light climate of the Broad with a strong inverse relationship between planktonic chlorophyll a concentrations and *Daphnia* numbers. Remaining fish were removed in winter 1990 and the clear-water season for the Broad extended from April to October with large ($>100l^{-1}$) populations of large-bodied *Daphnia* and greatly reduced ($<10ugl^{-1}$) chlorophyll a concentration for much of the summer.

The light climate can now be maintained (provided the fish recruitment is kept down by fishing each winter) ideal for plant growth long enough for full colonization to take place. This will be several years if extensive plantings are not made to overcome the physical problems of exposure noted in the early years. There is presently only a small plant inoculum in the main basin, with the result that thalloid algae (*Monostroma/Enteromorpha*) grew thickly on the bottom of the Broad in July 1990 but higher plant growth remained sparse. There was however an increase (0.04 ± 0.35 gd.wm-2) over 1989 (0.02) and 1988 (0.005 ± 0.002). We recommend planting of the main basin as soon as possible with use of fencing or other devices to counteract wind, wave and bird damage.

An interesting feature of Cockshoot Broad has been the change in its water chemistry. Initially the phosphorus concentrations fell but as the plant community in the Dyke increased they rose, and have been very high for the past few years. This results from sediment release from under the plant beds, a phenomenon which seems to be characteristic of dense beds in Broadland and elsewhere. Nitrogen levels however have not been high - the microorganisms associated with the sediment are efficient sinks. There is, however sufficient nitrogen available to support large algal populations, as shown by our dialysis bag experiments, but grazing prevents build up of these crops.

In 1990, phosphorus concentrations increased also in the main Broad from July onwards with symptoms of release from the sediment (high soluble reactive phosphorus concentrations). This is not unexpected because the large thalloid algal crops present on the bottom must create similar conditions at the sediment surface for phosphorus release as beds of vascular plants. If grazing potential is maintained by fish removal for a long enough 'window' for establishment of a plant community, the present phosphorus concentrations need not cause concern.

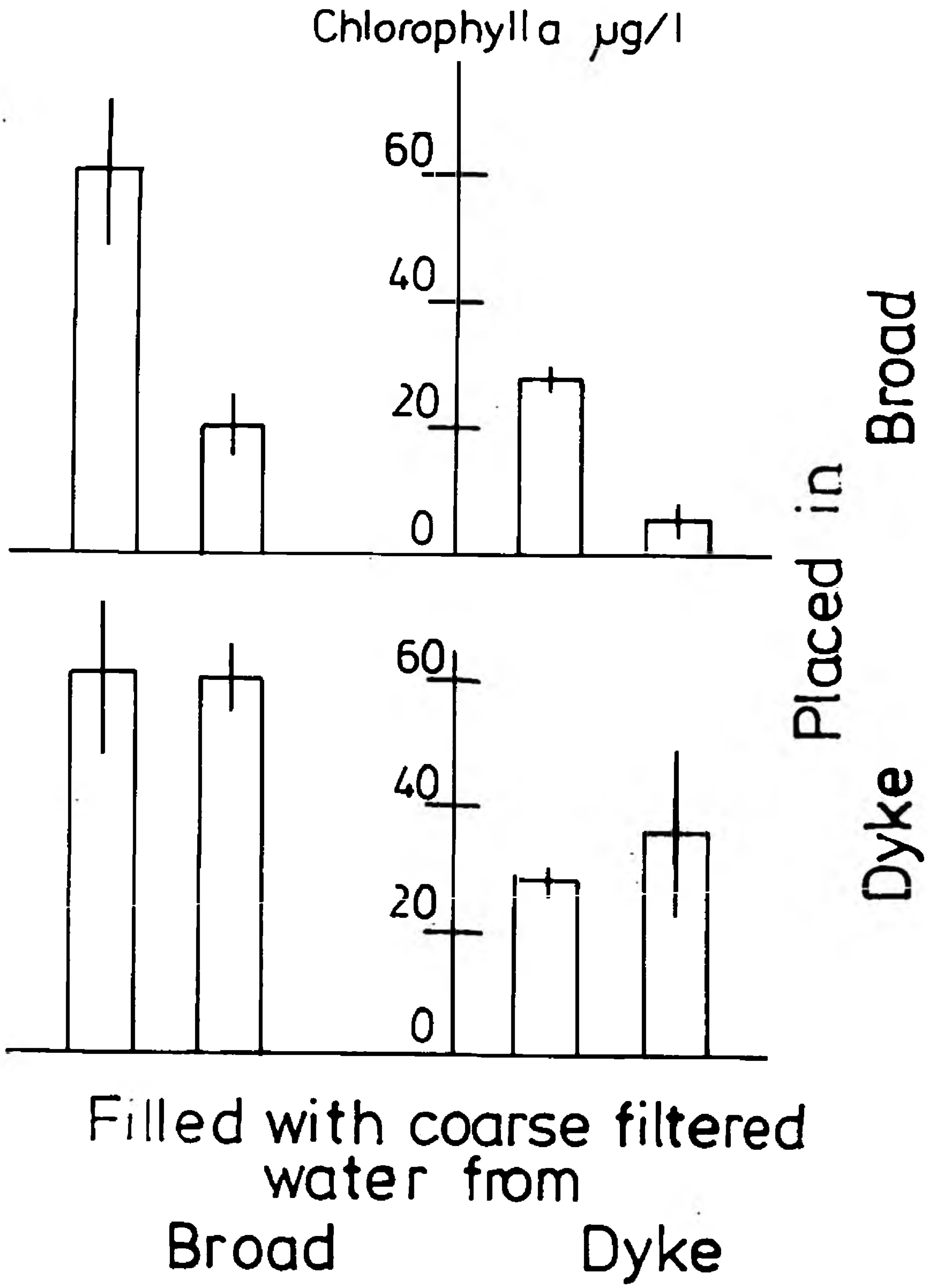


Fig 1.1 Water from Cockshoot Broad and Cockshoot Dyke was placed in dialysis bags (volume 100ml) after filtration to remove zooplankters but not phytoplankters. Forty bags were filled with Broad water and twenty of these replaced in the Broad and twenty in the Dyke. Similarly, of forty bags filled with Dyke water, twenty each were placed in the Dyke and Broad. Chlorophyll a concentrations were determined after one week. Nutrient conditions in the Broad were unable to maintain any increase in the Broad, despite large initial algal populations in the Broad water. Dyke water, the other hand, maintained chlorophyll levels or increased them. An even more graphic demonstration of the enhanced nutrient levels in the Dyke and their potential for supporting algal growth is the thick coating of algae on the outside of the bags in the Dyke, compared with those in the Broad, which were essentially uncolonised (Fig 1.2).

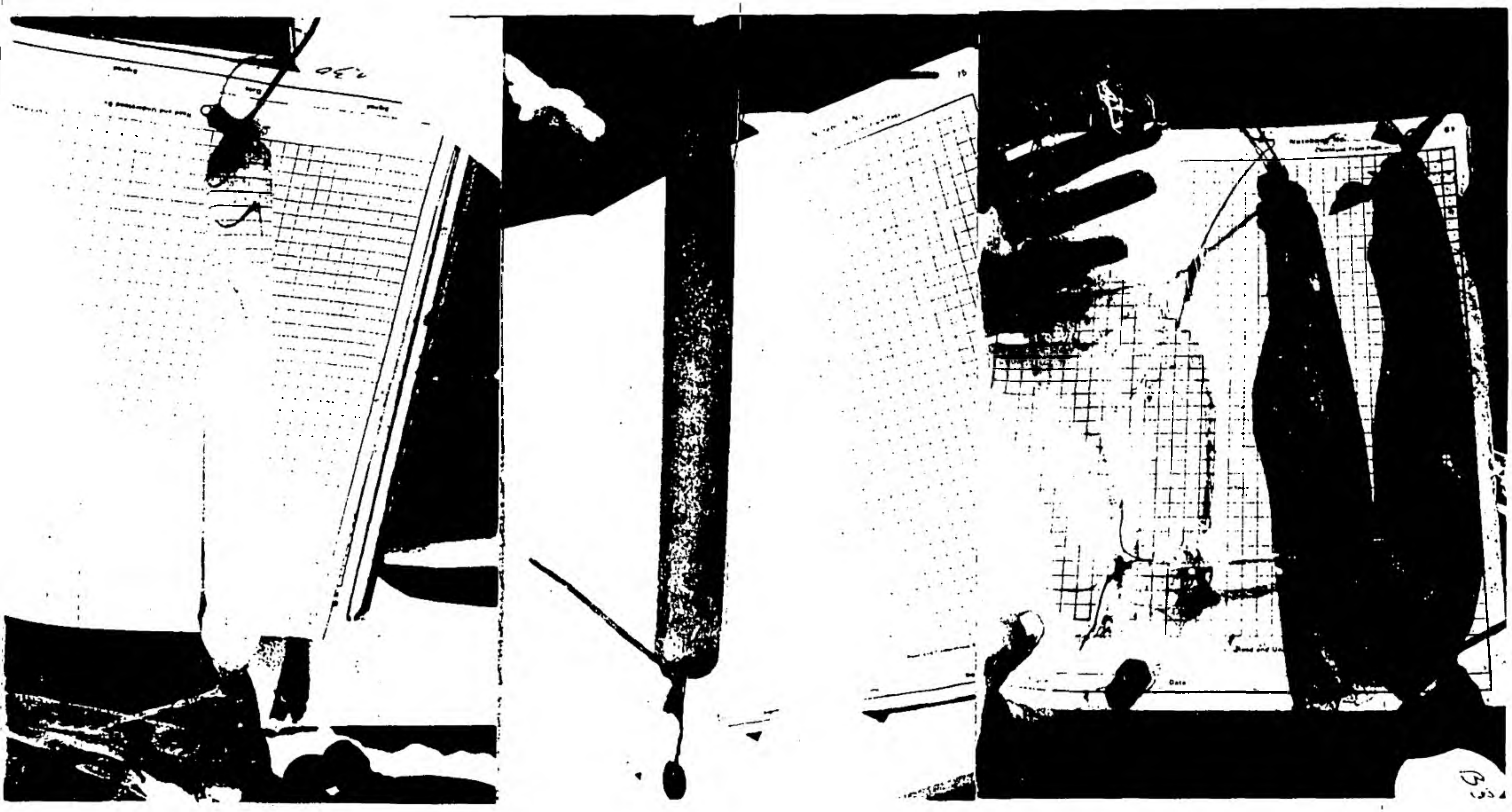


Fig 1.2 Dialysis bags after one week's growth. Left: typical bag incubated in Broad; Centre bag incubated in Dyke; Right: emptied bags from Broad (left) and Dyke (right).

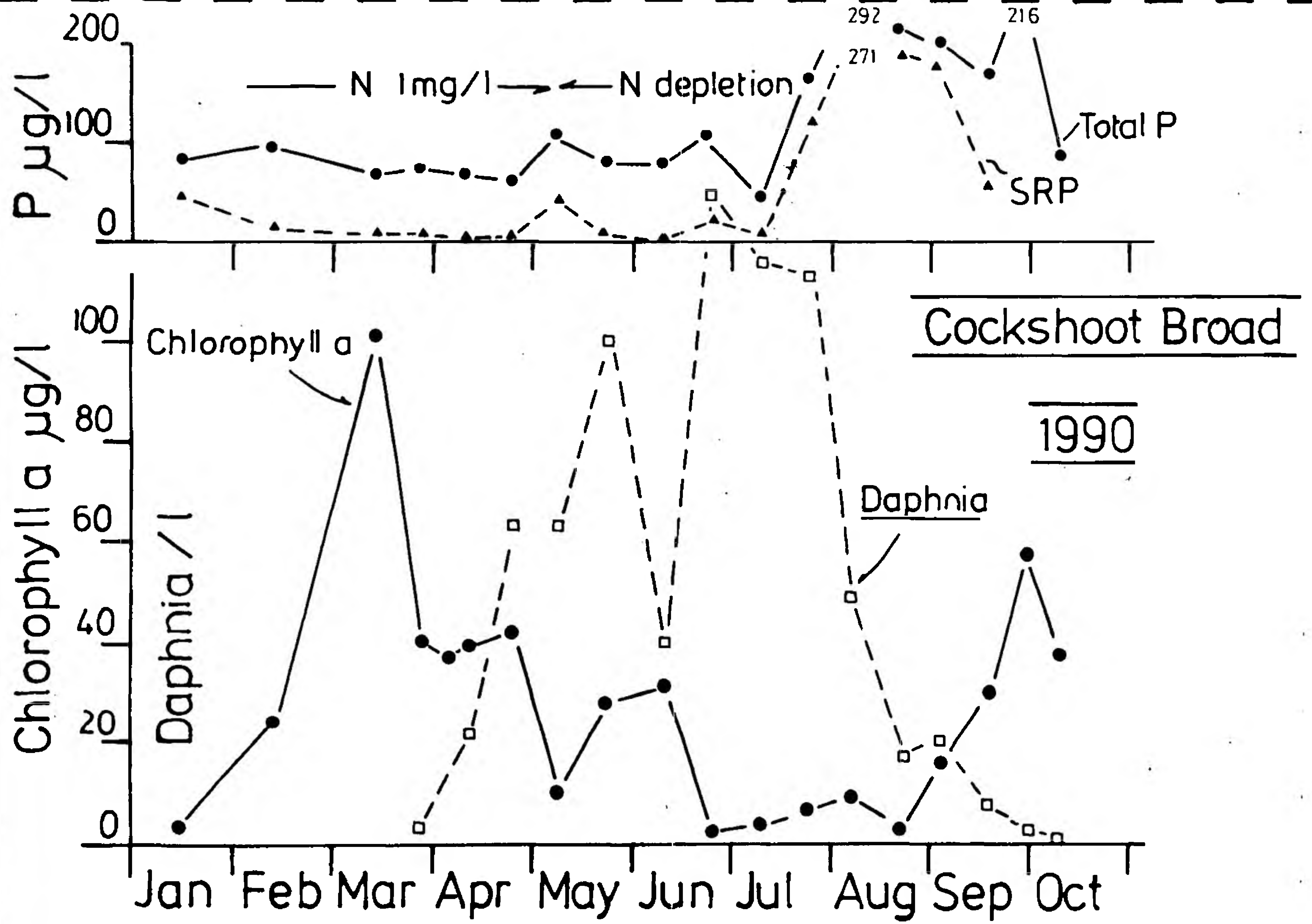


Fig 1.3 Changes in total phosphorus, chlorophyll a, and Daphnia in 1990 in Cockshoot Broad.

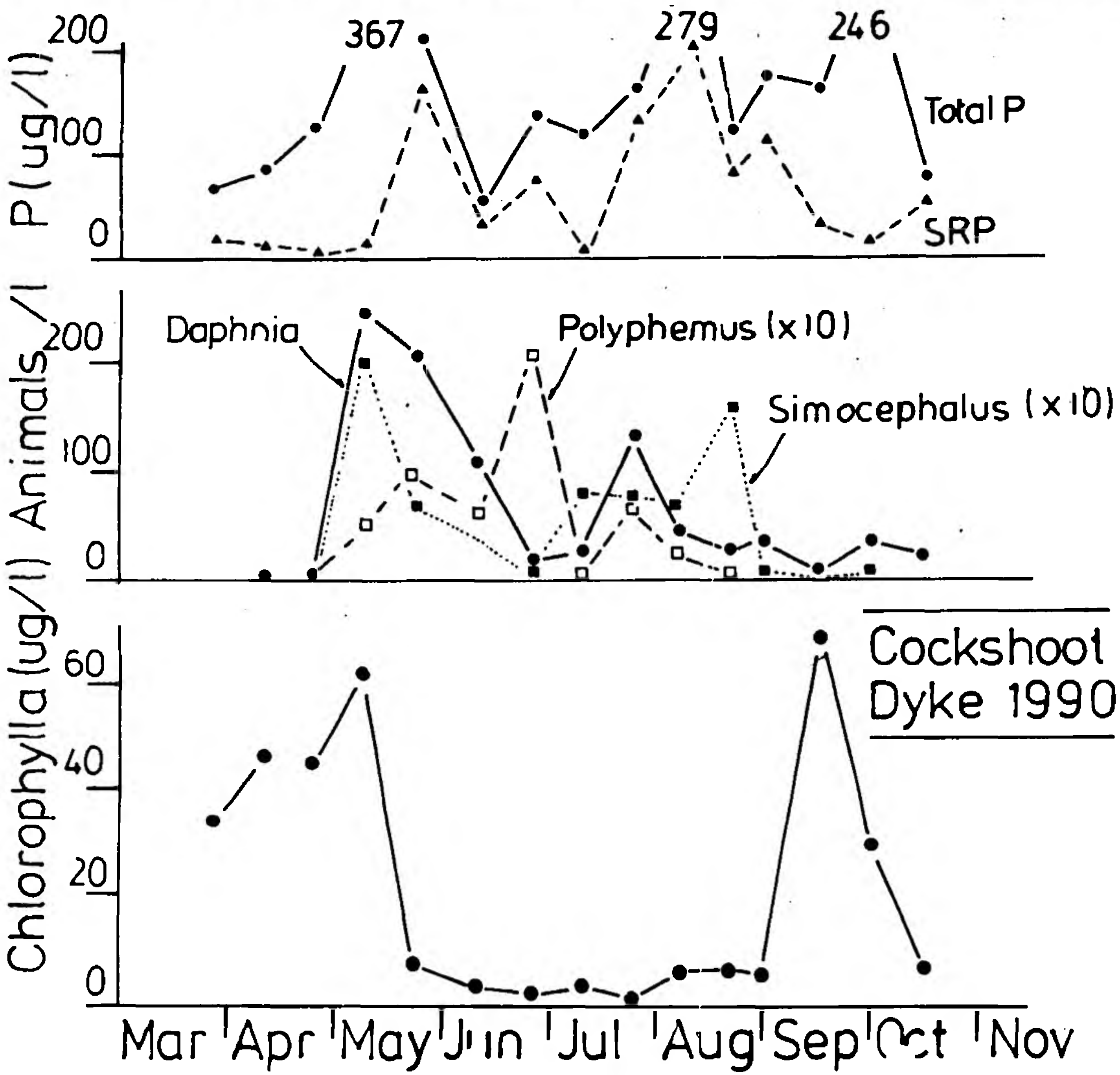


Fig 1.4 Changes in total and soluble phosphorus, numbers of Cladocera and chlorophyll a in Cockshoot Dyke in 1990.

SECTION THREE

HOVETON GREAT BROAD EXCLOSURE BIOMANIPULATION EXPERIMENT

Exclosure design and construction

The area chosen for the Hoveton Great Broad fish exclosure is a bay in the western end of the Broad (see Fig 3.1). The site is close to the nature trail which allows easy access and enables this important project to be shown to the public. There are two dykes in the area which had to be excluded so as to avoid risk of re-entry of fish from the Broad or river. This has left an area of approximately 1ha to form the exclosure.

The design of the barrier wall had to be such that it would allow tidal water to move in and out, thereby avoiding the need for a very strong barrier and allowing as high a flushing rate as posible. Flushing rate is important in maintaining similar rates of nutrient loading on both sides of the barrier and also to avoid favouring the growth of blue-green algae. At the same time fish, including very small fry, had to be prevented from getting back into the exclosure. These aims were achieved by building a solid barrier but with numerous windows of 1mm steel mesh. To prevent these becoming clogged with growths of algae, sponges etc., regular cleaning has been carried out.

Detailed design and also construction were undertaken by the Broads Authority. Fig 3.2 shows the main features of the design. Construction was started in April and finished in

Fig 3.1 Map of Hoveton Great Broad

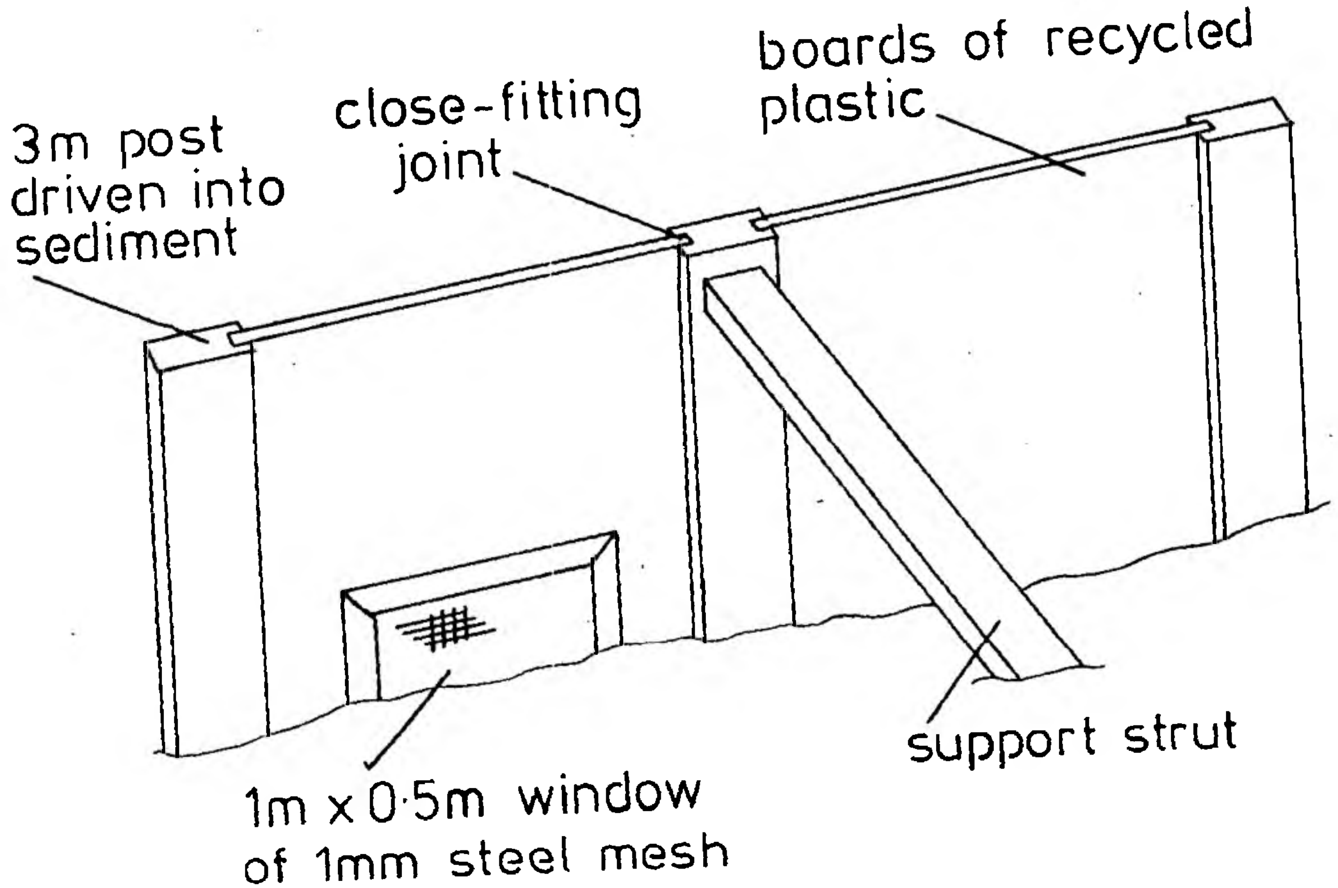


Fig 3.2 Simplified diagram of exclosure wall

early May. Due to unusually warm spring weather, fish spawning occured before the barrier was completed. As eggs and small fry are impossible to remove, it was not possible to create a fish-free environment in the exclosure in 1990. However, this has provided a valuable opportunity to test for any effects of the presence of the barrier on the water within it and to assess the starting conditions for the experiment. The results of this work are recorded below.

Fish removal has been carried out by the NRA fisheries team during January and February 1991. Electrofishing was used to catch fish from around the edges and netting was used in the central area. All fish were released back into the main Broad.

1990 results

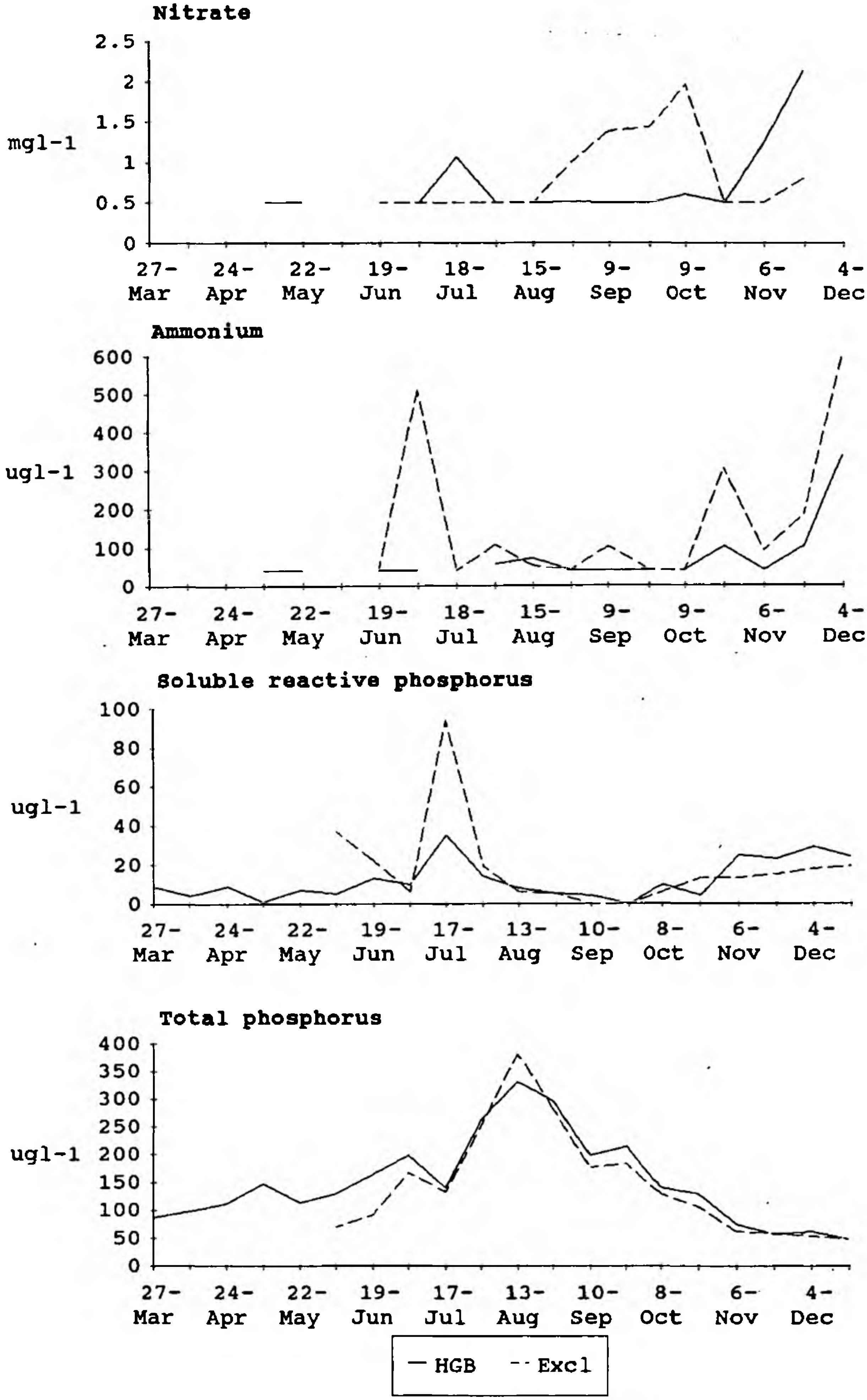
During 1990 the exclosure and Broad were monitored for water chemistry and algal, zooplankton and benthos populations. Benthos samples were stored until the winter due to lack of time for analysis. Preliminary results are presented in the following section of this report.

Chemistry, algae and flushing rate

Results from water chemistry and algal monitoring can be used to assess the effectiveness of the flushing rate in the exclosure. Flushing rate is important for two reasons: In order for this experiment to test the effects of the removal of fish and not the effect of enclosing a small body of water, it is important that other aspects, especially nutrient loading and algal community structure and density, be kept as similar as possible. Also blue-green algae are favoured by a low flushing rate. These algae are not readily grazed by Cladocera and so their presence would interfere with the aim of providing clear water in the exclosure.

A comparison of concentrations of nitrogen and phosphorus compounds is presented in Fig 3.3. Results are generally similar inside and outside the exclosure on the majority of sampling occasions for ammonium and phosphorus. Nitrate concentrations are higher in the exclosure than the main Broad in late summer and autumn and lower in the winter. Higher concentrations may be due to increased rates of mineralisation in the sediment due to the greater density of benthic invertebrates (see next section). In the period just after the exclosure was built high Daphnia populations in the exclosure kept algal populations low (see below for discussion). This resulted in lower total phosphorus and higher soluble reactive phosphorus in the exclosure. Phosphorus concentrations are otherwise similar, apart from a short period of phosphorus release which produced a higher concentration in the exclosure, probably due to the shallower water. Concentrations of ammonium are mostly below the limits of detection during the summer. In the exclosure there is an apparent release of ammonium although this isolated result could also be due to analytical error.

Fig 3.3 Water chemistry Hoveton Great Broad and exclosure

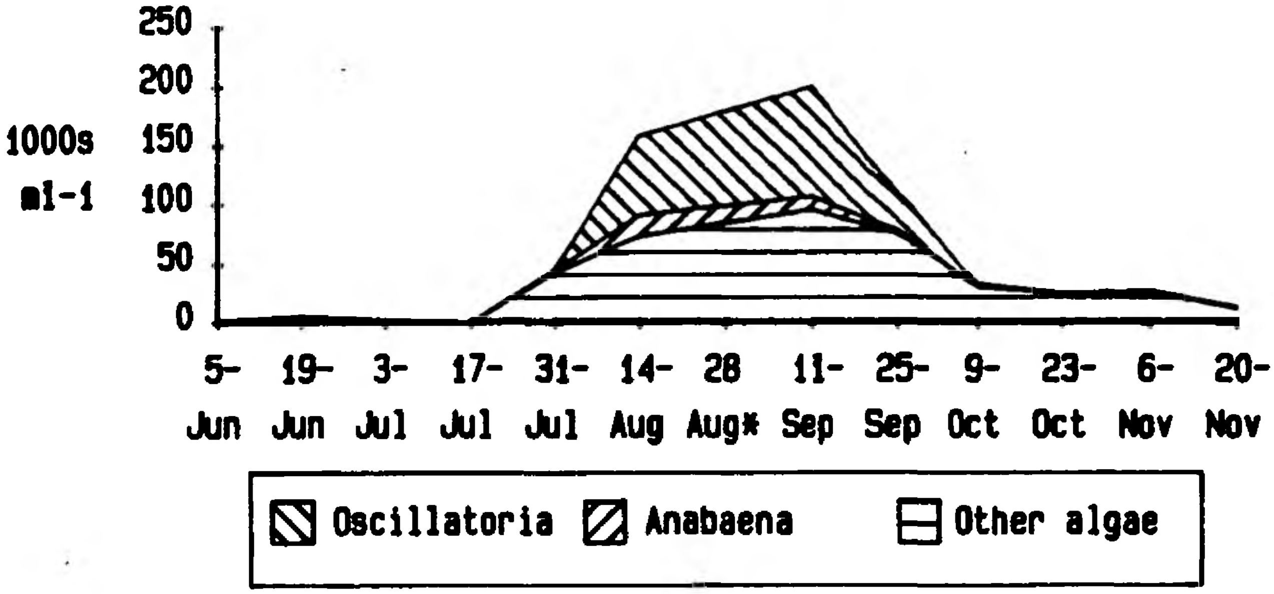


The assessment of flushing rate in relation to blue-green algae is complicated by the fact that the unusually dry, warm weather in the summer of 1990 allowed high populations of blue-green algae to develop in the main Broad. However, by comparing population size and timing of the first appearance of blue-green algae on both sides of the barrier, we can test if they have been further encouraged in the exclosure. Fig 3.4 shows a summary of the phytoplankton populations inside and outside the exclosure. The main blue-green algal genera, *Anabaena* and *Oscillatoria*, establish first in the main Broad at the end of July and in the exclosure by the following sampling date. During August and early September the numbers of *Oscillatoria* sp are higher in the exclosure, especially on September 11. The sample for the exclosure on August 28 is missing, data presented on the graph being means of sampling dates on either side for ease of graphical representation. Thus conditions in the exclosure may have favoured blue-green species somewhat over the main Broad. The frequency with which the mesh windows are cleaned will be increased to try and eliminate this problem.

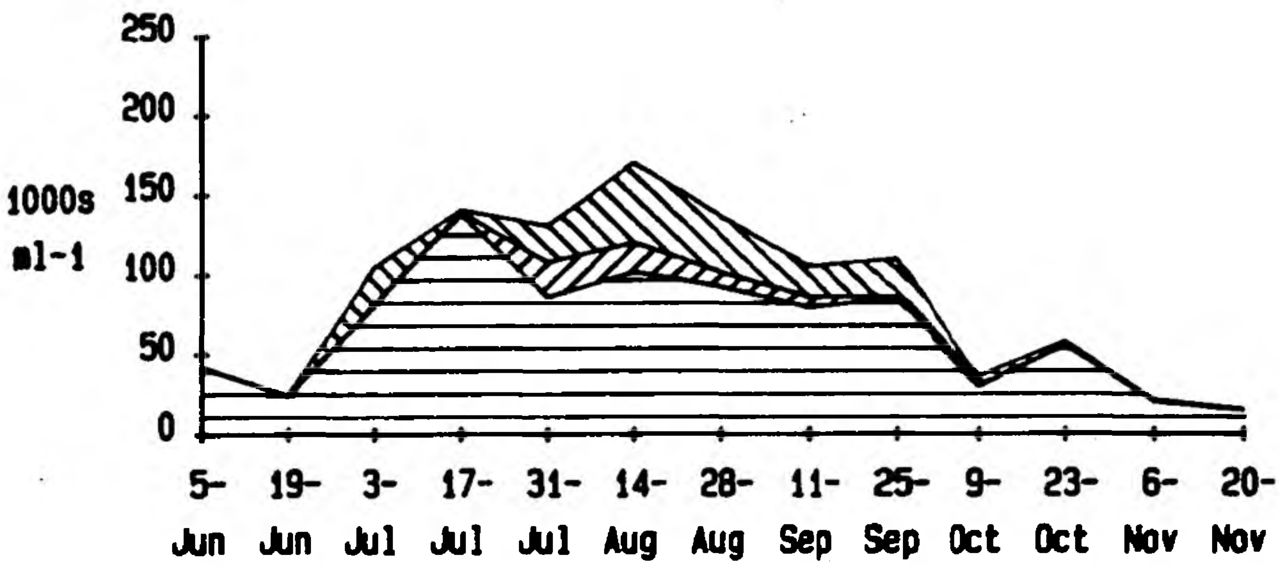
An opportunity to measure the flushing rate directly occured in September when a sea surge pushed salt water into the Broad and exclosure. By comparing the rates of dilution, we found the flushing rate in the exclosure was comparable to that in the Broad. Detailed calculations have yet to be completed.

Fig 3.4 Phytoplankton populations

Hoveton exclosure



Hoveton Great Broad



Several lines of evidence have therefore shown that the flushing rate in the exclosure is sufficient to produce similar concentrations of nutrients to the main broad, and not to greatly encourage growth of blue-green algae.

Fish and zooplankton

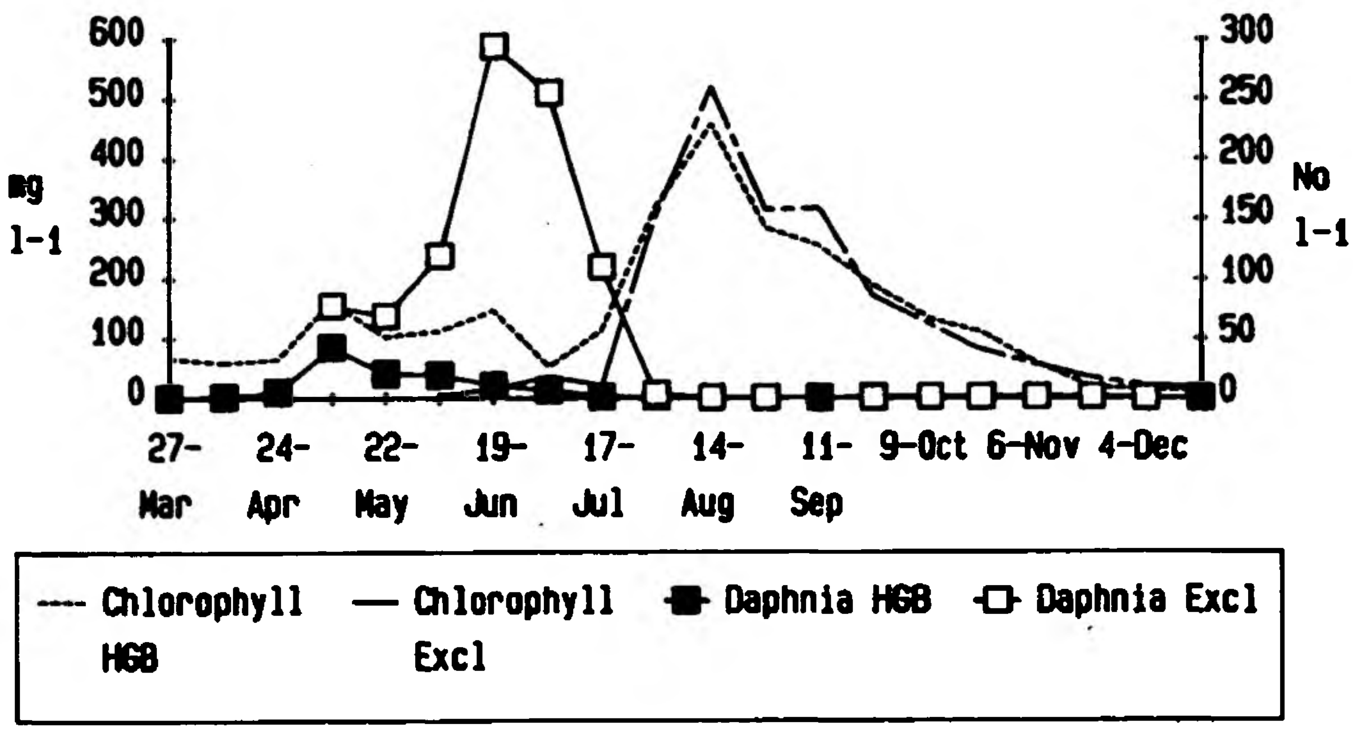
Data on the numbers of fish in the exclosure, obtained from the fish removal operation, can be used to assess the effect on zooplankton populations and explain some of the differences between the Broad and exclosure. The numbers of fish recovered in January are presented in Table 3.1. The main points about this fish community are the relatively low biomass and the virtual absence of adult fish of large species. It is thought that these were scared away by the engineering operations after they had laid their eggs.

The consequence of this community structure has been low predation pressure on zooplankton early in the year, in the period immediately after the exclosure was completed. While predation losses caused by the fish were lower than the reproductive capacity of the *Daphnia*, a large population developed in June and July (see Fig 3.5). Although no data are available for the main Broad, it can be assumed that the density of one year and older fish was relatively high. Predation by these fish, and the young of the year when they became large enough, kept *Daphnia* populations low throughout the year. In mid July the point was reached in the exclosure when *Daphnia* reproduction could no longer keep pace with

Number (approx.)	Species	Age
5000	Roach	0+
2-300	Eels	Adult
40	Perch	0+, 1+
20	Ruff	Adult
10	Tench	Adult
10	Bream	0+
5	Rudd	Adult
5	Gudgeon	Adult

Table 3.1 Fish recovered from Hoveton Great Broad exclosure 1990

Fig 3.5 Chlorophyll concentrations and Daphnia populations



increasing predation losses, as the fish became larger, and the population crashed.

The effect of the changing numbers of *Daphnia* on the chlorophyll concentration can be see in Fig 3.5. Very low concentrations of chlorophyll were maintained in the exclosure during the period of high *Daphnia* numbers, compared with moderately high concentrations in the Broad. Chlorophyll concentrations increase in both Broad and exclosure after the fall in *Daphnia* numbers due to the success of blue green algae.

These results have shown that clear water can be produced in the exclosure when fish predation is low and has also provided quantitative information on the relationship between *Daphnia* and zooplanktivorous fish.

SECTION 4

A REPORT ON BENTHOS SAMPLING IN HOVETON GREAT BROAD, 1990-91.

Aims of Sampling

The aim of this aspect of the experiment is to investigate the response of the benthic fauna to fish removal, directly as a result of reduced predation and indirectly by the effects of any changes in the water quality. This will include looking at changes in animal numbers, the population dynamics of the chironomid larvae and any change in the species diversity. It also gives an opportunity to examine, in more detail, influences the benthos may exert upon the Broad, such as nutrient release from the sediment.

Sampling Method.

Benthos samples have been taken from Hoveton Great Exclosure and Main Broad since April 1990.

Samples are taken fortnightly using an Ekman grab. Ten are taken in the exclosure and ten in the main Broad. These are sieved on site through a 0.5mm mesh net. Samples taken in the exclosure are handled in the main Broad. The remaining material is placed in a bottle and sealed for processing at the laboratory. Samples taken in 1990 were preserved and stored and we have now begun sorting these samples. There has only been one set of samples taken so far this year due to icing on the Broad; this was sorted live.

Sample Handling

Animals are sorted from the detritus under a stereo microscope and then identified. It has been necessary to devise a subsampling method so that only a proportion of the whole sample is looked at because of time considerations. This has taken up mnch of the available time so that the routine for processing has only recently been finalised. Two sets of samples from 1990 have been completed.

The sample taken in 1991 was sorted live, again using a subsampling method to reduce the time spent to a manageable level. It is intended to continue sorting future samples live as more immediate feedback is given and it is eventually quicker than preserving the samples. In both cases only the total number of chironomids and tubificid worms have been recorded.

The next step is to continue sorting preserved samples and to identify animals when sorted. It is intended to identify the oligochaetes to species and the chironomid larvae mainly to genus, some to species.

Subsampling Method

Preserved Samples

The formaldehyde is drained off the sample through a 0.5mm mesh sieve. The drained contents are then washed thoroughly on 0.3mm sieve and any large objects removed. To subsample, the material is suspended in a suitable volume of water, usually 2.5l. The suspension is then stirred thoroughly and a subsample taken by lowering a beaker of a known small volume into the well mixed sample. This is continued until the required number of subsamples have been taken.(See below) These are then sorted under a stereo microscope.

Live Samples

The same procedure as above is followed but the large chironomids are removed prior to dilution of the complete sample. These are removed because they do not give a representative subsample. The sample is sorted through on a white tray.

Results

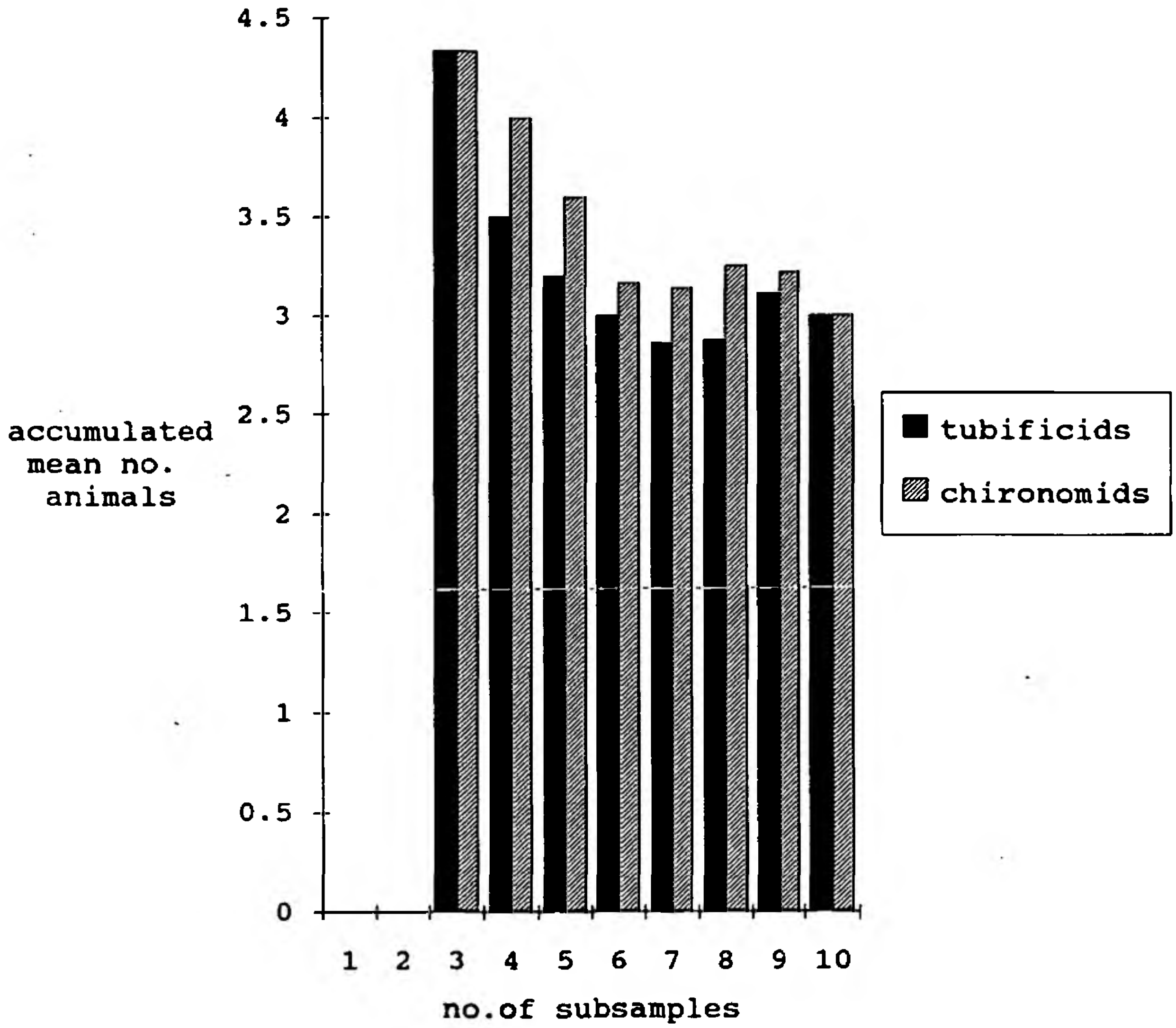
Method verification

The aims of this were to ensure reproducibility. Initially, each subsample was counted separately. Accumulative means were calculated and plotted (Figure 4.1). Where the mean values stopped fluctuating greatly was taken to be the minimum number of subsamples that could be taken.

Figure 4.1

Accumulated mean numbers of Tubificids - Number 2

PRESERVED SAMPLE



This was determined to be 5. We further designated a minimum number of animals to be found (100) and a minimum proportion of the sample to be sorted (greater than or equal to half). Both the first criteria (5 subsamples) and either of the second must be met for each sample.

Live benthos subsampling was initially carried out using the method described above, except that after all the subsamples had been taken the rest of the sample was sorted. However, it was found that the chironomid numbers fluctuated to some extent between subsamples,(Figure 4.2 and Table 4.1a) and a chi-squared test on the observed numbers versus those expected gave a poor result, chi-square = 11.9198, p = 0.05. To try to solve this problem it was decided to pick out the large chironomids from the whole sample prior to subsampling. This gave a much improved result, chi-squared = 2.379, p = 0.05, (Table 4.1b) the observed results do not deviate significantly from the expected. There also appeared to be less fluctuation between the subsamples (Figure 4.3). This was the method finally adopted.

A summary of the mean animal numbers found is given in Table 4.2 and Figure 4.4. The benthos mainly consists of tubificid worms and chironomid larvae and only these figures are shown. Occasionally, other animals have been recorded including *Gammarus* spp., Pea mussels(*Pisidium*) and Helmid beetles.

TABLE 4.1 A AND 4.1B: TO SHOW RESULTS OF LIVE SUBSAMPLING BEFORE AND AFTER THE REMOVAL OF LARGE CHIRONOMUS

TABLE 4.1A.

HGB BENTHOS SORTED LIVE
INSIDE EXCLOSURE NUMBER 2
29-Jan-91 Large Chironomus NOT removed

TUBIFICIDS subsample no.	numbers	Accumulative mean	std dev	CHIRONOMIDS subsample no.	numbers	Accumulative mean	std dev
1	12			1	0		
2	10			2	3		
3	9	10.333	1.528	3	1	1.333	1.528
4	4	8.750	3.403	4	2	1.500	1.291
5	3	7.600	3.912	5	0	1.200	1.304
6	7	7.500	3.507	6	2	1.333	1.211
7	8	7.571	3.207	7	1	1.286	1.113
8	6	7.375	3.021	8	1	1.250	1.035
9	6	7.222	2.863	9	0	1.111	1.054
10	12	7.700	3.093	10	1	1.100	0.994
11	8	7.727	2.936	11	2	1.182	0.982
Tot. subsamples	85			Tot. subsamples	13		
Tot. rest sample	93			Tot. rest sample	34		
TOTAL	178			TOTAL	47		

CHI-SQUARED TEST

	Total subsample	Total rest sample		Total subsample	Total rest sample
observed	85	93	observed	13	34
expected	93.98	84.02	expected	24.82	22.18
difference	-8.98	8.98	difference	-11.82	11.816
chi-squared=	1.819		chi-squared=	11.920	

TABLE 4.1B

INSIDE EXCLOSURE NUMBER 3
29-Jan-91 Large Chironomus REMOVED

TUBIFICIDS subsample no.	numbers	Accumulative mean	std dev	CHIRONOMIDS subsample no.	numbers	Accumulative mean	std dev
1	39			1	2		
2	46			2	2		
3	40	41.667	3.786	3	3	2.333	0.577
4	37	40.500	3.873	4	4	2.750	0.957
5	51	42.600	5.771	5	4	3.000	1.000
6	39	42.000	5.367	6	1	2.667	1.211
7	38	41.429	5.127	7	7	3.286	1.976
8	44	41.750	4.833	8	1	3.000	2.000
9	49	42.556	5.126	9	3	3.000	1.871
10	51	43.400	5.522	10	2	2.900	1.792
11	43	43.364	5.240	11	2	2.818	1.722
Tot. subsamples	477			Tot. subsamples	31		
ot. rest sample	429			Tot. rest sample	40		
	906			whole sample	71		

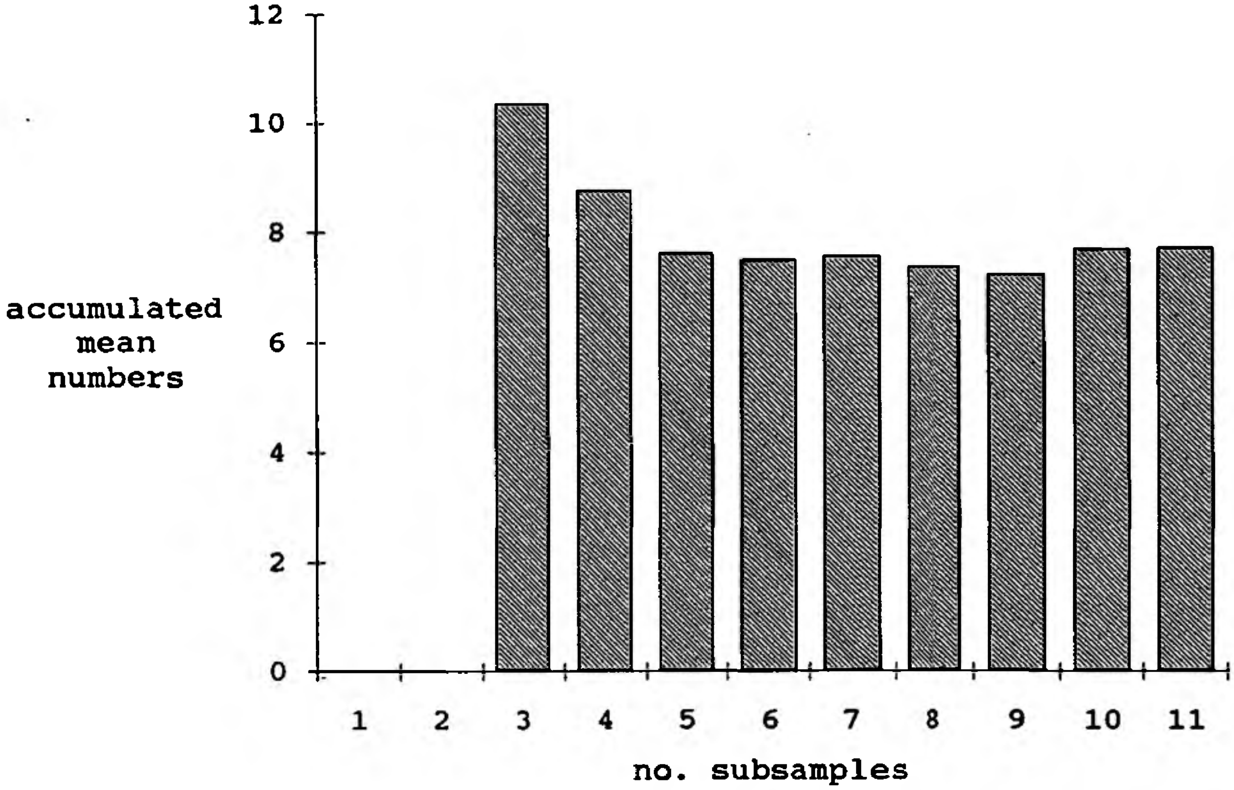
CHI-SQUARED TEST

	Total subsamples	Total rest sample		Total subsamples	Total rest samples
observed	477	429	observed	31	40
expected	478.00	427.63	expected	37.49	33.51
difference	-1.368	1.368	difference	-6.488	6.488
chi-squared =	0.008		chi-squared=	2.379	

Figure 4.2

Accumulated mean numbers of Tubificids - Number 2

Sorted live



Accumulated mean numbers of Chironomids - Number 2

Large Chironomus NOT removed

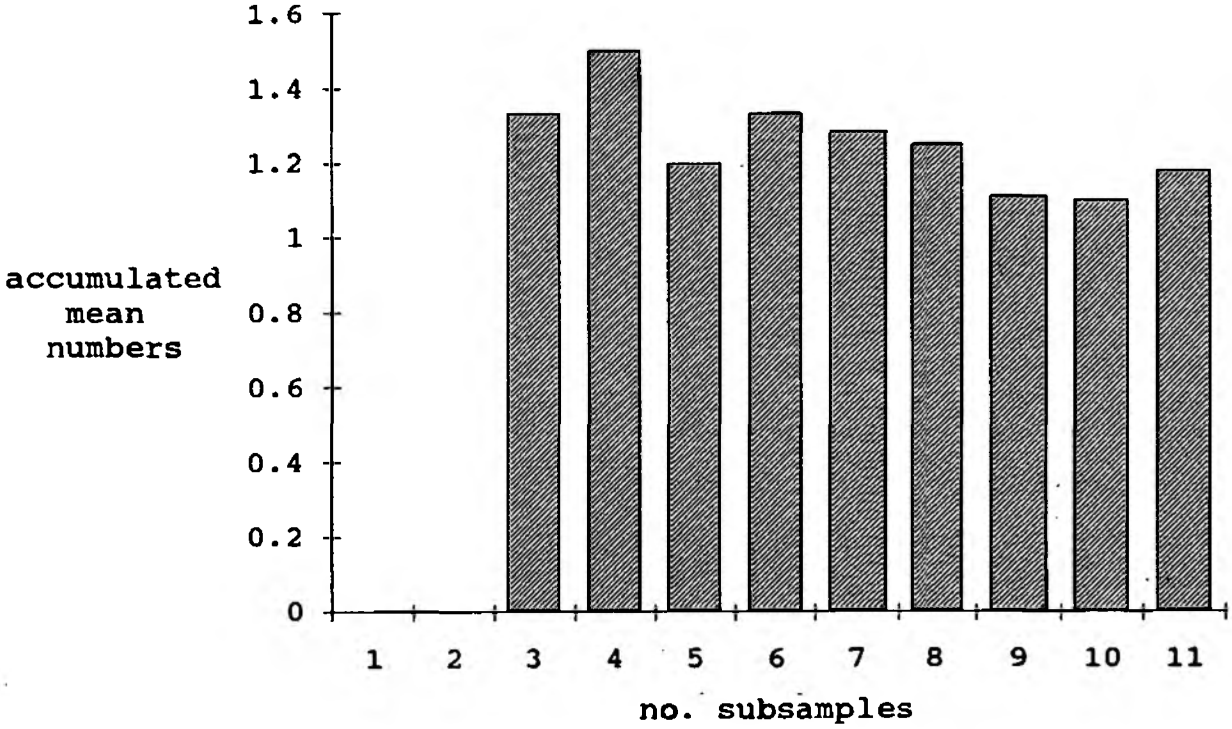
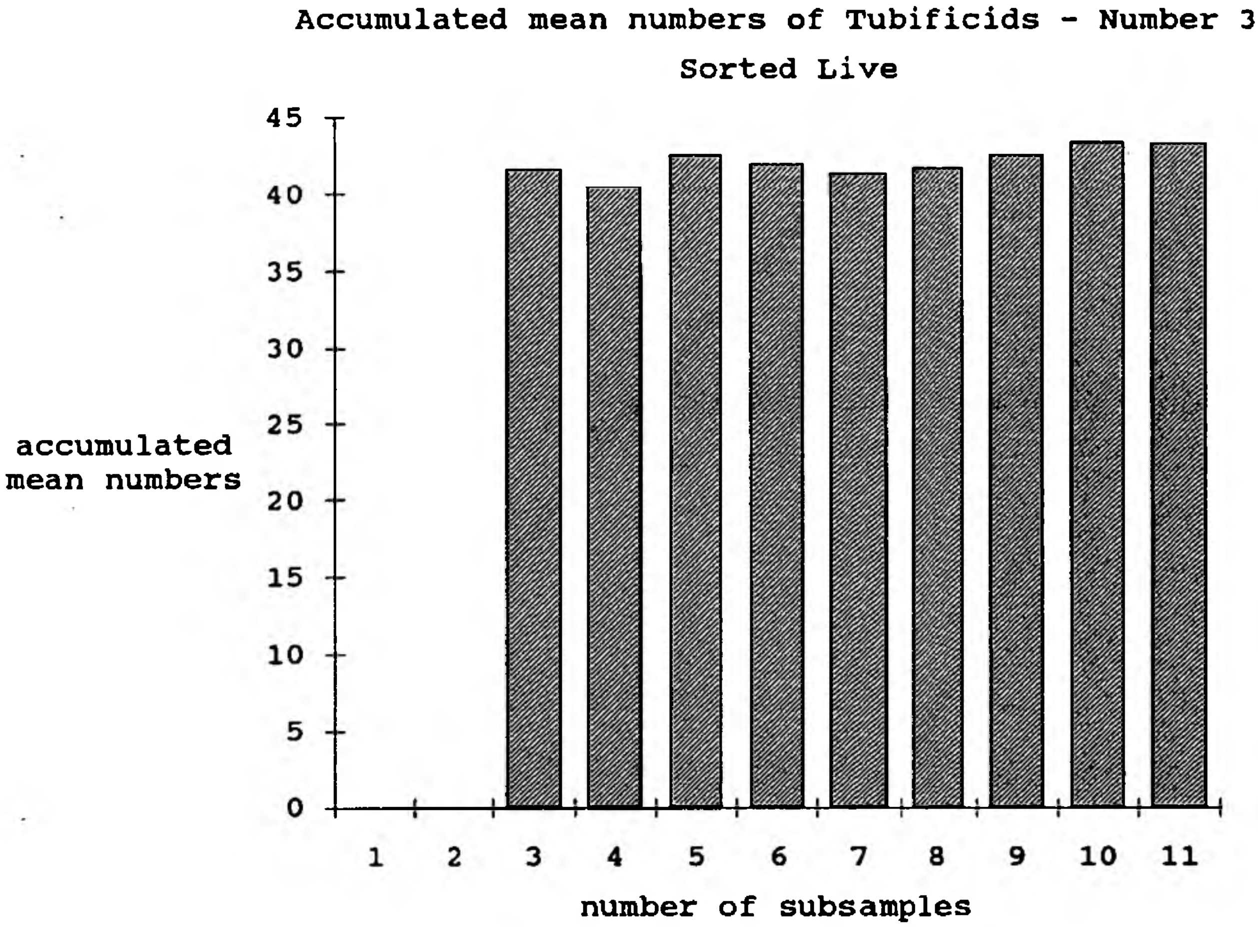
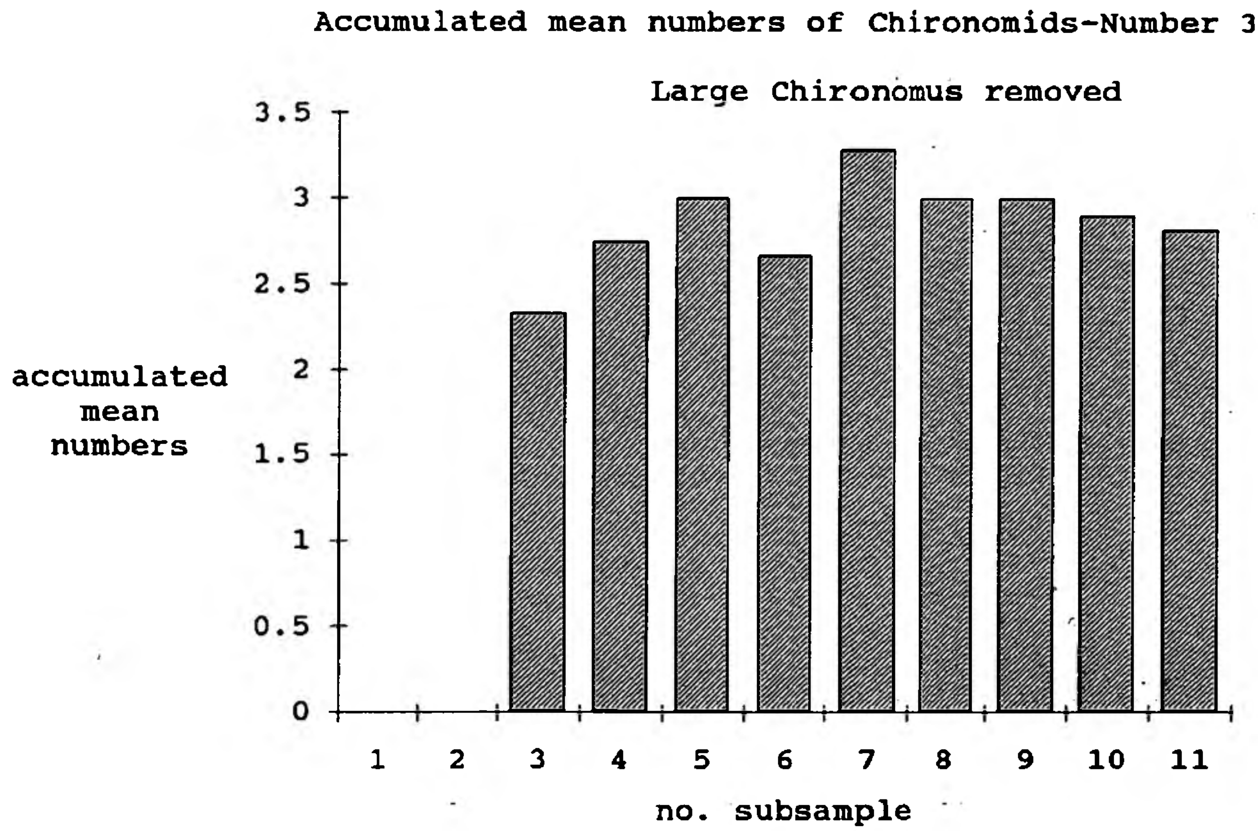


Figure 4.3



Accumulated mean numbers of Tubificids - Number 3
Sorted Live
45
40
35
30
25
20
15
10
5
0
accumulated mean numbers
1
2
3
4
5
6
7
8
9
10
11
number of subsamples

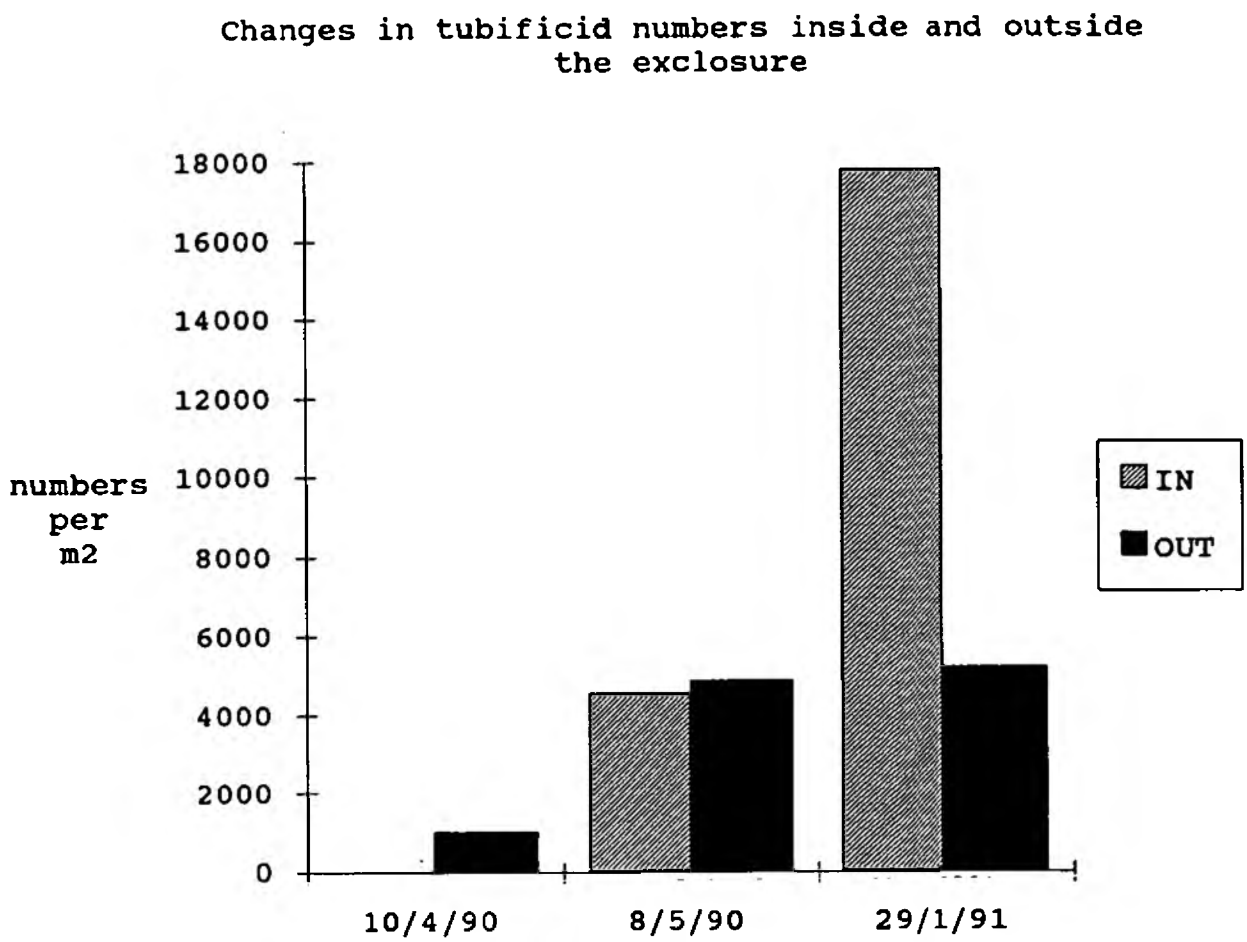


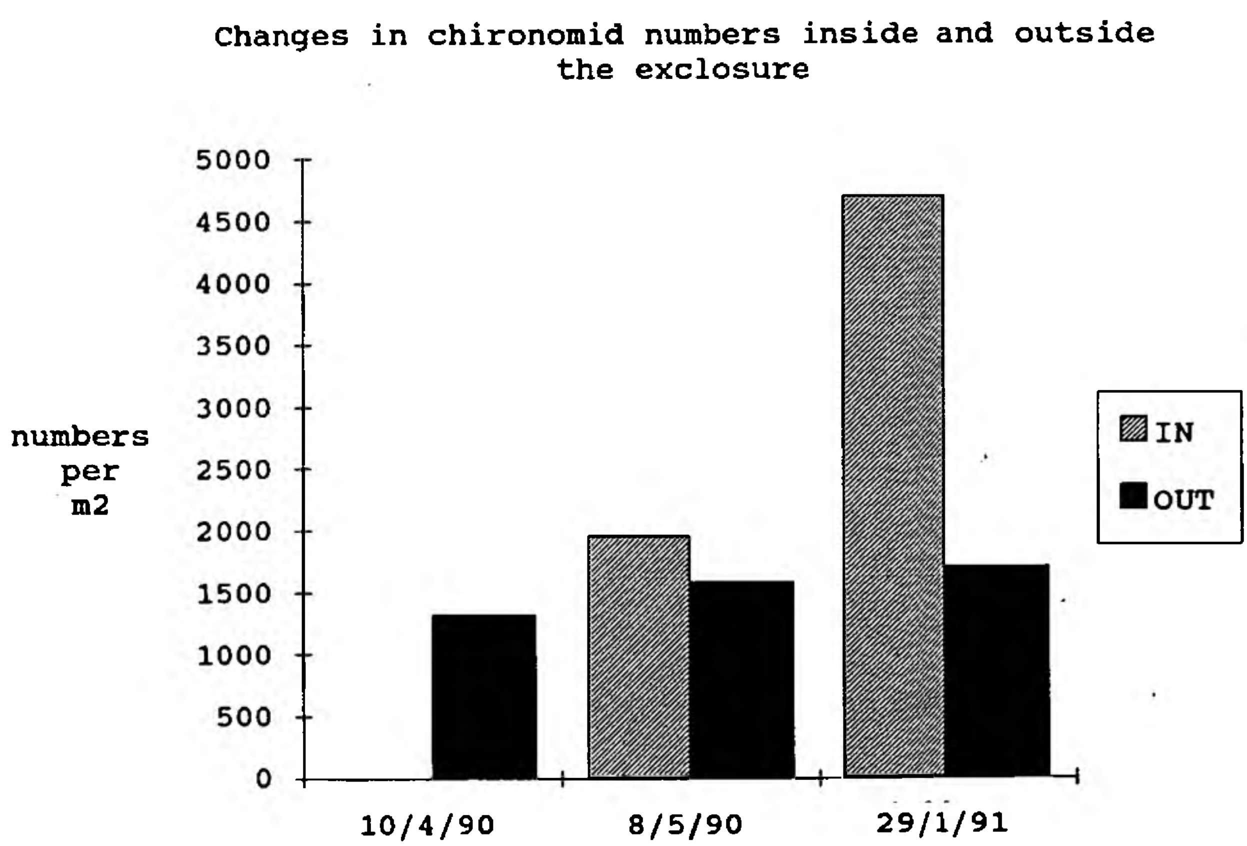
Accumulated mean numbers of Chironomids-Number 3
Large Chironomus removed
3.5
3
2.5
2
1.5
1
0.5
0
accumulated mean numbers
1
2
3
4
5
6
7
8
9
10
11
no. subsample

TABLE 4.2: SUMMARY OF THE DATA OBTAINED AND RESULTS OF T TEST OF THE DIFFERENCES BETWEEN MEAN NUMBERS INSIDE AND OUTSIDE OF THE EXCLOSURE.

DATE		TUBIFICIDS			CHIRONOMIDS			PUPAE	
		mean numbers m^{-2}	std dev	t test value	mean numbers m^{-2}	std dev	t test value	mean numbers m^{-2}	std dev
10/4/90		1317	925		1015	660		24.6	21
8/5/90	IN	4557	3057	10.524	1961	932	21.42		
	OUT	4866	2327		1577	677			
29/1/91	IN	17774	15002	2.608	4697	592	8.956		
	OUT	5202	2713		1706	159			

Figure 4.4


Changes in tubificid numbers inside and outside the exclosure
numbers per m2
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
10/4/90
8/5/90
29/1/91
IN
OUT


Changes in chironomid numbers inside and outside the exclosure
numbers per m2
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
10/4/90
8/5/90
29/1/91
IN
OUT

Data from three sampling dates are shown. Samples from April 10 1990 were taken before the exclosure was completed, hence there is only one set of figures and only 10 samples were taken. The samples were also sorted earlier in 1990 using a different procedure. On this date an average of 24.6 chironomid pupae m^{-2} were found,(Table 4.2). Pupae were not found on the other two dates.

There was an increase in animal numbers between the sample dates in April and May 1990. By Jan 29 1991, (Figure 4.4), it can be seen that there had been a dramatic increase in the number of animals inside the exclosure. The animal numbers outside the exclosure had not altered greatly.

T tests have been done to test the significance of the differences seen between animal numbers on the outside and inside of the exclosure on both dates. These values are shown in Table 4.2. F tests were carried out beforehand. These showed no significant differences between the variances of the two populations on the May 8 1990 but the results of Jan 29 1991 gave a significant difference between the variances of the two populations for both species. Therefore, the t test result for this date may need to be treated with caution, although there are large differences between the means of both the tubificids and the chironomids.

The t tests showed the means to be significantly different($p = 0.05$) on both dates. Higher t test values were obtained on the May 8 1990, although there was not a great difference between the means on the inside and outside of the exclosure. On Jan 29 1991 lower t test values were obtained even though there was a much larger difference between the mean values under test.

Discussion.

The main point to be noted from these initial results is the high number of animals found in the exclosure relative to the main Broad at the beginning of this year even though no fish were removed. This difference may have arisen because of the structure of the fish population within the exclosure. The results of the electrofishing in the Hoveton exclosure, (Table 3.1), show that the most numerous fish present were roach in the 0+ age class. These fish were unlikely to feed off the benthos. The small number of adult fish present were unlikely to exert a great influence on the benthos numbers. Thus we had a situation where, compared with the main Broad, the numbers of benthivorous fish present were very low and probably as a result of this the benthic animal numbers increased greatly within the exclosure. Continued sampling this year will give us the opportunity to assess any changes in the benthos that may occur as a result of complete fish absence and to get an idea of the effects the fish population exerted during 1990. Continued processing of the 1990 samples will show the changes that occurred following the completion of the exclosure in May.

The chironomid pupae found on the 10 April 1990 could indicate the start of activity of the chironomids after the winter. Again more information on this will be obtained as more samples are dealt with.

In summary, although only limited data is available, the indications are that there are will be some interesting and useful results to come.

SECTION FIVE

PLANT EXPERIMENTS

During 1990 we have been able to refine and revise our plans for plant experiments in the light of experience gained by ourselves and the Broads Authority.

In Belaugh Broad an experiment has been run by the Broads Authority on the survival of plant inocula that have been protected from bird grazing. In 1989 four large enclosures were built, 10m across and octagonal in shape (see Fig 5.1). They were planted with *Nymphaea alba* in 1989 and *Stratiotes* and *Apium* sp in 1990. Survival and growth of these species was good and in addition *Ceratophyllum demersum, Hydrocharis morsus-ranae, Lemna minor and L. trisulca* have colonised. Water lilies planted outside the enclosures did not survive.

The importance of bird grazing was further tested in 1990 by a controlled experiment using small (1.5 x 1.5m) enclosures. Four replicates each of *Stratiotes* and *Ceratophyllum* were planted with and without bird protection. In all cases the plant material disappeared by the end of the growing season where it was not protected, but considerable growth was achieved under protection (see Table 5.1).

In Belaugh Broad the high flushing rate (calculated at 8% per tidal cycle on one occasion in 1990) and mud pumping provide clear water and a good rooting medium for plants. In

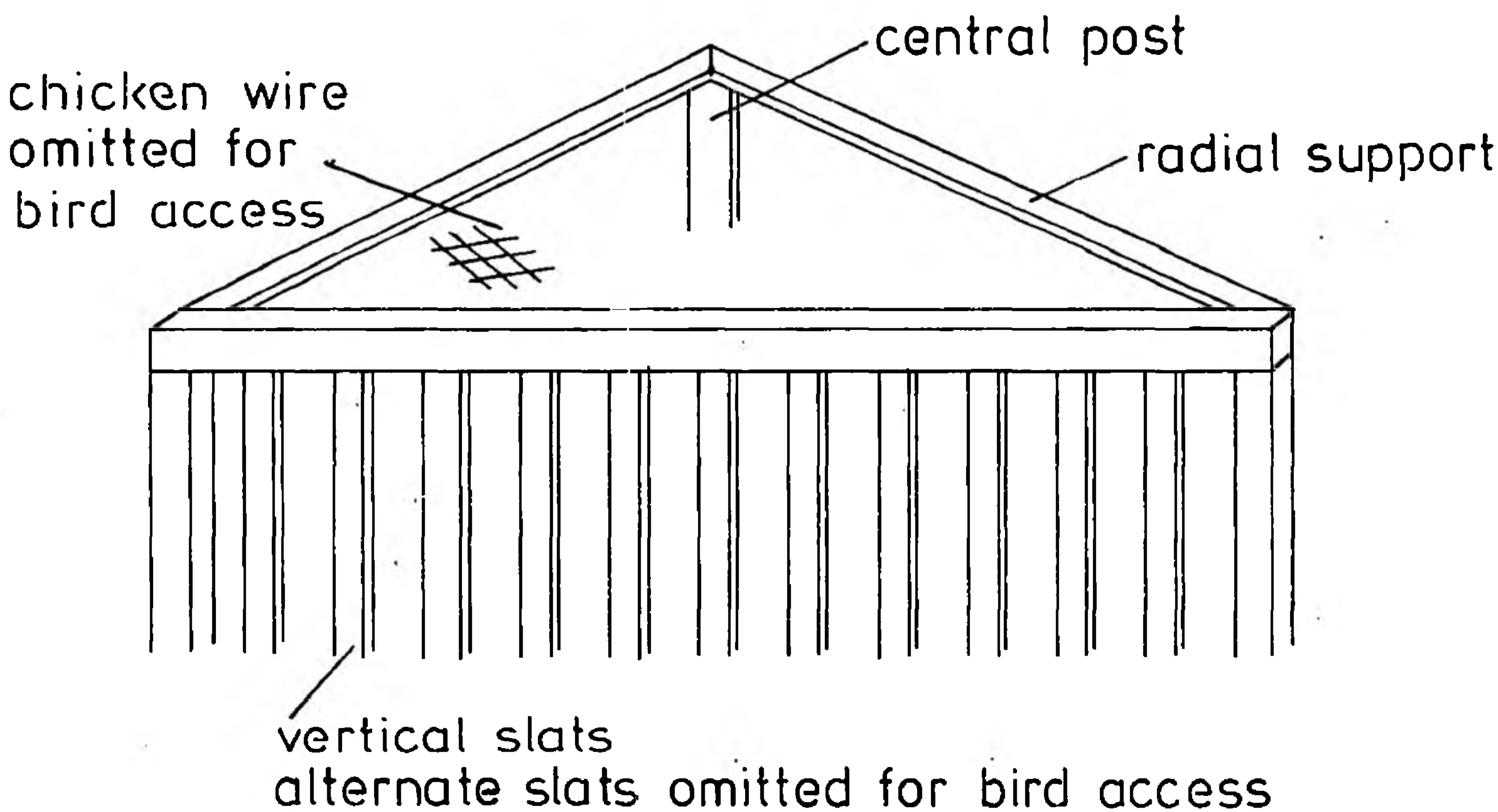


Fig 5.1 Single section of octagonal plant enclosure

Table 5.1 Belaugh Broad bird grazing experiment 1990

Dry weights of plants harvested from bird-proof enclosures

Stratiotes		
Enclosure no.	Dry weight (g)	No. of plants
1	22.8	2
2	63.1	5
3	17.7	3
4	12.6	1

Ceratophyllum		
Enclosure no.	Dry weight (g) Ceratophyllum	Dry weight (g) Filamentous alga
1	14.8	0
2	6.2	45.2
3	13.3	60.3
4	25.2	42.3

1991 we plan to use the large enclosures to test the effect of bird grazing on plant survival in a variety of environments within Broadland. In order to test for any effect produced by the physical presence of the enclosure, such as sediment stabilisation and protection from wind and wave disturbance, pairs of enclosures will be used. One will exclude birds and the other will allow them access by wider spacing of the vertical slats and ommission of the chicken wire lid (see Fig 5.1). Experience has shown that birds will readily enter such structures in order to feed.

Hoveton Great Broad provides an environment where mud pumping has not been carried out and the flushing rate allows dense algal populations to develop. The exclosure provides a similar set of conditions but without fish. The flushing rate in Hoveton Great Broad is sufficient in most years to prevent blue green algae from becoming dominant. Ranworth Broad is an example a broad where blue-green algae are abundant during the summer in most years. Enclosures will be built in all these sites and also in Belaugh Broad in order to provide a valid comparison with the other Broads.

All enclosures will be planted with similar proportions of water lily, *Ceratophyllum, Stratiotes*, *Elodea* and *Hydrocharis*. Growth will be monitored by monthly estimate of percentage cover, carried out by two independent observers.

In addition to these mixed species trials, a more quantitative, replicated single species (*Elodea*) experiment is planned for Hoveton Great Broad. Bird protection is to be provided by 1.5m square wooden frames covered with chicken wire and the plants will be grown individually in trays of pots, four trays per enclosure (see Fig 5.2). This design was tried out during 1990 and found to work well apart from the fact that individual plants could not be harvested separately, because the plants tangled together as they grew. *Elodea* growth will be investigated over the next three years under four treatment conditions: bird protected and not protected, inside and outside the enclosure (i.e. with fish and no fish). For each treatment twelve trays of twenty plants each will be placed either in open water or within enclosures. One tray will be harvested on four occasions over each of the three years.

The results from these experiments will give us a very good idea of how important bird grazing is in the restoration of aquatic plant communities to Broadland, and the potential for plants to grow under different water quality conditions.

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SECTION SIX

POUND END RESTORATION EXPERIMENT

Introduction.

Hoveton Little and Pound End have been chosen to carry out an experiment on biomanipulation. Both Hoveton Little and Pound End have had excess sediment removed by mud pumping. Pound End has had the fish removed from it and further colonization prevented.

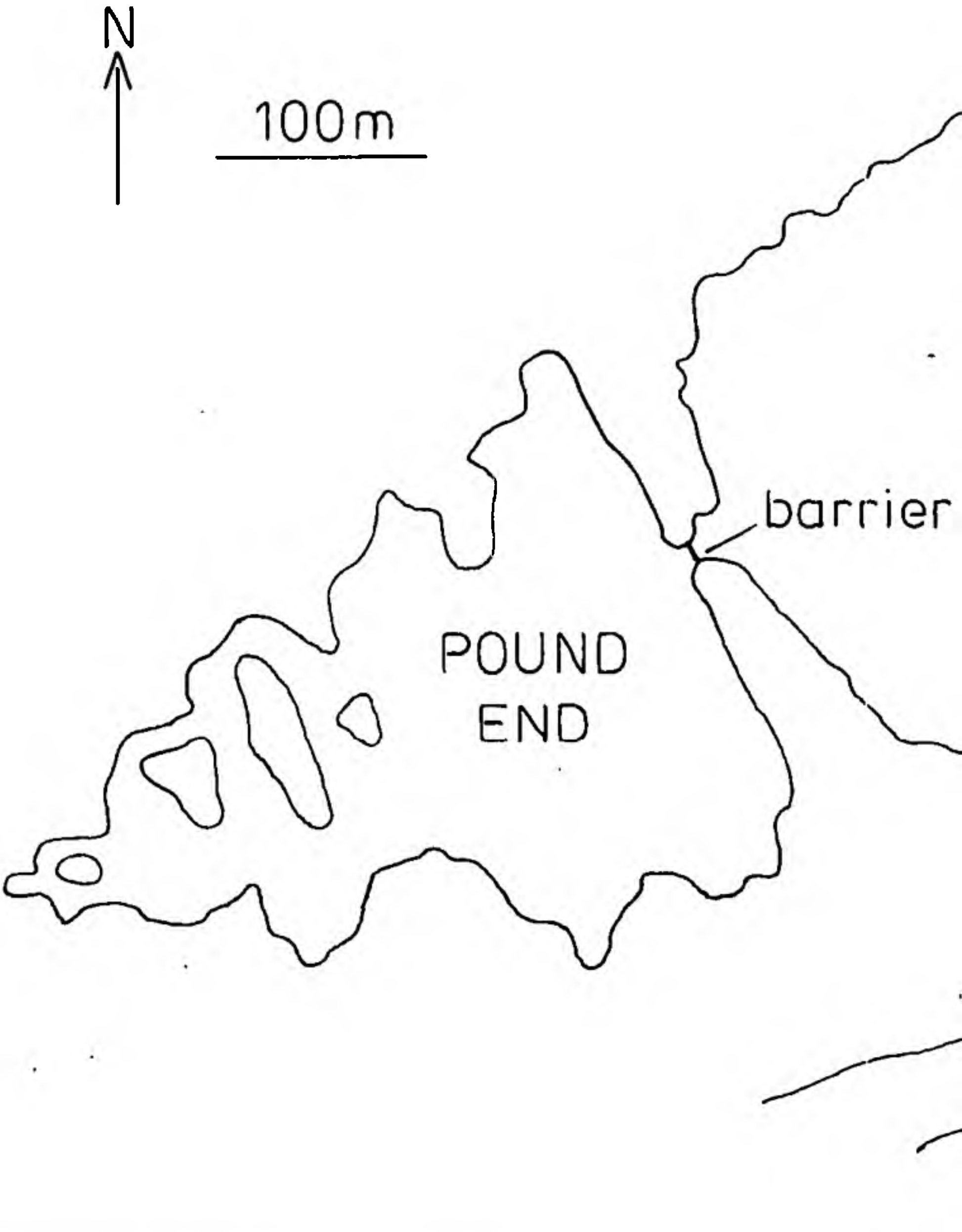
Major differences between Hoveton Little and Pound End.

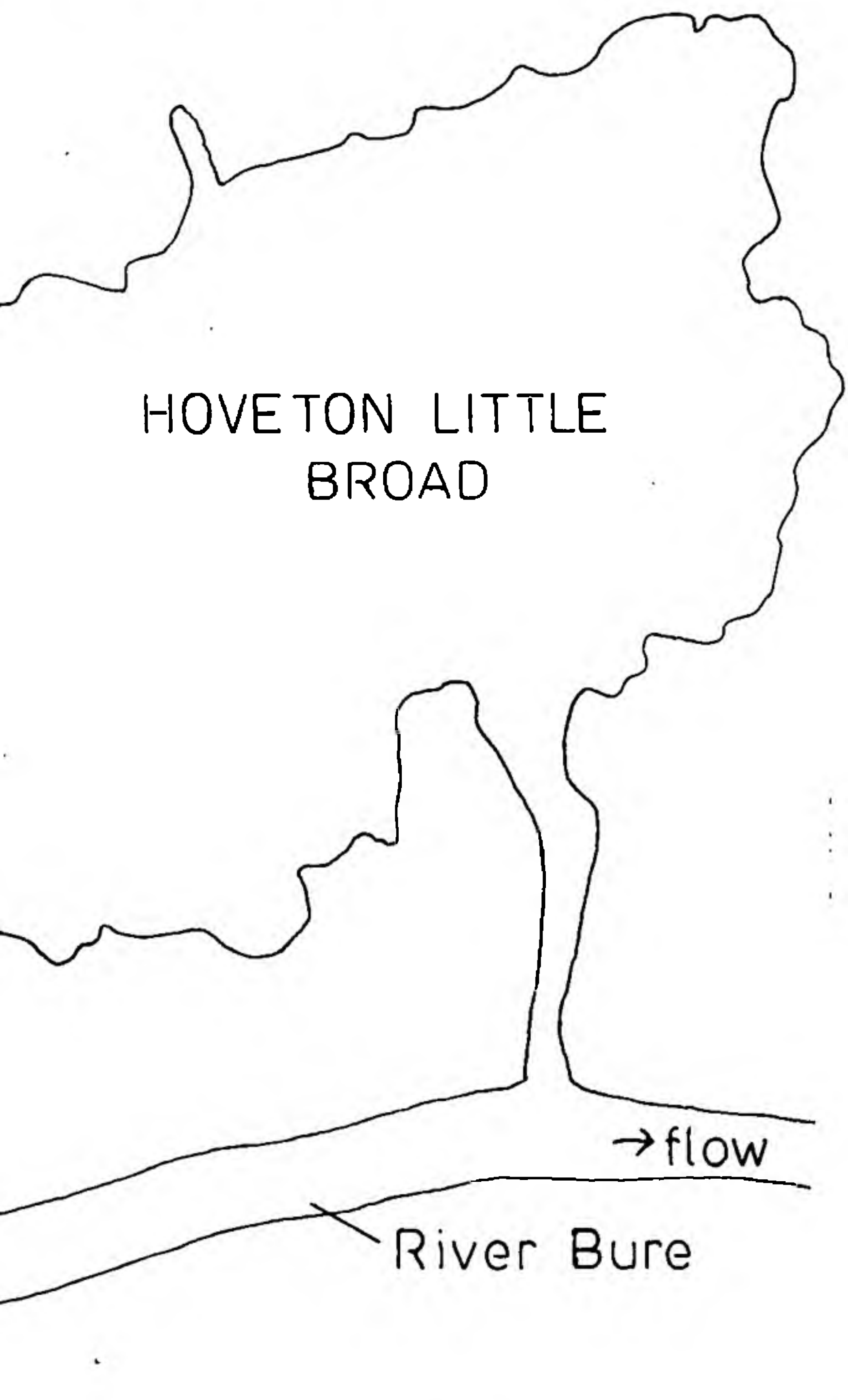
Hoveton Little has a larger surface area, is deeper and is directly connected with the River Bure. Pound End is separated from Hoveton Little by a constriction and is connected to the river only through Hoveton Little (fig 6.1). It had silted up to the extent that during drought periods the sediment was at or near the surface. Pound End has no access to recreational boating activities whereas Hoveton Little has access only during the holiday season.

Preparation for biomanipulation.

Between January and April 1990 Pound End was mud pumped to an approximate water depth of 1m (fig 6.1). At the beginning of May the Broad was netted and electro-fished. Most of the adult fish were removed. Subsequent visits have been made to clear any remaining fish. However it is possible there may have been spawning prior to fishing in

Fig 6.1 Map of Pound End and Hoveton Little Broad




HOVETON LITTLE BROAD
→flow
River Bure

which case there might be a residuum of first year fish. In mid May 1990 Pound End was cut off from Hoveton Little by a wooden framed recycled plastic barrier at the constriction with Hoveton Little. Pound End monitoring started on the 31st July 1990. Mud pumping of Hoveton Little started early April. Work was suspended from mid July to the end of October for the holiday season and has continued during the winter of 1990/1.

Analysis of data

Secchi readings taken so far show that transparency in Pound End is greater than Hoveton Little. Fig 6.2 shows that light is able to penetrate to the bottom during the summer.

Chlorophyll a concentrations in Pound End are appreciably lower than in Hoveton Little (fig 6.3). Late summer and early autumn concentrations in Pound End are related to the changing population of Daphnia (fig 6.4).

Zooplankton counts show the Daphnia population of Hoveton Little remained low after the initial growth despite high chloropyll a levels (fig 6.5). The collapse of the population is characteristic of predation from first year fish. In contrast the Daphnia population in Pound End have sustained large numbers during the growing season (fig 6.6).

The recent salt water incursion of mid September 1990 caused high chloride levels in both broads. This allowed

Fig 6.2

SECCHI READINGS

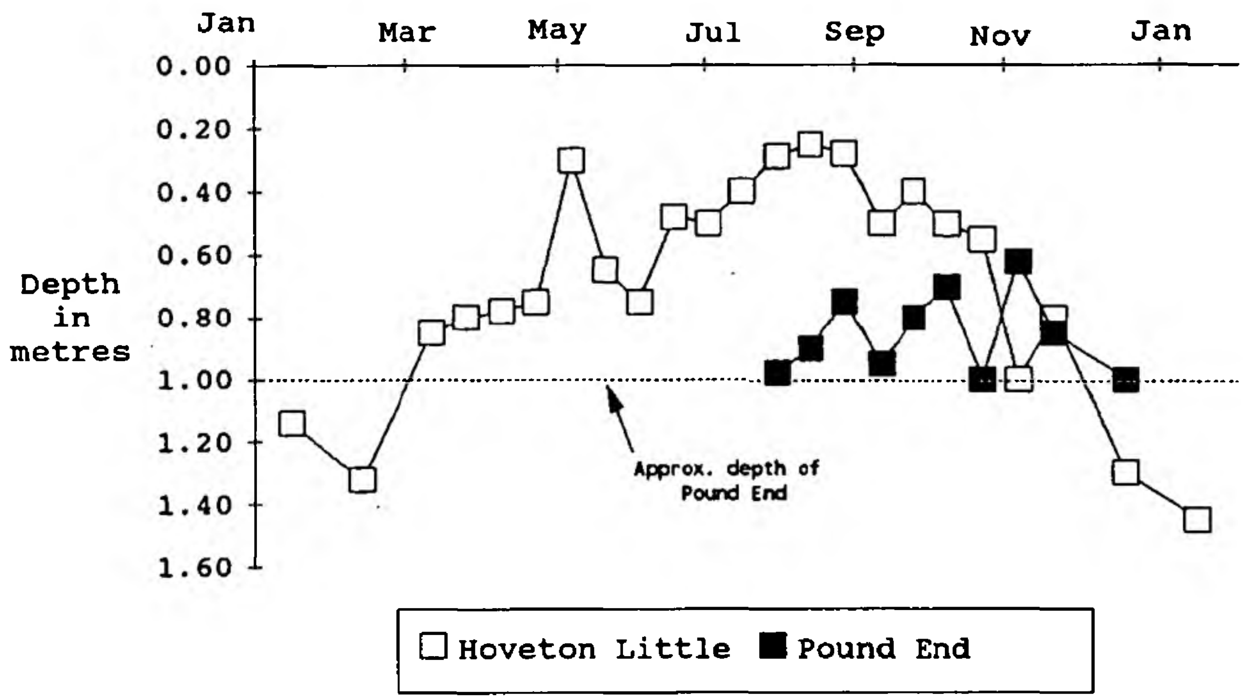


Fig 6.3

CHLOROPHYLL a

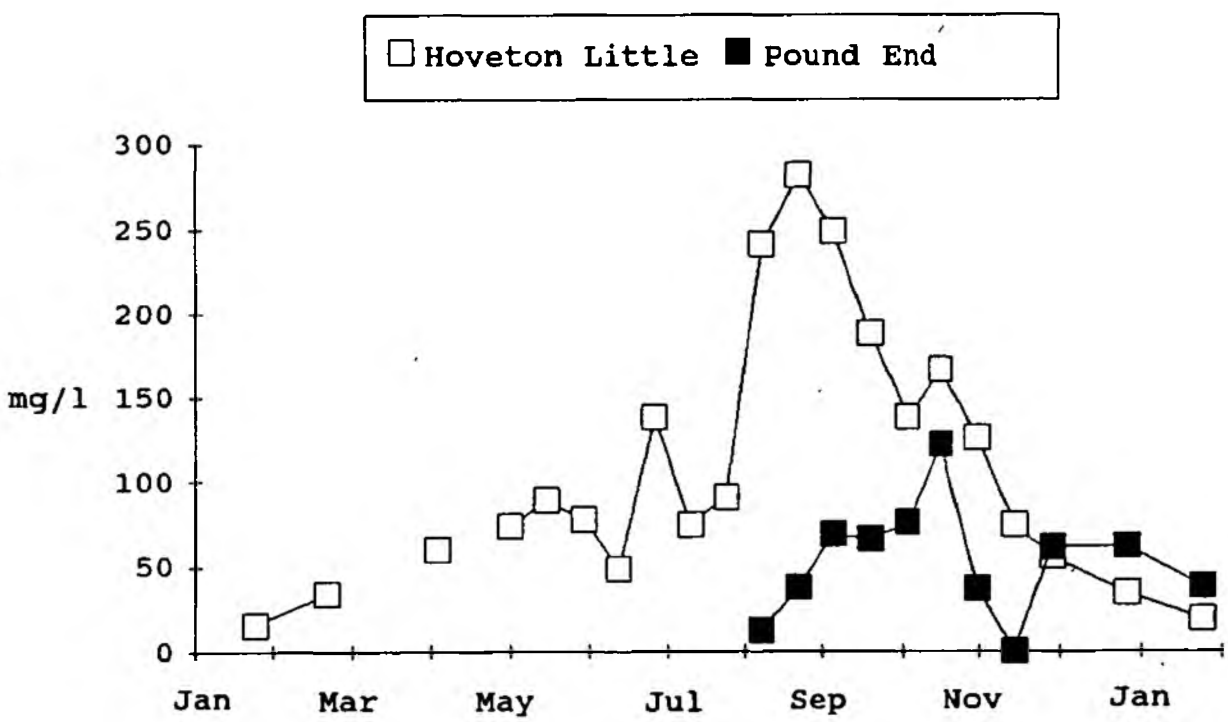


Fig 6.4

POUND END

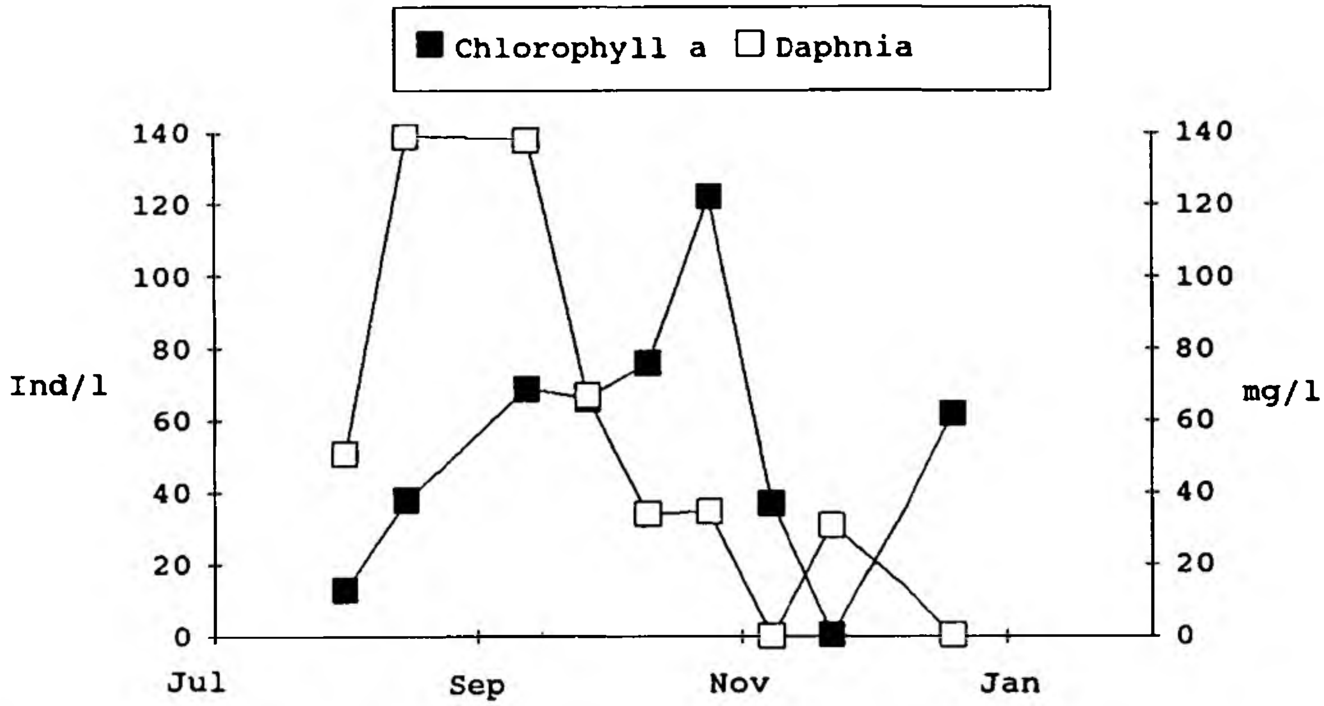


Fig 6.5

HOVETON LITTLE

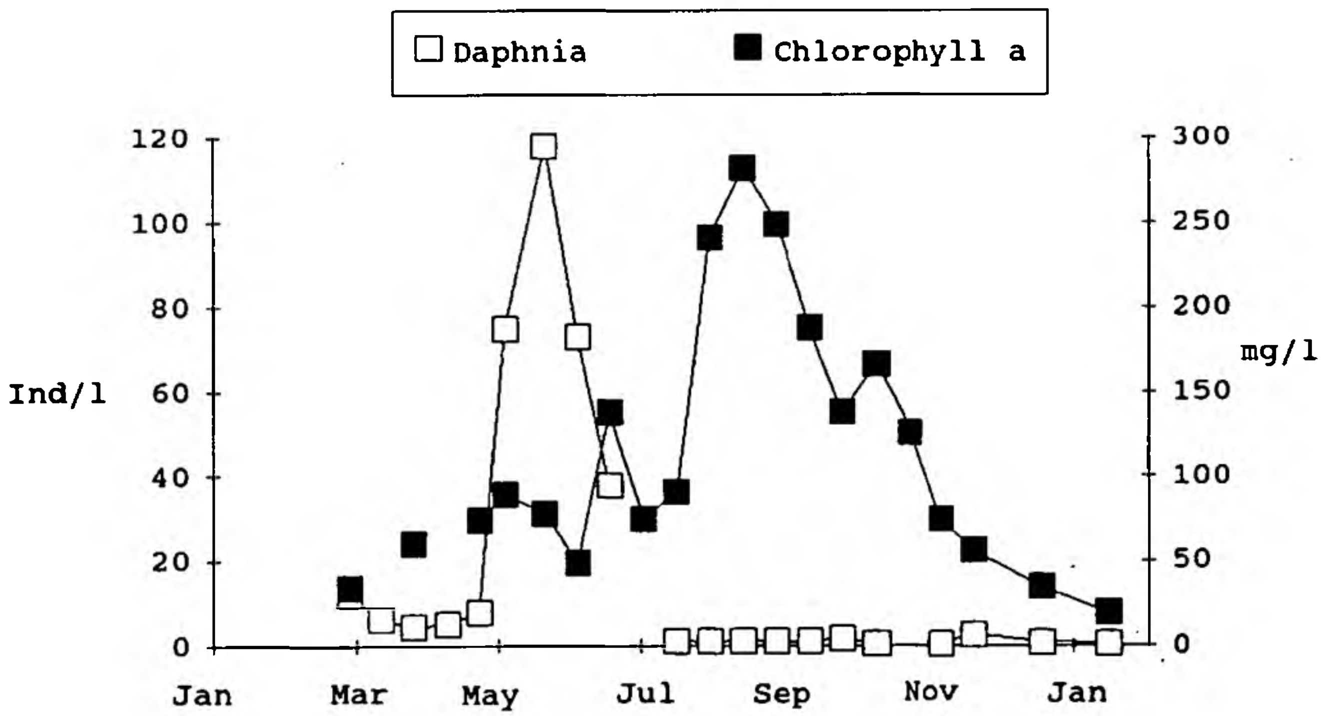


Fig 6.6
DAPHNIA

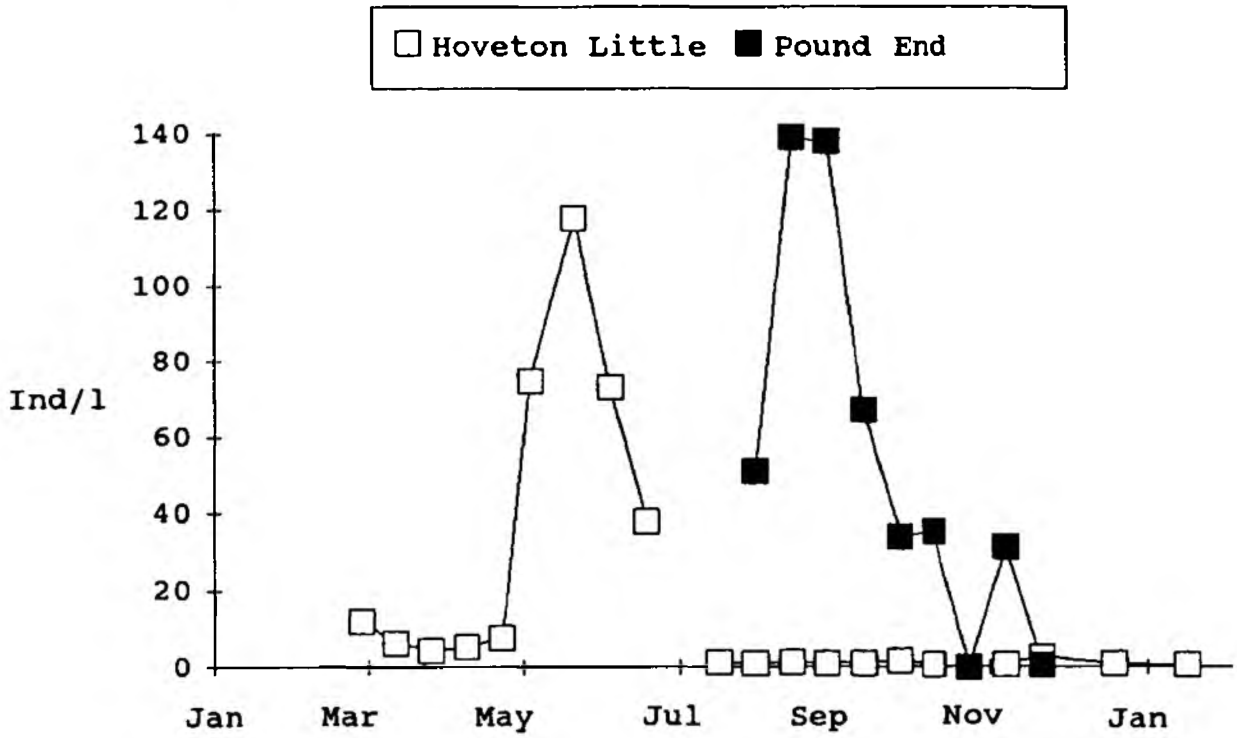
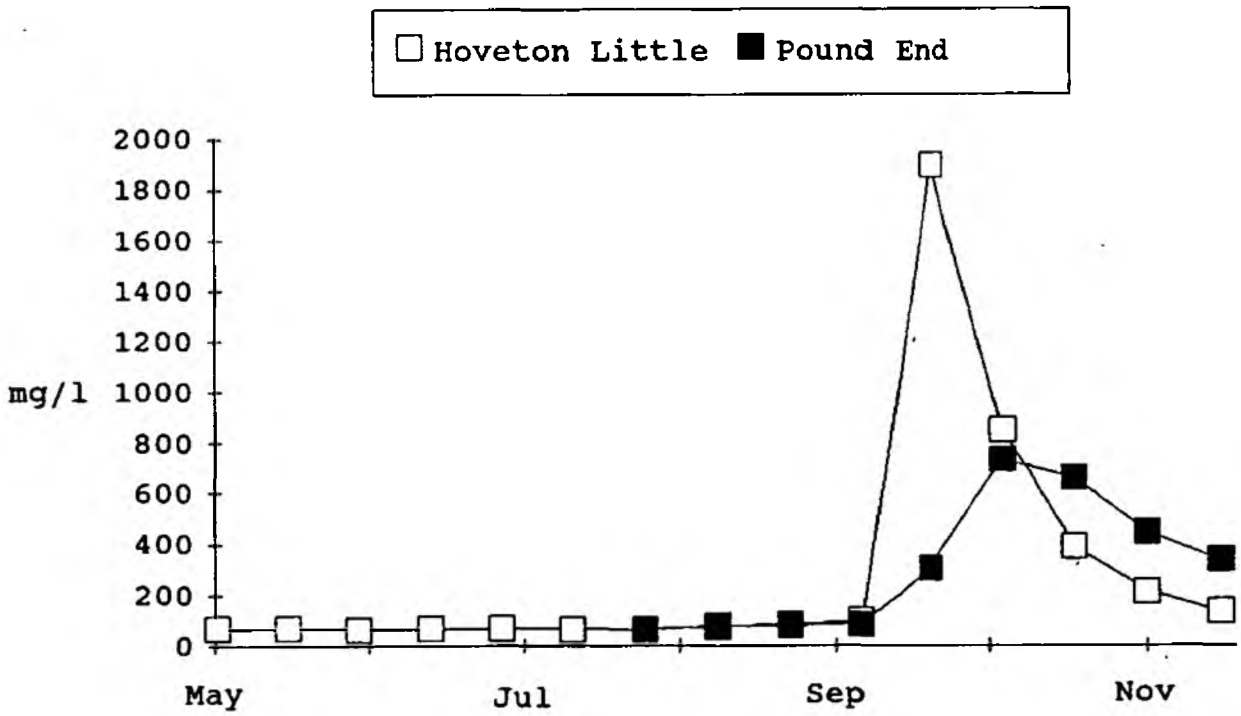


Fig 6.7

CHLORIDE



estimates of flushing of Pound End compared to Hoveton Little. Fig 6.7 shows that Pound End has reduced mixing, an effect that is now accentuated by the barrier. The residence time in Pound End is increased for the same reason.

Analysis of the data is encouraging. It shows Pound End behaving to the predicted requirement for a suitable environment for submerged plant growth. There are low fish numbers. There is Daphnia in substantial numbers and the water is clear.

SECTION SEVEN - APPENDIX

AN INVESTIGATION INTO THE FLUSHING RATE OF BELAUGH BROAD

In early August 1990 an investigation was made into the flushing rate of Belaugh Broad. The data collected were as follows:

1. Depth profile of the Broad at 94 approximately equally spaced intervals, at high tide.
2. Surface area of the Broad from map and aerial photo.
3. Change in water depth at the mouth of the dyke, hourly 11am - 12pm. See Fig 7.1.
4. Turbidity transect along the arm of the Broad (see Figs 7.2 & 7.3), two hourly intervals 11.30am - 5.30pm.

A second method of estimating flushing rate was also tried - measuring the amount of water flowing in the dyke, but this was found to be unreliable.

Mean depth of the broad was measured at 1.11m and the surface area 1.69 ha. This gives a volume of water in the Broad at high tide of $18,686m^3$. The change in water depth over one tidal cycle was 8.5cm, giving a volume of $1,435m^3$. This represents 8% of the volume of the Broad leaving on each tidal cycle.

Because the water flow is chanelled along the dyke (maximum recorded speed approximmately $10cms^{-1}$) it is injected into the broad as the tide rises and this causes mixing with the rest of the broad water. The extent of this

Fig 7.1 Change in water level Belaugh Broad

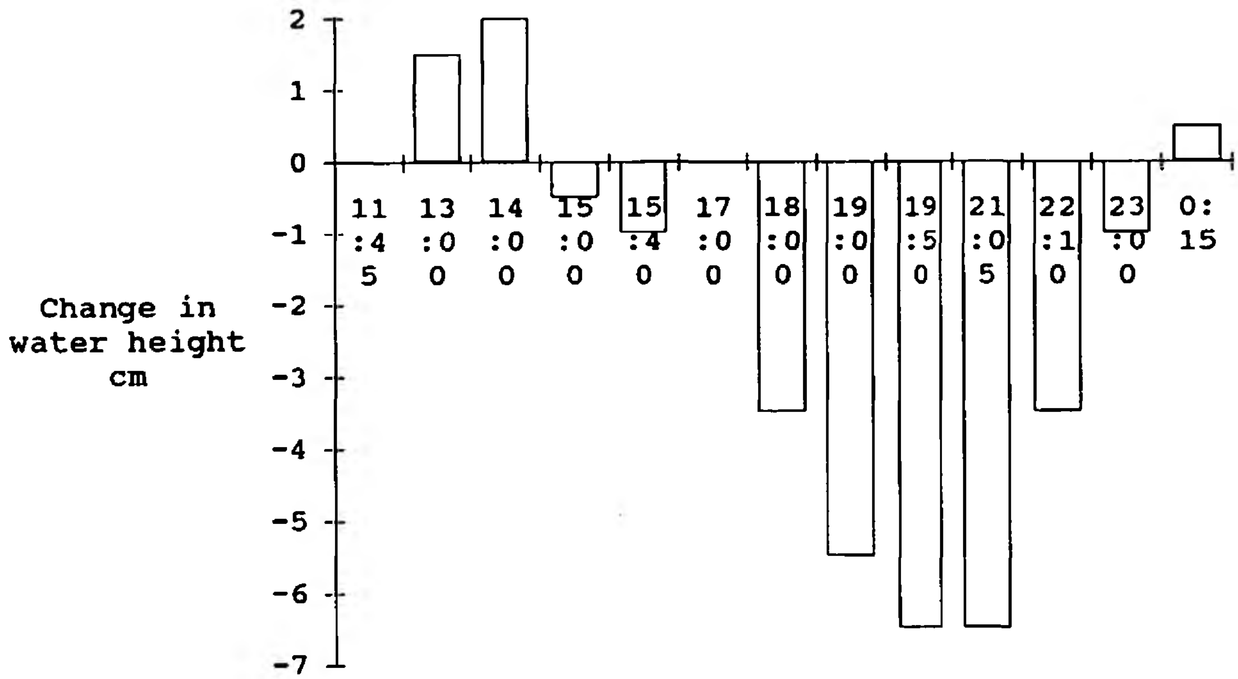
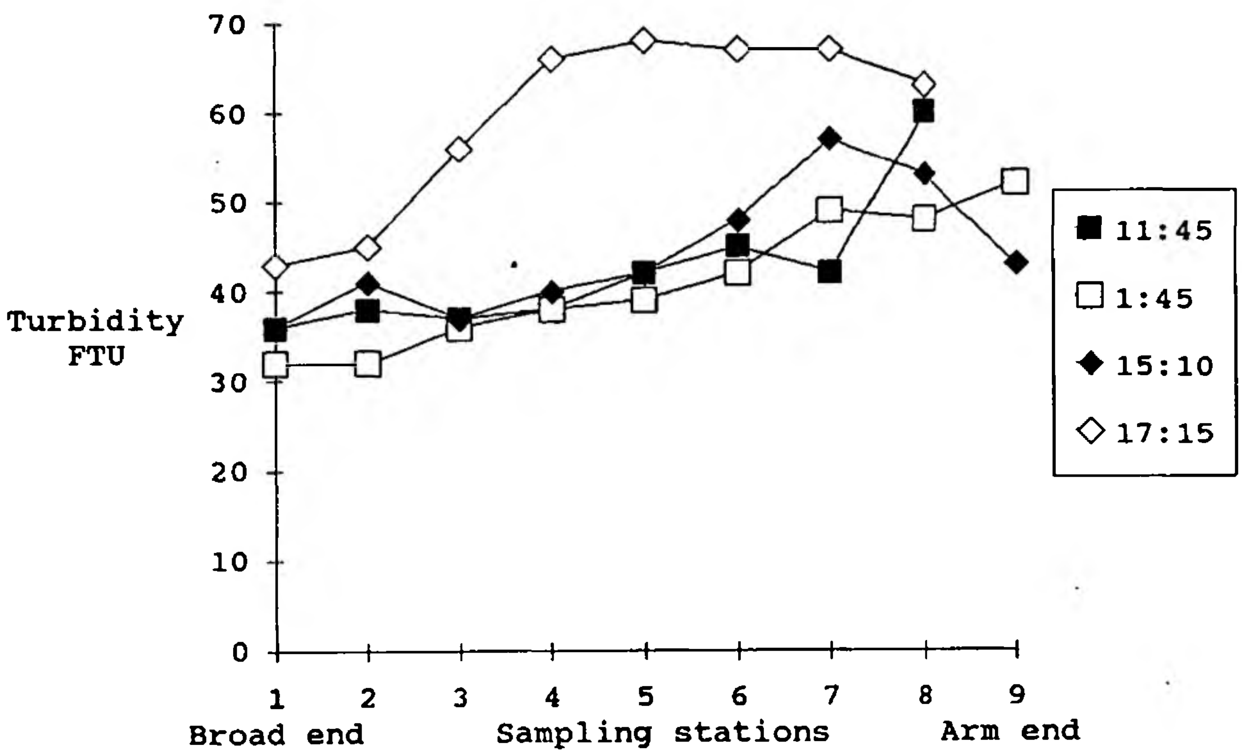


Fig 7.2 Turbidity transect Belaugh Broad



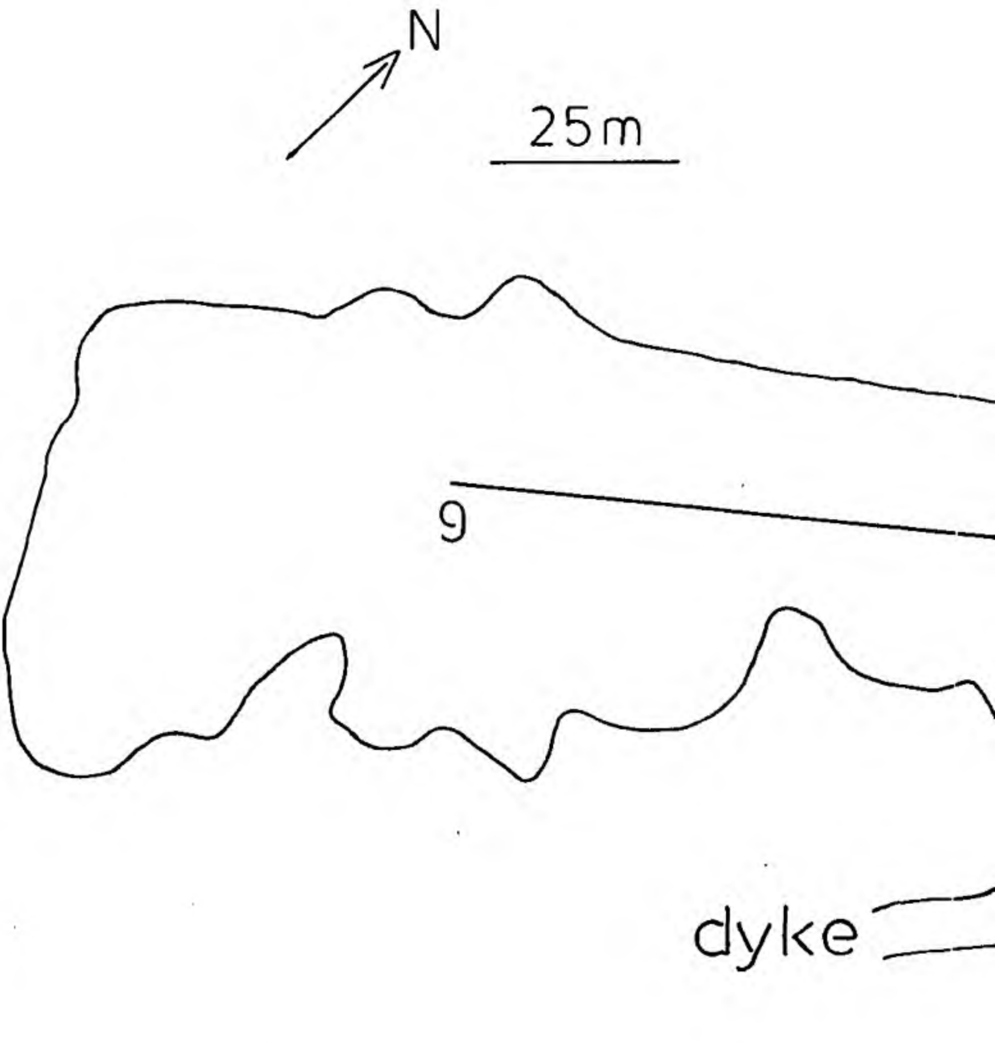
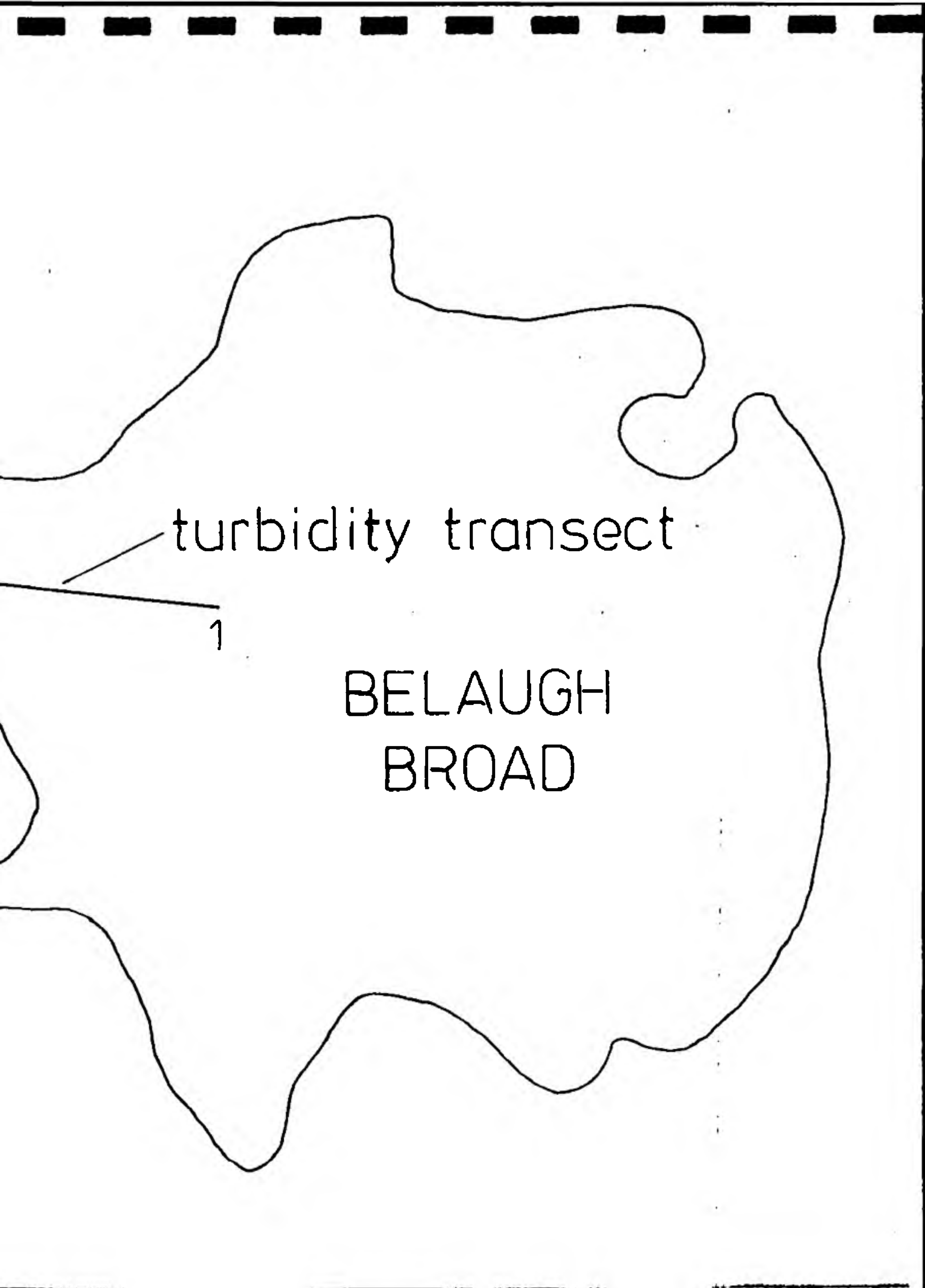


Fig 7.3 Map of Belaugh Broad



turbidity transect
1
BELAUGH
BROAD

mixing was investigated in the distal arm of the Broad by recording changes in turbidity during the day. The results (see Fig 7.2) show a residual mass of turbid water (largely due to algae) at the far end of the arm. There is little change during the early part of the day while water was flowing into the Broad on the end of the incoming tide and started flowing out again. Between 15:10 and 17:15 the change in turbidity suggests that the outgoing tide may have pulled the turbid water further down the arm to replace water lost from the Broad. It is also possible that this result was caused by another phenomenon. Zooplankton populations were monitored in the arm of the Broad in late summer and compared to results for the main Broad. Little difference was found between the two areas which implies that the arm is also fairly well flushed.

This result suggests that the majority of the Broad is well flushed by the tidal movement of river water. This would be expected from the relatively large amount of water exchanged on each tide and is borne out by the low populations of phyto- and zooplankton commonly found in the Broad. Conditions in August 1990 may not be typical - low river flows caused by the drought would have allowed tidal water movement to penetrate further up river than normal, giving a greater than usual change in water height, and therefore flushing rate in the Broad. However, changes in fluvial flow are usually much greater than tidal changes and the present results are probably an underestimate of longer-term flushing rate.