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EXPERIMENTS ON THE EFFECTS OF THE HERBIVOROUS FISH, GRASS CARP (CTENOPHARYNGODON IDELLA VAL.) ON AQUATIC VASCULAR PLANTS, ALGAE, ZOOPLANKTON AND PHYTOPLANKTON AND THE IMPORTANCE OF WATER TEMPERATURE ON THE SUCCESS OF WEED CONTROL

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EXPERIMENTS ON THE EFFECTS OF THE HERBIVOROUS FISH, GRASS CARP (*CTENOPHARYNGODON IDELLA* VAL.), ON AQUATIC VASCULAR PLANTS, ALGAE, ZOOPLANKTON AND PHYTOPLANKTON AND THE IMPORTANCE OF WATER TEMPERATURE ON THE SUCCESS OF WEED CONTROL.

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SUMMARY

Three experiments with grass carp (*Ctenopharyngodon idella* Val.) were carried out in outdoor polyethylene lined pools and channels at the Weed Research Organization. 1. The alga *Cladophora* sp. was eaten by grass carp after *Elodea canadensis* had been grazed. *Ceratophyllum demersum* increased. 2. In larger channels grass carp controlled young regrowth of *E. candensis*. A larger biomass of fish failed to control mature plant growth. 3. April water temperatures were raised artificially with electric cables and polyethylene tunnels and this enabled the grass carp to control early growth of *Elodea* spp.

The phytoplankton ond zooplankton data from a 5 year lake experiment (Pusey) is given. Grass carp appeared to have no detrimental effect on zooplankton but may have indirectly affected phytoplankton blooms. Lengths and weights of grass carp are discussed.

INTRODUCTION

Ever since grass carp showed some success in controlling water weeds in other European countries (Cross 1969, Opuszynski 1972), they have interested aquatic weed scientists in this country. Much of our water, be it in drainage and river systems or in lakes and reservoirs, contains plants whose growth at times becomes excessive and thus needs to be removed. Many methods are used including manual and mechanical cutting and specialised herbicides. Grass carp are known to eat many of the plants which cause problems and much experimental work has been and is being done. (Stott and Robson 1970, Fowler and Robson 1978, Mugridge et al 1982, Fowler 1984 (in press). Given the right conditions, the fish can alleviate water weed problems either alone or as a complement to other methods. In the long term their use can reduce the expense of weed control operations.

Due to the original scarcity of fish only very small trials were carried out before 1978. Recently larger bodies of water have been stocked, but the results have been mixed. Factors such as water temperature, preference for different plant species and stocking density of fish all influence the outcome of each trial. Buckley (1981) reported successful control of Elodea sp. in small, shallow, fairly warm ponds in southern England while Mugridge et al (1982) reported no success in controlling Elodea sp. in a nearby colder canal. In small lake experiments (Fowler 1984) grass carp success was tempered by the plant species present and the differing climatic conditions in consecutive years.

This report deals with some of the lake data not published elsewhere and some small scale outdoor experiments carried out at the Weed Research Organisation. These experiments were done in semi-natural habitats, in pools and channels exposed to normal weather conditions. The fish were necessarily small but the value of the results is enhanced by the replication which is impossible in large unreplicated natural waters.

The experiments described are as follows:-

1. Cladophora sp. as a food for grass carp.
2. The effects on Elodea sp. of cutting it in early spring and then stocking with grass carp.
3. The effect of different spring temperatures on grass carp feeding on Elodea sp.
4. Zooplankton and phytoplankton populations in Pusey Lake, stocked with grass carp.

Appendix 1. Lengths and weights of grass carp used in these experiments.

EXPERIMENTS

1. CLADOPHORA SP. AS A FOOD FOR GRASS CARP.

Floating masses of green filamentous algae often occur in still water, and its efficient removal poses problems. Having determined the effect of different stocking densities of grass carp on mixed vascular plant communities (Fowler and Robson 1978), there was a need to test their selectivity when filamentous algae formed a large proportion of the available food.

Twelve circular polyethylene-lined pools, surface area 3.5 m^2, were prepared in the autumn of 1977. About 5 cm mud was put in and vascular plant species were introduced immediately i.e. a few plants each of Ceratophyllum demersum L., Elodea canadensis Michx, Hippuris vulgaris L., Ranunculus aquatilis L., Myriophyllum alterniflorum DC, and Potamogeton pectinatus L. The alga Cladophora sp was introduced although it was present on some of the other plants. In mid-June 1978, vegetation maps were prepared showing the areas occupied by each species and the extent of both submerged and floating algae. Following stocking with fish in late June, mapping was repeated four times in 1978 and 3 times in 1979. Beginning in April zooplankton counts were taken 5 times during 1978. Using a 15 cm circumference plankton net, 3 vertical samples, bulked, from each pond were subsampled, counted and the numbers of each species expressed per litre.

Grass carp were introduced to the pools on 30th June 1978. Four replications of 2 stocking densities, 306 kg/ha; 7 fish (mean wt. 16.7g) and 152 kg/ha; 4 fish (mean wt. 15.2g) were used and four pools were left unstocked as controls (Fig 1). The fish were caught and weighed in April 1979 and again in August when the experiment was terminated. All remaining plants and algae were harvested and the mean fresh weight of each species per treatment was determined.

RESULTS

The zooplankton numbers within each treatment differed widely as might be expected when there was no deliberate attempt to introduce known numbers of animals. The same species were, as a rule, present in all pools. On average there were no differences seen between treatments, the apparent peak of Bosmina in the controls in August being the result of one pool in the four having a very high count. (Fig 1).

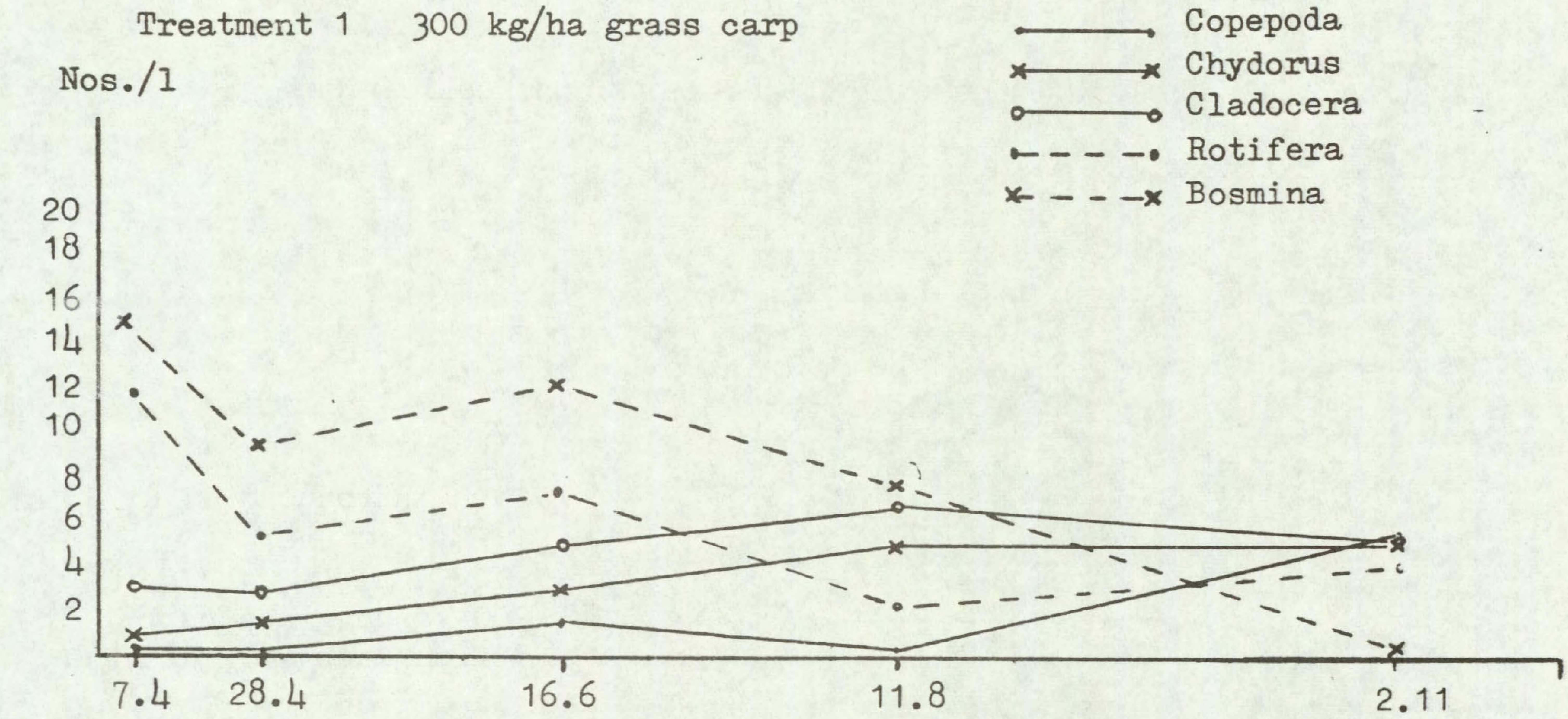
Table 1. Plant cover in polyethylene-lined pools (mean percentage cover for each species)

	Floating algae			Submerged algae			Elodea canadensis			Ceratophyllum demersum		
	H	L	C	H	L	C	H	L	C	H	L	C
20.6.78	23	13	22	77	73	71	15	14	12	4	8	3
				Fish introduced 30.6.78								
28.7.78	31	19	23	57	77	70	17	10	13	2	2	2
24.8.78	27	42	41	69	56	53	8	8	9	5	2	0
18.9.78	23	40	29	87	91	93	7	11	9	3	1	0
31.10.78	38	41	29	100	100	99	9	11	12	1	1	0
23.4.79	58	35	41	75	96	91	3	12	21	0	0	0
27.7.79	76	70	85	0	0	0	0	6	15	10	2	1
28.8.79	25	65	90	0	0	0	0	2	15	27	9	1

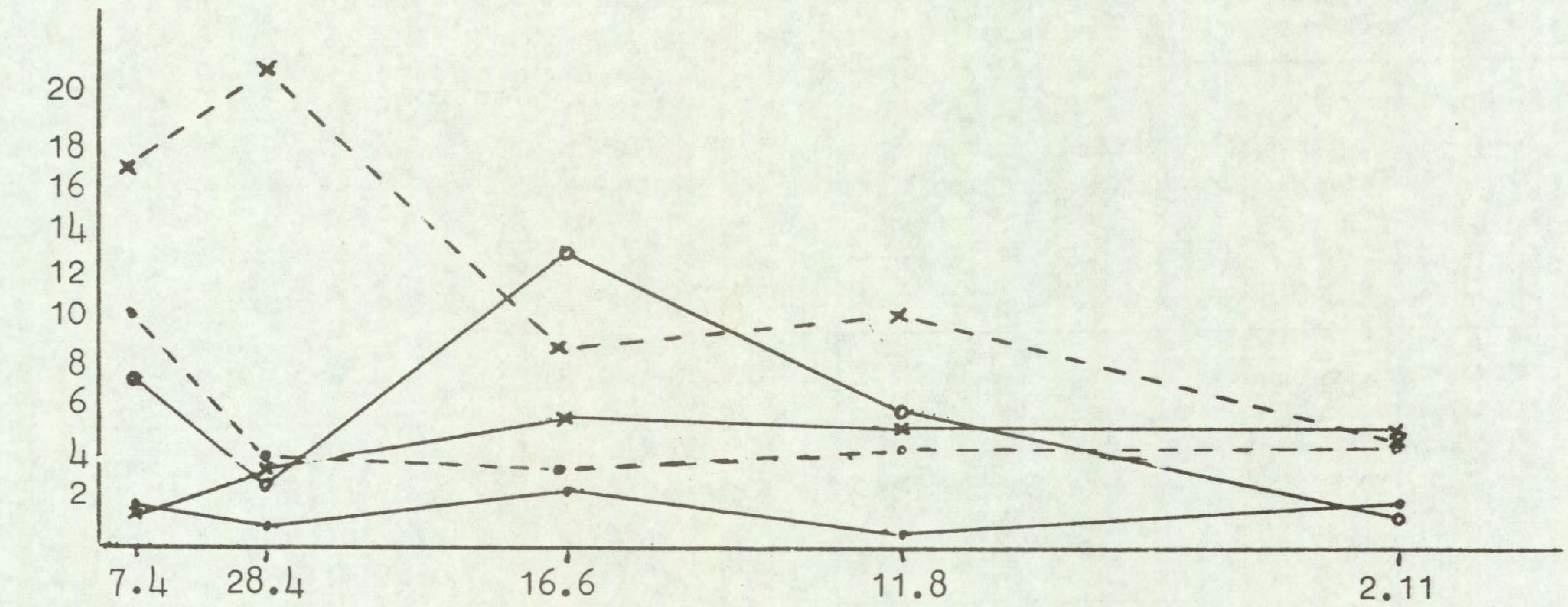
Key:- H= 300 kg/ha, L= 150 kg/ha, C= control

Fig. 1 Populations of invertebrate zooplankton in pools 1978

Treatment 1 300 kg/ha grass carp



Treatment 2 150 kg/ha grass carp



Treatment 3 Control

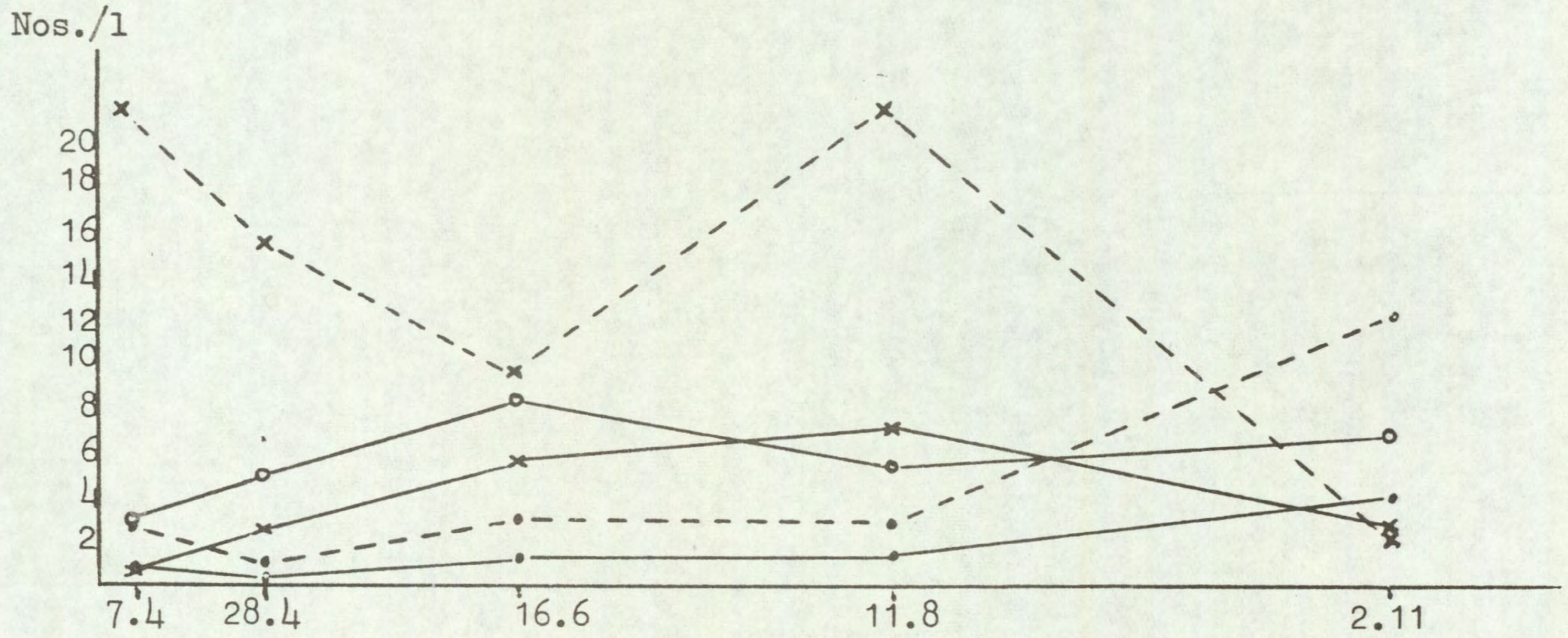
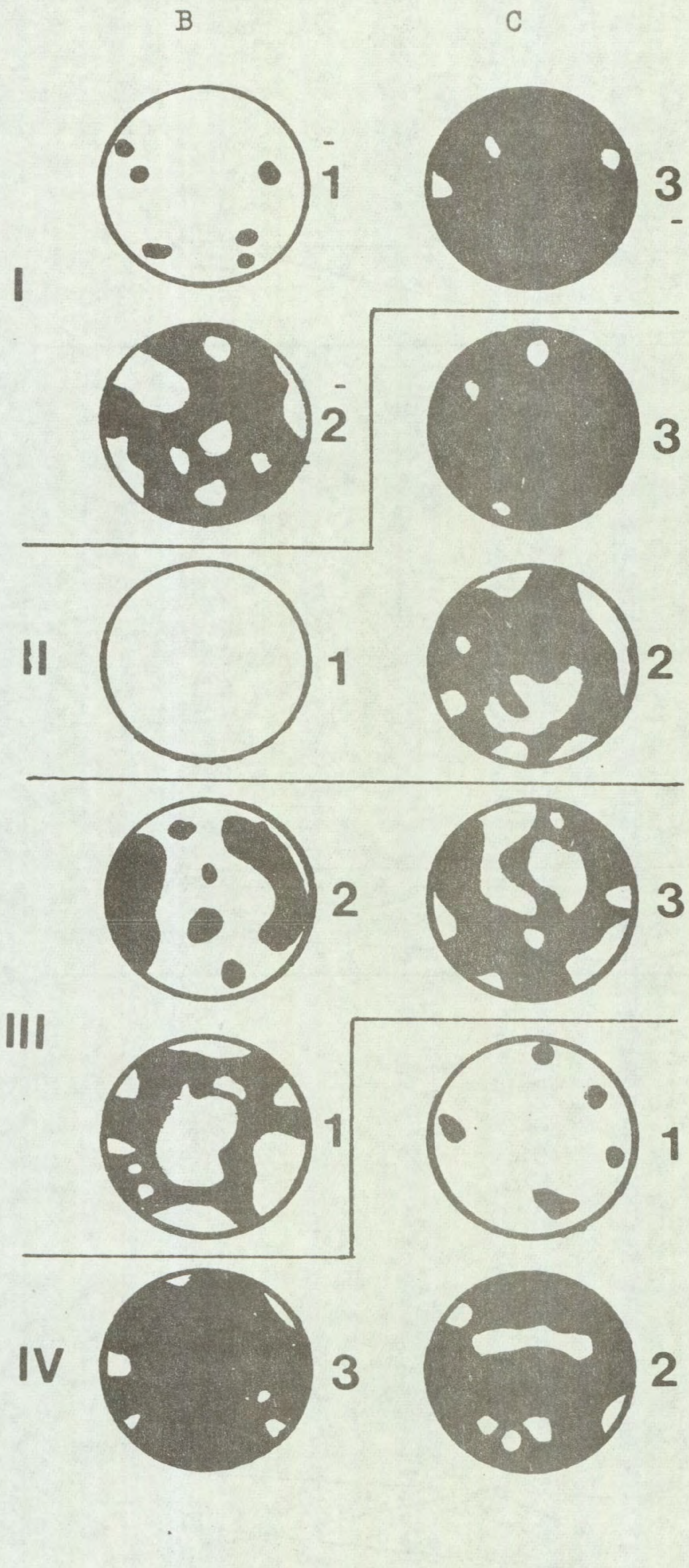


Fig. 2 Layout of polyethylene-lined pools, treatments and replications

28.8.79 Extent of floating algae



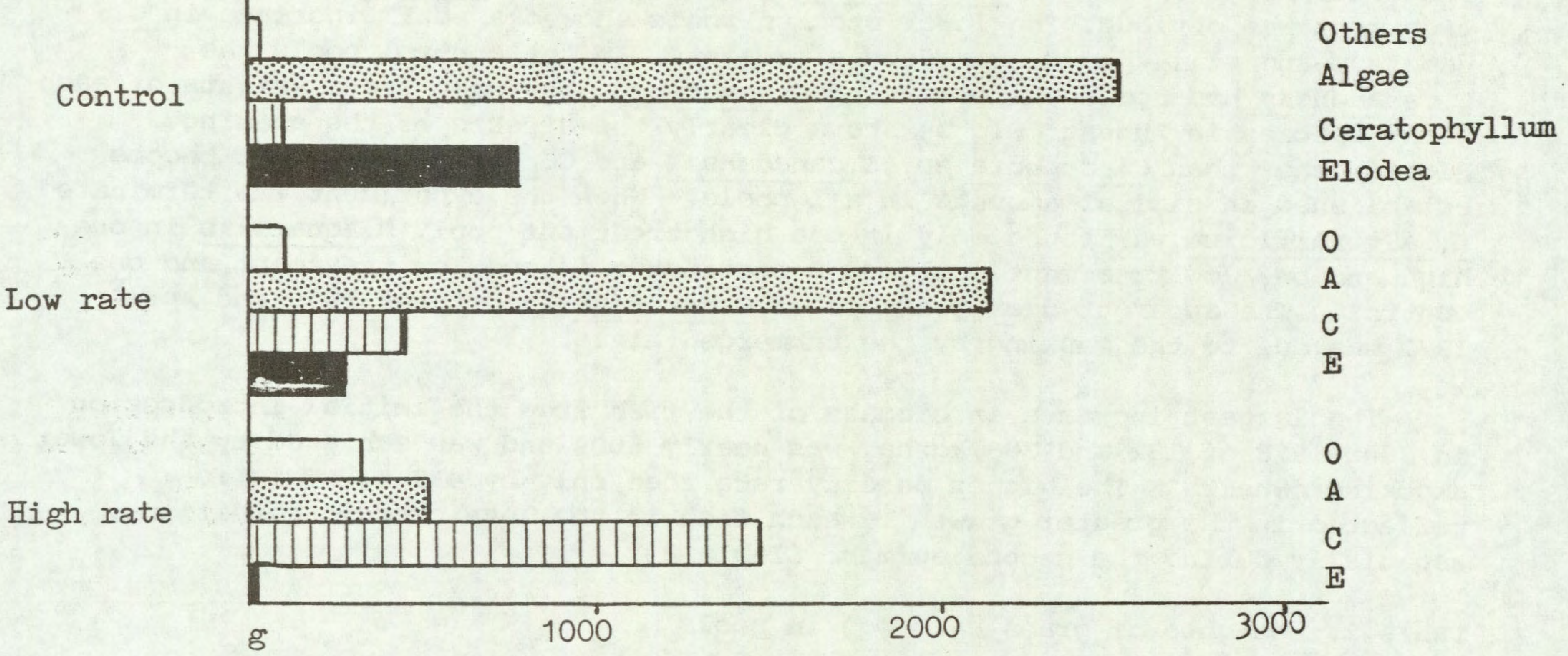
Fish introduced 27.6.78

1. 300 kg/ha grass carp
   7 fish mean wt. 16.7g

2. 150 kg/ha grass carp
   4 fish mean wt. 16.7g

3. Control

Fig. 3. Mean fresh wt. of plants harvested in August 1979



Very little difference could be seen between treatments by the end of 1978 (Table 1). In April 1979 when much of the algae was still submerged the high treatments showed less E.canadensis than the low treatments or the controls. By July the algae had all floated and the high treatment appeared to have no E.canadensis but an increase in C.demersum. By the end of August there was far less floating algae in the high treatment compared to the low treatment while the controls were almost completely covered. Fig 2 shows the algae cover on all the pools on 28 August 1979, fourteen months after grass carp were introduced. The continued decrease of E.canadensis and increase of C.demersum in the high treatment was obvious. The lower stocked pools showed a small increase in C. demersum and still had E. canadensis present. In the control pools the E.canadensis had spread, suppressing C.demersum. The mean fresh weights of each plant species in August (Fig 3) shows clearly the effects of the grazing. Plants other than Cladophora sp. E.canadensis and C. demersum did not become established in similar amounts in all pools. When the experiment was terminated M. alterniflorum was found only in one high treatment pool, R.aquatilis in one high and one low treatment pool and P.pectinatus in one low treatment and one control. The apparent disappearance of C.demersum in October 1978 and April 1979 was due to the masking by the submerged algae.

The largest increase in biomass of the fish from the initial introduction in June 1978 of 152 and 306 kg/ha, was nearly 600% and was achieved by the lower stocking density. The higher density rate rose only by 437 %. This is reflected in the greater growth by each fish in the less crowded conditions, especially during the second summer. (Table 2).

Table 2. Weights of grass carp (g) in pools

Initial	Mean fish wt (g) on dates shown			Final	%
stocking rate	30.6.78	25.4.79	29.8.79	stocking rate	increase
152 kg/ha	15.2	27.9	90.5	905 kg/ha	593.4
306 kg/ha	17.6	28.2	76.5	1339 kg/ha	437.6

CONCLUSIONS.

This evidence suggests that the alga Cladophora sp. is palatable to grass carp, which will, at the size used in this experiment, eat it in preferance to C.demersum once the E.canadensis is gone. Cladophora sp., when it forms thick floating mats is considered to be a weed as it is unsightly, interferes with fishing and boating and can seriously block water movement in canals and drainage systems. Grass carp could be active in its removable but as it is almost inevitable that other preferred plants would be present the algae would be the last eaten, therefore a high stocking density would be needed.

2. THE EFFECTS ON ELODEA SP. OF CUTTING IN EARLY SPRING AND THEN STOCKING WITH GRASS CARP.

A polyethylene-lined sunken channel, 20x3, m. and 0.5m. in depth with well established E. canadensis and E.ernstae growing in mud, was divided into three equal sections with plastic netting barriers, which prevented the passage of fish from one side to the other. Horizontal strips of Netlon were attached along the top of the barrier and around the entire channel to deflect jumping fish. Vegetation sampling sites were selected at random and identified by permanent marks on the channel sides.

The Elodea spp. plants were fairly tall, being mostly last seasons growth which had overwintered. The vegetation in all three sections was cut by hand to within 10 centimeters of the mud on the 17 May 1982. Grass carp (8 fish, mean weight 62 g. equivalent to 235 kg/ha) had been introduced into Section 1 on 6 April 1982. By 19 July this section contained only patches of Elodea spp.regrowth while the other two sections contained a solid mass of the plants. Grass carp were introduced into these two sections on the 20 July to see if they could reduce this mature plant growth. In section 2 a stocking density of 495 kg/ha grass carp was introduced and in section 3 a density of 249 kg/ha, similar to that originally put in section 1.

By this time Cladophora sp had appeared in patches among the Elodea spp. tending to rise from the bottom and spread out on the water surface. Sometimes, especially in section 1 the surface cover of algae bore little relation to the amount of Elodea spp underneath, making distribution estimates difficult.

RESULTS

One year later, on the 20 July 1983, the channel was drained and the fish caught and weighed.(Table 3). In section 1 seven fish were retrieved, only one was missing. The average weight was 274 g, an increase of 340% and there was an increased stocking density to 914 kg/ha. There was no vegetation at all.

In section 2 two fish were missing from the eleven stocked in July 1982. The stocking density had increased to 805 kg/ha. There was a patchy residue of Elodea spp remaining in this section estimated at 272g/m2.

In section 3 all the grass carp were still present and the stocking density had increased to 553 kg/ha. There was both Elodea spp. and Cladophora spp. present, in total 1288g/m2, covering about half the section.

Table 3. Growth of grass carp in the three sections of a channel

Section	1			2			3		
	No.of fish	Mean wt.(g)	Kg/ha	No.of fish	Mean wt.(g)	Kg/ha	No.of fish	Mean wt.(g)	Kg/ha
06.4.82.	8	62	235						
20.7.82				11	90	495	7	70	247
20.7.83	7	274	914	9	188	805	7	166	553
weight increase (%)		340			109			137	

CONCLUSIONS.

Weed control was achieved more efficiently with relatively few fish, stocked early in the season when regrowth was young than with a higher density of fish stocked when the plants were mature. Buckley (1981) made similar observations in a lake after mature Elodea sp. was cut.

3. THE EFFECT OF DIFFERENT SPRING TEMPERATURES ON GRASS CARP GRAZING ON ELODEA SP.

To compare the effects of different water temperatures early in the year on grass carp grazing, three sunken, polyethylene lined channels (20 x 3m, 0.5m deep) were used in 1983. E.canadensis and E.ernstae were already established in a mud substrate. Each channel was divided in two with a barrier made of rigid plastic piping and covered with plastic netting, as described in Experiment 2.

Channel 1 had, in early April, a thin low covering of Elodea spp bearing dormant winter buds. Channel 2 had been used for a pilot experiment the previous year when a significant rise in water temperature was achieved using electric soil warming cables (2x80m, 1000 watt cables made by Simplex) and a polyethylene "tunnel" cover. The cover had been removed and the cables turned off before winter but in spite of this, in 1983, the plant growth was long and straggly. It was cut by hand to within a few centimeters of the bottom. Channel 3 had a thick phytoplankton bloom although the Elodea spp. was in a similar state to that in Channel 1. The main component of the phytoplankton was Dictyosphaerium sp.

Polyethylene "tunnels" were erected over Channels 2 and 3 on the 18 April and two heating cables installed and switched on in both on 24 April. Temperature was recorded electronically using a microcomputer-based datalogger. Occasional gaps in the records were caused by power failures.

Grass carp at a mean weight of 53g and a mean stocking density of 250kg/ha were introduced into one half of each channel on 26 April. The fish were removed and weighed on 22 June.

The plant assessment method, which had to be non-destructive in so small an area, was based on a measurement of a Biomass Index (Tew, unpublished data). This relies on two visual scores, one of plant height and one of plant abundance (amount) on scores of 0-5. Multiplying one score by the other gives a 0-25 Biomass Index, 25 indicating a 100% water volume occupancy by vegetation. In order to measure these parameters in both clear and opaque water a clear perspex cylinder of 15 cm diameter with the bottom end sealed, was pushed down into the water until it touched the plants. The height of the vegetation could be calculated by deducting the length of cylinder submerged from the known water depth and the abundance estimated by the amount of vegetation visible through the cylinder bottom. The Biomass Index was established immediately before the fish were introduced in late April and three times in May. When the fish were removed by draining the channels, samples of the remaining plant growth were taken by cutting at mud level,(20 x 0.25m^2/channel). The channels were refilled immediately and a final Biomass Index was calculated in October to measure the regrowth.

Fig. 4 Mean daily water temperatures

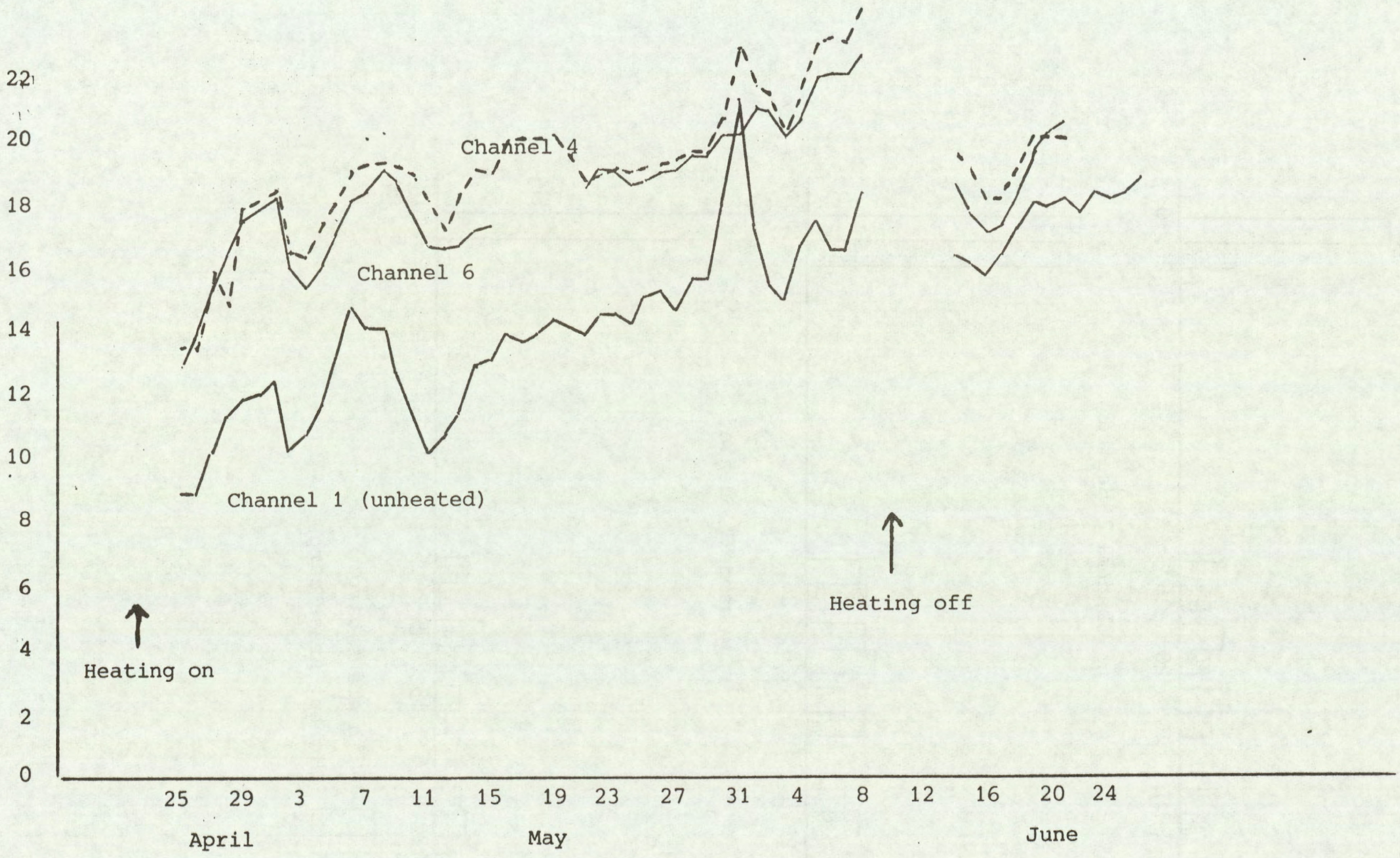
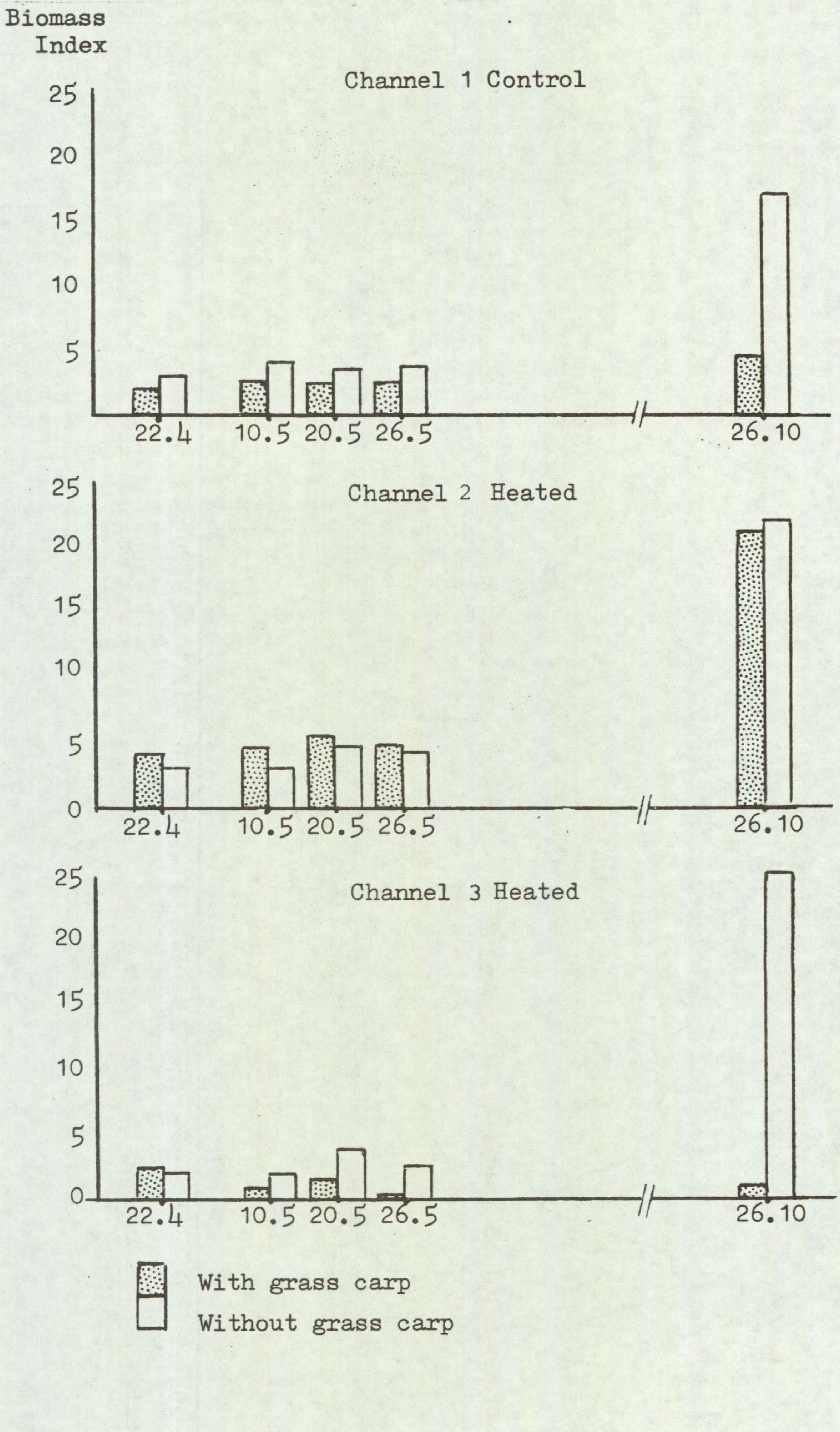


Fig. 5 Biomass index values for the three channels



RESULTS

Fig 4 shows the water temperature data. The mean daily records show a 5-6oC difference, between the heated and unheated channels, maintained throughout the experimental period. When the heating cables were switched off on 10th. June the polythelene covers still maintained a 2-3 degree difference.

Table 4. Growth of grass carp in two water temperatures

Date	No.of fish	Mean weight (g)	Stocking density (kg/ha)	Weight increase (%)
Channel 1 unheated				
26.4.83	15	51.1	255	
22.6.83	15	83.4	417	63
Channel 2 heated				
26.4.83	14	53.4	248	
22.6.83	14	150.2	700	182
Channel 3 heated				
26.4.83	13	53.4	249	
22.6.83	13	127.0	549	120

Table 5. Effect of grazing on plant biomass(g/m^2)*.

Channel	With Fish		Without Fish	
	Fresh weight	Dry weight	Fresh weight	Dry weight
1	89.6	13.6	392.0	40.0
2	575.2	64.0	774.0	76.8
3	0	0	438.4	40.0

* Biomass measured on 22.6.83

The state of the plants in Channels 1 and 3 was similar initially. The plants in Channel 2 had been cut which may have stimulated the growth, thus resulting in the much higher biomass initially present in that channel. There appeared to be little control of the plants in Channel 2 although the fish achieved the greatest growth rate, almost tripling their weight in two months (Table 4). Fish growth was slower in Channel 1, subject to normal water temperatures, than in Channel 3 with water temperatures higher by some 4-6 degrees Celcius. By June there was nothing left to eat in Channel 3 compared with 89.6 g fresh weight of plants/m^2 in Channel 1 (Table 5). The final visual survey in October indicated practically no regrowth in Channel 3 and in Channel 1 some had regrown although enough had been eaten by the fish to prevent maximum return to full production. Fig 5 shows the Biomass Index calculations for each Channel on the four occasions.

CONCLUSIONS.

The raising of the water temperature in early spring just as the Elodea spp. was beginning to grow, enabled the grass carp to feed actively and prevent the plants reaching maturity. Once the plants became mature the fish could not control them so easily.

Warm weather early in the year is essential to the success of grass carp to control weed. A late spring does not slow the growth of water plants very much but it will delay grass carp activity.

4. ZOOPLANKTON AND PHYTOPLANKTON POPULATIONS IN A LAKE STOCKED WITH GRASS CARP.

While monitoring the effects of grass carp in Pusey Lake (Fowler 1984), routine estimates were made of the zooplankton population for the years 1978-1984. During the same period water samples were analysed for chlorophyll a content, as a measure of the phytoplankton present, and records of dissolved oxygen were kept.

The lake has an area of about 0.60 ha. and is up to 1 m deep. On each visit 15 zooplankton samples were taken from a boat by lowering a 15 cm. diameter plankton net and raising it slowly through a column of water. The volume sampled was calculated according to the length of the water column. The contents of the glass reservoir attached to the net were transferred to bottles and returned to the laboratory where they were sub-divided and the animals identified, counted and populations expressed in numbers per litre.

Chlorophyll a was determined using Talling's method. The phytoplankton was not, as a rule, identified. Dissolved O_2 readings were taken using an EIL meter

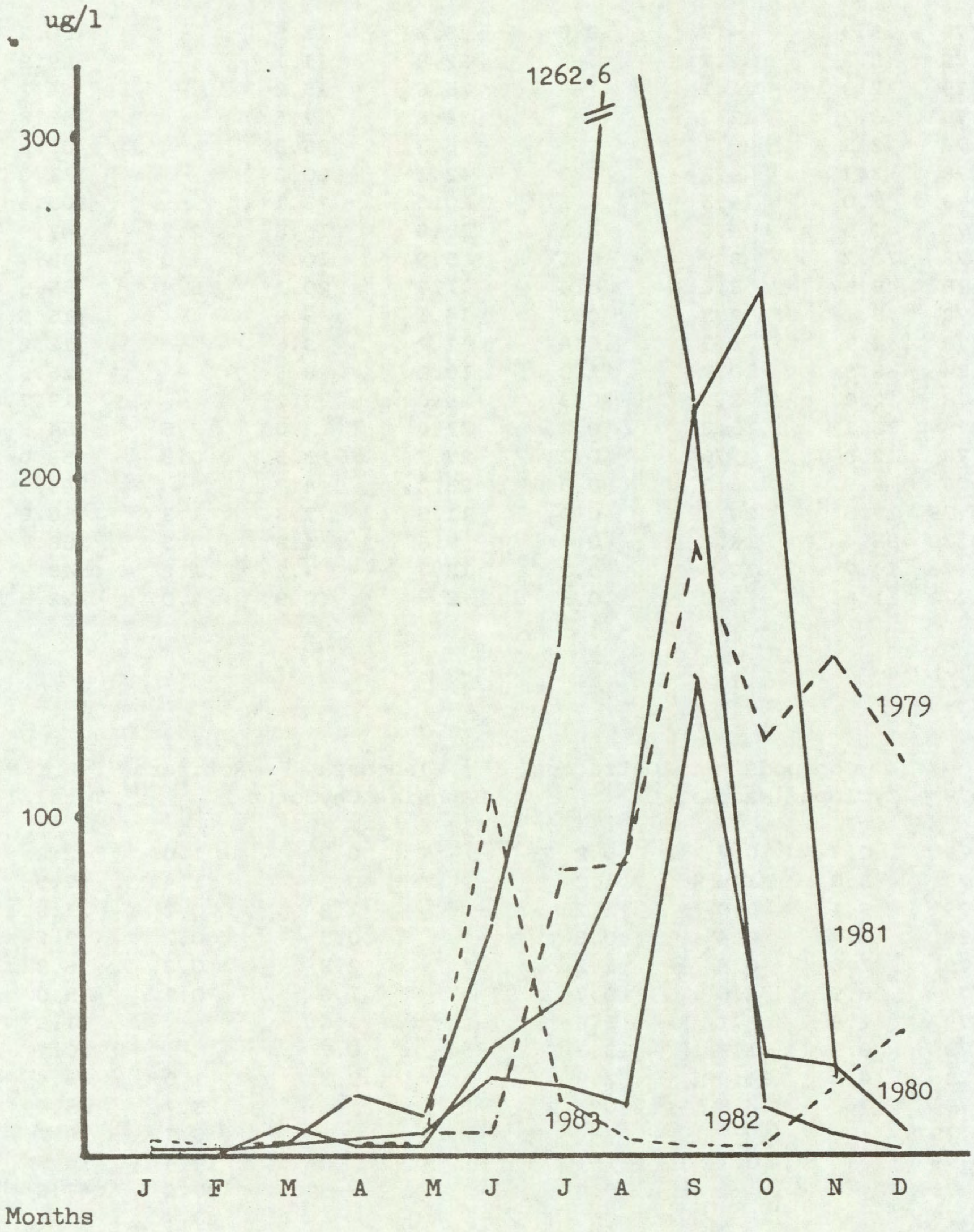
RESULTS

Total numbers of zooplankton were high in late May/early June in each year, with occasional blooms of Rotifera sp. in autumn. The dominant Copepod was from the sub-group Cyclopoida and very occasionally a member of Calanoida was identified. The dominant Cladocerans were from the families Chydoridae and Daphnidae. Rotifers included many species including Karatella quadrata and members of the families Coluridae, Rattulidae and Brachionidae. Tables 6-12.

Daphnia sp. were recorded in 1978, before grass carp were introduced and in 1983, after the fish had been removed. Their absence between these years was not the direct effect of the grass carp. The lake had been suction dredged in the winter of 1977/78 and during 1978 there was a diverse population of zooplankton including Daphnia, and an increasing population of young stickle-backs (Gasterosteus aculeatus L.) developed. From 1979 the stickle-backs fed on the Daphnia sp. In 1983 when the lake was again virtually dredged for the grass carp, a great many stickle-backs were removed. When the lake refilled, stickle-back numbers were very low and Daphnia sp. re-appeared.

Mean monthly chlorophyll a concentrations are shown in Fig 6. Except in 1983 there was always a peak in late summer or autumn. Whether this is a natural occurence or encouraged by the fish having eaten most of the competing vascular vegetation is not certain, but only once did a phytoplankton bloom, identified as Chlamydomonas sp become a problem. The death of this bloom in September 1982 caused an abrupt fall of the dissolved oxygen levels (Table 13). Although the mean dissolved oxygen level for that month was 44%, on three of the four visits the dissolved oxygen was well below 20%. This caused distress to both the grass carp and stickle-backs, a few of the former and many of the latter dying. In 1983 the lake was drained right down when the fish were removed. After it refilled the phytoplankton population remained low and it was some weeks before a low stocking density of grass carp were re-introduced, but no phytoplankton bloom appeared.

Fig. 6 Mean monthly chlorophyll 'a' concentrations in Pusey Lake 1979-1983



Tables 6 to 12. Zooplankton populations in Pusey lake during 1978-1984

	Copepods		Ostracods	Cladocera		Rotifers		
1978	Cyclops	Nauplii		Daphnia	Chydorus		Total/l	No.l
24.5.78	3.9	4.8	0.8	9.2	11.5	–	30.2	219
31.5.78	3.3	2.7	–	32.8	11.1	–	49.9	212
7.6.78	2.3	11.1	–	25.6	15.2	–	54.2	210
14.6.78	3.7	12.7	–	34.8	7.6	–	58.8	198
21.6.78	2.5	20.1	–	26.3	36.3	–	85.2	140
28.6.78	3.7	4.2	0.2	42.1	60.8	–	111.0	160
3.7.78	7.0	4.5	0.3	20.5	73.1	–	105.4	160
12.7.78	7.5	4.6	0.1	17.6	15.8	2.3	47.9	160
18.7.78	10.2	3.9	0.5	9.9	10.2	1.0	35.7	160
26.7.78	9.5	8.0	0.4	11.8	20.1	5.8	55.6	160
1.8.78	5.1	2.3	0.1	4.1	3.9	–	15.5	160
8.8.78	4.7	1.3	0.4	2.2	3.6	–	12.2	160
15.8.78	6.3	0.7	1.3	10.0	8.5	–	26.8	150
22.8.78	2.9	2.3	0.3	5.0	3.2	–	13.7	158
12.9.78	13.1	15.2	0.2	21.8	2.0	2.6	54.9	168
19.9.78	12.8	7.9	0.2	27.7	3.5	0.9	53.0	168
27.9.78	8.9	6.0	0.3	23.2	4.7	–	43.1	157
10.10.78	17.6	20.8	0.2	11.6	7.3	1.3	58.8	144
24.10.78	35.4	16.2	0.4	9.6	4.8	0.3	66.7	163
7.11.78	14.7	10.6	0.3	12.7	3.2	1.8	43.3	162
21.11.78	11.6	3.0	0.3	3.7	0.9	3.0	22.5	158

Table 7

	Copepods		Ostracods	Cladocera		Rotifers		
1979	Cyclops	Nauplii		Daphnia	Chydorus		Total/l	No.l
8.3.79	0.7	0.7	0.2	–	0.2	1.0	2.8	23
20.3.79	3.0	1.4	1.2	–	0.5	1.4	7.5	120
3.4.79	3.1	5.0	1.2	–	1.8	0.2	11.3	114
17.4.79	1.7	0.4	0.8	–	0.5	0.2	3.6	170
1.5.79	1.6	0.9	1.2	–	2.3	0.3	6.3	170
9.5.79	0.9	1.6	0.7	–	1.6	0.2	5.0	184
15.5.79	2.6	2.1	3.6	–	3.6	–	11.9	161
19.6.79	8.9	1.3	13.3	–	6.7	–	30.2	196
18.7.79	4.5	34.8	2.8	–	2.3	1.0	45.4	86
5.9.79	7.3	4.3	0.1	–	–	23.7	35.4	192
3.10.79	–	–	–	–	–	8.7	8.7	152
15.10.79	–	0.1	–	–	–	14.4	14.5	174
30.10.79	–	–	0.4	–	–	47.4	47.8	127
15.11.79	–	–	–	–	–	48.7	48.7	86
11.12.79	–	–	–	–	–	3.9	3.9	158

Table 8

	Copepods		Ostracods	Cladocera		Rotifers		
1980	Cyclops	Nauplii		Daphnia	Chydorus		Total/l.	No.l
8.1.80	–	–	–	–	–	–	–	160
12.2.80	–	–	0.5	–	–	–	0.5	154
2.4.80	0.3	–	0.9	–	–	–	1.2	164
14.4.80	0.8	0.2	1.8	–	0.4	4.0	7.2	176
24.4.80	0.6	3.3	0.3	–	0.4	0.6	5.2	173
6.5.80	4.0	0.7	2.3	–	1.8	0.3	9.1	177
12.5.80	2.6	0.5	0.9	–	0.7	–	4.7	186
20.5.80	5.2	2.8	1.4	–	2.4	–	11.8	182
27.5.80	7.9	2.8	2.7	–	6.3	34.6	54.3	180
2.6.80	7.2	5.2	4.4	–	6.4	0.5	23.7	175
16.6.80	15.0	12.7	1.3	–	2.0	7.8	38.8	97
23.6.80	12.1	4.8	3.3	–	2.8	3.4	26.4	182
30.6.80	7.8	4.4	5.8	–	2.0	0.1	20.1	180
15.7.80	5.4	2.7	3.9	–	1.5	0.3	13.8	175
21.7.80	3.9	2.0	2.8	–	1.2	0.2	10.1	177
4.8.80	4.8	1.2	3.0	–	1.0	0.8	10.8	162
18.8.80	0.7	0.4	0.4	–	–	0.4	1.9	147
8.9.80	0.5	0.5	0.4	–	–	0.7	2.1	160
15.9.80	0.5	0.3	0.4	–	0.1	1.0	2.3	171
29.9.80	0.3	0.4	0.8	–	–	4.8	6.3	174
6.10.80	0.2	0.1	0.1	–	–	3.3	3.7	173
21.10.80	0.1	0.1	0.2	–	–	1.7	2.1	175
28.10.80	0.1	0.4	0.7	–	–	1.5	2.7	171
10.11.80	0.1	–	0.1	–	–	–	0.2	79
24.11.80	0.1	0.1	2.8	–	–	0.2	3.2	172
15.12.80	0.2	0.2	0.9	–	–	0.3	1.6	181

Table 9

	Copepods		Ostracods	Cladocera		Rotifers		
1981	Cyclops	Nauplii		Daphnia	Chydorus		Total/l	No.1
6.1.81	0.1	0.2	0.7	–	–	0.7	1.7	181
19.1.81	0.1	0.2	0.5	–	–	–	0.8	158
2.2.81	0.2	0.2	0.3	–	–	0.9	1.6	179
19.2.81	0.3	0.1	1.1	–	–	1.4	2.9	140
2.3.81	0.5	0.3	5.5	–	–	1.6	7.9	178
16.3.81	1.8	1.0	6.8	–	0.4	1.3	11.3	145
31.3.81	2.3	0.9	7.5	–	0.9	1.8	13.4	144
22.4.81	1.9	0.9	2.1	–	0.3	0.4	5.6	170
5.5.81	5.7	2.5	2.8	–	0.7	0.4	12.1	167
18.5.81	14.4	8.0	5.8	–	1.5	0.1	29.8	176
1.6.81	45.2	10.0	14.7	–	3.7	–	73.6	174
15.6.81	80.9	22.0	19.5	–	2.9	–	125.3	126
29.6.81	132.3	49.0	60.7	–	12.3	–	254.3	171
6.7.81	55.0	14.3	23.2	–	12.5	–	105.0	149
20.7.81	24.4	9.0	8.9	–	7.4	–	49.7	165
30.7.81	13.0	10.9	7.2	–	8.4	0.1	39.6	152
10.8.81	21.1	10.8	3.0	–	16.1	1.7	52.7	171
20.8.81	6.7	10.1	1.4	–	0.9	6.6	25.7	167
1.9.81	19.0	13.9	7.0	–	4.5	3.1	47.5	179
10.9.81	6.6	6.1	5.3	–	2.2	2.1	22.3	178
21.9.81	4.2	4.0	5.9	–	1.7	1.4	17.2	177
28.9.81	2.4	2.6	2.5	–	0.8	5.9	14.2	177
5.10.81	0.7	0.5	0.4	–	0.1	7.6	9.3	178
19.10.81	1.3	0.6	2.7	–	0.6	13.6	18.8	178
2.11.81	0.3	0.2	1.6	–	0.2	7.0	9.3	177
16.11.81	0.9	0.9	8.0	–	0.5	1.0	11.3	171

Table 10

	Copepods		Ostracods	Cladocera		Rotifers		
1982	Cyclops	Nauplii		Daphnia	Chydorus		Total/l	No.l
5.1.82	0.2	0.1	1.6	–	–	–	1.9	170
25.1.82	0.1	0.3	4.6	–	–	–	5.0	137
8.2.82	0.7	0.9	4.9	–	0.2	0.3	7.0	152
8.3.82	0.5	0.2	1.5	–	0.1	0.1	2.4	168
29.3.82	2.6	1.1	5.4	–	1.2	0.5	10.8	128
19.4.82	3.0	1.5	2.4	–	1.2	0.9	9.0	149
26.4.82	4.8	1.9	4.3	–	1.5	0.1	12.6	148
10.5.82	2.5	3.1	2.4	–	1.5	0.9	10.4	161
18.5.82	11.0	8.6	6.7	–	8.0	0.7	35.0	162
24.5.82	25.2	12.9	9.2	–	10.2	9.0	66.5	164
7.6.82	44.8	24.4	7.4	–	31.4	16.0	124.0	160
28.6.82	20.9	5.4	2.3	–	1.4	2.4	32.4	161
5.7.82	1.8	15.3	0.9	–	1.2	5.9	25.1	169
13.7.82	5.9	9.4	0.7	–	0.4	4.8	21.2	155
19.7.82	4.7	6.9	2.3	–	0.7	6.9	21.5	155
26.7.82	5.0	8.2	3.4	–	0.7	8.5	25.8	161
9.8.82	6.6	3.3	5.0	–	0.6	52.6	68.1	165
16.8.82	4.4	2.0	1.8	–	0.3	33.8	42.3	160
23.8.82	2.9	4.2	4.1	–	1.2	7.9	20.3	162
8.9.82	0.5	–	0.8	–	0.1	3.9	5.3	155
13.9.82	0.1	0.2	1.1	–	–	4.3	5.7	149
28.9.82	0.3	0.7	0.3	–	–	120.6	121.9	156
12.10.82	–	1.9	0.3	–	–	74.6	76.8	169
1.11.82	–	1.5	1.8	–	–	4.1	7.4	132
15.11.82	–	0.5	0.9	–	–	10.2	11.6	168
29.11.82	–	–	0.1	–	–	0.8	0.9	136
13.12.82	–	0.2	0.3	–	–	0.2	0.7	170

Table 11

	Copepods		Ostracods	Cladocera		Rotifers		
1983	Cyclops	Nauplii		Daphnia	Chydorus		Total/l	No.l
10.1.83	0.1	0.1	0.9	–	–	0.1	1.2	172
25.1.83	0.2	0.3	1.6	–	–	0.7	2.8	145
1.3.83	0.1	0.4	1.2	–	–	1.2	2.9	158
28.3.83	0.1	0.6	1.3	–	0.1	1.4	3.5	155
26.4.83	0.5	0.4	0.4	–	0.2	0.5	2.2	166
10.5.83	0.2	0.8	0.4	–	0.2	0.5	2.1	135
24.5.83	2.9	3.2	0.7	–	0.4	2.0	9.2	178
6.6.83	1.4	2.7	0.7	–	0.7	1.5	7.0	166
4.7.83	15.6	22.3	0.9	–	3.1	40.6	82.5	172
19.7.83	56.4	26.6	0.9	5.1	16.4	71.8	177.2	168
8.8.83	0.9	2.4	1.0	13.0	0.7	0.6	18.6	164
23.8.83	7.4	7.7	1.0	6.5	0.5	0.8	23.9	166
6.9.83	7.5	11.0	1.1	4.5	0.1	1.2	25.4	174
26.9.83	8.2	10.3	1.5	3.5	0.3	0.2	24.0	169
17.10.83	5.8	3.7	0.6	6.4	–	0.8	17.3	165
14.12.83	3.5	7.2	0.4	2.7	–	62.2	76.0	161

Table 12

	Copepods		Ostracods	Cladocera		Rotifers		
1984	Cyclops	Nauplii		Daphnia	Chydorus		Total/l	No.l
10.1.84	1.6	3.2	0.2	3.3	–	1.2	6.4	173
19.3.84	3.4	1.7	1.4	–	–	1.1	21.0	169
2.4.84	2.5	0.7	0.9	–	–	0.4	4.5	167
16.4.84	3.0	4.4	1.0	–	–	2.5	10.9	142
3.5.84	2.4	6.5	0.9	0.2	0.1	6.9	17.0	169
21.5.84	1.6	5.0	1.8	2.9	0.6	4.4	16.3	157
4.6.84	1.8	1.9	1.1	4.5	1.5	0.7	11.8	175
25.6.84	4.2	2.2	2.3	10.0	10.2	0.4	29.3	170
16.7.84	5.0	1.2	5.6	12.5	27.6	1.9	53.8	166

Table 13. Mean Monthly Dissolved Oxygen level (%)* in Pusey lake 1979-1984.

	1979	1980	1981	1982	1983	1984
Jan	–	–	89	90	127	120
Feb	–	96	115	140	–	108
Mar	112	–	110	108	143	156
Apr	147	160	190	165	>200	>200
May	159	187	174	>200	>200	>200
Jun	190	142	145	>200	–	>200
Jul	–	138	149	186	80	>200
Aug	–	96	143	187	149	
Sept	–	141	157	44	118	
Oct	95	100	158	100	93	
Nov	123	87	74	111	–	
Dec	112	79	–	–	111	

* Values are the means of two or more visits per month especially from April to October. The blanks indicate that no recordings were made.

CONCLUSIONS.

The lack of any adverse effects on the zooplankton attributable to grass carp grazing agrees with the work in canals in The Netherlands by Van der Zweerde et al (1978). It seems reasonable to assume that the absence of Daphnia sp. while grass carp were present was due to the stickle-back population.

Phytoplankton can colonize water where there is lack of competition by vascular plants and there were blooms towards the end of the years when the fish had grazed the other species. One parameter which was not monitored and which could have had a profound effect on plant and algae growth was the possible fluctuation of nutrient or pollutant input from the land drains entering the lake.

GENERAL DISCUSSION.

The three most important factors influencing the degree of weed control achieved by grass carp are:- water temperature; species of plant present; and biomass of fish introduced.

1. Water temperature.

In much of the experimental work it has become clear that the uncertain British climate, and therefore fluctuations in water temperature, during the crucial period of early summer can make the difference between success or failure of weed control. If the temperature in April is high enough for the fish to start feeding early and so prevent plants reaching maturity and reproducing, the summer weed problems will be reduced and the "seed bank" and ,therefore, regrowth will be reduced for the next season. Conversely, if the spring weather is cold the weeds will be relatively unaffected by the fish, reach maturity and reproduce.

2. Species of plant present.

Grass carp do have definite food preferences among aquatic plants. For example Elodea spp. are preferred to Ceratophyllum demersum which has increased its area when Elodea spp or another preferred species has been grazed. This is also true for Myriophyllum spicatum, Potamogeton natans and some filamentous algae, all being avoided by the fish, (Fowler and Robson 1978, Fowler 1984.) Only if the stocking density is very high and the fish become seriously starved of food will they taste, break off, uproot or damage other plants they would normally avoid. The result can be that if a void is created an alga such as Vaucheria spp which can grow in the cold conditions in February and March will take advantage of the lack of competition. The fish at this time of year are not actively grazing or hungry, and will allow the weed to spread unhindered. The ideal would be to introduce sufficient grass carp to eat only a proportion of the vegetation leaving enough to prevent predominance of an even worse plant pest. This balance must be the chief aim of water managers.

3. Biomass of grass carp.

A reasonable estimate of the size and number of fish to introduce can be made if the range of plant species is known. A decision on just how much weed control is required is a help, i.e. total clearence or a degree of reduction. The weather conditions during the critical period are not as easy to forecast. Whatever amount of fish is put in will almost inevitably increase its biomass, and a carefully calculated balance one year may be upset in the second because of increased pressure on the food supply or unseasonable temperatures.

APPENDIX 1. Weights and lengths of grass carp used in these experiments.

At various times during these experiments and those carried out at outside sites the fish have been weighed and measured. If the fish were small the safest way was by putting them in a known volume of water in a container on a balance. At outside sites or if the fish were very large it was found that by placing each fish in a black polythylene bag and using a spring balance, fairly accurate weights were obtained with minimal damage to the fish. This method was preferred to that of anaesthetising the fish. The graph in Fig 7 shows all the accumulated data of weights and lengths. Length in itself is not an accurate estimate of probable weight, for example between the lengths of 40-45 cms the range of weight is 850-1400 gms. and between 45 and 50 cms the weight range extends to 2300 gms.

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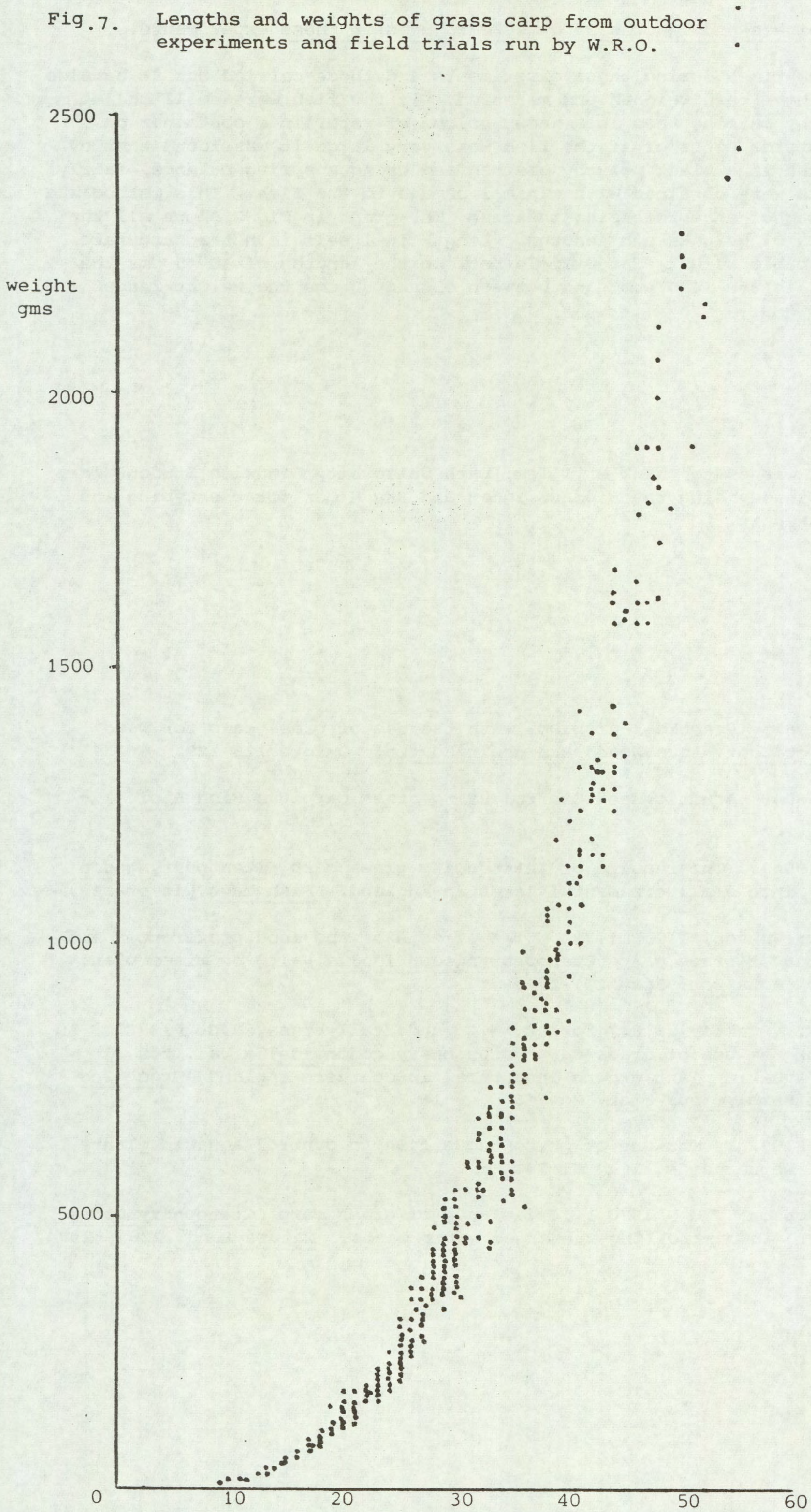
Fig.7. Lengths and weights of grass carp from outdoor experiments and field trials run by W.R.O.



ABBREVIATIONS

ångström	Å
Abstract	Abs.
acid equivalent*	a.e.
acre	ac
active ingredient*	a.i.
approximately equal to*	≃
aqueous concentrate	a.c.
bibliography	bibl.
boiling point	b.p.
bushel	bu
centigrade	C
centimetre*	cm
concentrated	concd
concentration	concn
concentration x time product	ct
concentration required to kill 50% test animals	LC50
cubic centimetre*	cm^3
cubic foot*	ft^3
cubic inch*	in^3
cubic metre*	m^3
cubic yard*	yd^3
cultivar(s)	cv.
curie*	Ci
degree Celsius*	^{o}C
degree centigrade	^{o}C
degree Fahrenheit*	^{o}F
diameter	diam.
diameter at breast height	d.b.h.
divided by*	÷ or /
dry matter	d.m.
emulsifiable concentrate	e.c.
equal to*	=
fluid	fl.
foot	ft
freezing point	f.p.
from summary	F.s.
gallon	gal
gallons per hour	gal/h
gallons per acre	gal/ac
gas liquid chromatography	GLC
gramme	g
hectare	ha
hectokilogram	hkg
high volume	HV
horse power	hp
hour	h
hundredweight*	cwt
hydrogen ion concentration*	pH
inch	in.
infra red	i.r.
kilogramme	kg
kilo ($x10^3$)	k
less than	<
litre	l.
low volume	LV
maximum	max.
median lethal dose	LD50
medium volume	MV
melting point	m.p.
metre	m
micro ($x10^{-6}$)	μ
microgramme*	μg
micromicro (pico: $x10^{-12}$)*	μμ
micrometre (micron)*	μm (or μ)
micron (micrometre)*†	μm (or μ)
miles per hour*	mile/h
milli ($x10^{-3}$)	m
milliequivalent*	m.equiv.
milligramme	mg
millilitre	ml

† The name micrometre is preferred to micron and μm is preferred to μ.

millimetre*	mm
millimicro* (nano: x10^{-9})	n or mμ
minimum	min.
minus	-
minute	min
molar concentration*	M (small cap)
molecule, molecular	mol.
more than	>
multiplied by*	x
normal concentration*	N (small cap)
not dated	n.d.
oil miscible concentrate	o.m.c. (tables only)
organic matter	o.m.
ounce	oz
ounces per gallon	oz/gal
page	p.
pages	pp.
parts per million	ppm
parts per million by volume	ppmv
parts per million by weight	ppmw
percent(age)	%
pico (micromicro: x10^{-12})	p or μμ
pint	pint
pints per acre	pints/ac
plus or minus*	±
post-emergence	post-em
pound	lb
pound per acre*	lb/ac
pounds per minute	lb/min
pound per square inch*	lb/in^2
powder for dry application	p. (tables only)
power take off	p.t.o.
precipitate (noun)	ppt.
pre-emergence	pre-em.
quart	quart
relative humidity	r.h.
revolution per minute*	rev/min
second	s
soluble concentrate	s.c.
soluble powder	s.p.
solution	soln
species (singular)	sp.
species (plural)	spp.
specific gravity	sp. gr.
square foot*	ft^2
square inch	in^2
square metre*	m^2
square root of*	$\sqrt{}$
sub-species*	ssp.
summary	s.
temperature	temp.
ton	ton
tonne	t
ultra-low volume	ULV
ultra violet	u.v.
vapour density	v.d.
vapour pressure	v.p.
varietas	var.
volt	V
volume	vol.
volume per volume	v/v
water soluble powder	w.s.p. (tables only)
watt	W
weight	wt
weight per volume*	w/v
weight per weight*	w/w
wettable powder	w.p.
yard	yd
yards per minute	yd/min

* Those marked * should normally be used in the text as well as in tables etc.

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40. The activity and pre-emergence selectivity of some recently developed herbicides: RP 20810, oxadiazon, chlornitrofen, nitrofen, flamprop-isopropyl. August 1976. W G Richardson, M L Dean and C Parker. Price - £2.75.

41. The activity and pre-emergence selectivity of some recently developed herbicides: K 1441, mefluidide, WL 29226, epronaz, Dowco 290 and triclopyr. November 1976. W G Richardson and C Parker. Price - £3.40.

42. The activity and post-emergence selectivity of some recently developed herbicides: KUE 2079A, HOE 29152, RH 2915, Triclopyr and Dowco 290. March 1977. W G Richardson and C Parker. Price - £3.50

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