THE ECOLOGY AND MANAGEMENT OF THE COARSE FISH POPULATIONS OF THE LOWER WELSH DEE

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Brian. P. Hodgson.

Summary

Studies were carried out into the coarse fish populations of the lower Welsh Dee to establish reasons for reported declines in anglers' catches, particularly in respect of roach *Rutilus rutilus* (L.). The ecology of the fish community and the elements of the river regime that impacted upon it, were evaluated, so that a basis for a long term management plan for improvement could be formulated.

Species composition was determined, principally from the sampling of anglers' catches, and it was found that dace dominated throughout the study area and that they had wide distribution in the main river and tributaries between Bangor-on Dee and the tideway below Chester. Tagging of dace showed seasonal migratory movement, which on occassions, was very rapid and over long distances. Roach were to be found at Chester but then only infrequently, mainly comprising of older fish with no strong year classes being evident. Extensive migratory movements, comparable to dace, were not found but, the limited sample established some spawning migration within the deeper lowland section.

A study of the pressures impacting on fish populations determined that, as a consequence of regulation, there had been a lowering of river temperature which was found to be an important factor in influencing the growth development of juvenile roach. It was established that the extra water volume and faster run-off compounded the natural limitations of the catchment, with its steep mid-river profile and short lowland plain section. The deeper, heavily shaded length of river, along much of the Cheshire Plain, reduced light penetration to the water surface and again restricted any temperature rises.

Historical anthropogenic activities to reduce the impact of flooding on lowland areas, was found to concentrate flows in the flood plain within a river channel with steep banks and high flood embankments. At times of spate, flow velocities could exceed the swimming capabilities of roach and bream and as few slackwater, sanctuary areas were available, losses of fish could occur. The channel profile, flow regime and also erosive activities, whether it be from recreational boat traffic at Chester or

cattle damage elsewhere, were shown to limit the development of the margin ecology which could provide a spawning, feeding and resting habitat for fish. Diet studies indicated that juvenile roach were more dependant than dace on marginal feeding area but, the high presence of detritus in the diet of both species, suggested that the food resource of the lower Dee was poor, especially in cold summers.

An ecological appraisal determined a natural succession of bankside plants which ultimately developed a tree dominated habitat. Trees were found to reduce light transmission to the water surface which curtailed the development of the aquatic plants that would create a more beneficial habitat for fish. Trials to recreate weedy margins were undertaken which were successful in overcoming the unstable nature of margin sediments. Time scales of the natural successions were also determined. The trials, with refinement, offered the prospect for expansion of the methodology elsewhere on the river.

It was established that the problems of the roach population were likely to be as a consequence of the pressure elements impacting on the juvenile stocks. The limitations of the river corridor and the tributaries for improvement to provide suitable habitat, directed the investigations towards establishing whether off-stream roach fry rearing facility was a more viable alternative than in-river improvement. In the trial area of Serpentine Lake, fry growth was found to be variable between seasons and no better than the river, on account of deficiencies in the natural feeding programme that was followed. Alternative feeding regimes were pursued under separate trials and potential improvements to the scheme have been highlighted for future implementation.

The study showed that as a result of the problems impacting on the lower Dee catchment, the present ecology was particularly deficient for juvenile roach and probably bream and perch. As many of the factors were found to be largely irreversible, effective amelioration measures are going to be difficult to implement. Recommendations on suggested areas for practical improvement are put forward, together with areas of further research which could bring longer term benefits to the coarse fish populations of the lower Dee.

Chapter 1 The River Dee

1.1 Introduction

The Welsh River Dee has been long renowned as a salmonid river and over the years this has overshadowed its importance as a coarse fishery. This is not surprising because most rivers which maintain a respectable stock of migratory fish are principally recognised for that resource, regardless of whether the trout or the coarse fish populations are of a high standard.

Nonetheless the Dee, throughout its length, has always maintained good coarse fish stocks (O'Hara, *et al* 1983). At the upper end, in Llyn Tegid, roach *Rutilus rutilus* (L.), perch *Perca fluviatilis* (L). and pike *Esox lucius* (L). are prominent. From Bala down to Bangor-on-Dee it is the grayling *Thymallus thymallus* (L.) which is successful (Woolland, 1972 and Woolland and Jones, 1975) but it is probably only since the demise of the salmon *Salmo salar* (L.) fishery along with a national decline in other rivers, that this species is gaining in reputation with the angler. During the mid 1960's and early 1970's large grayling were captured from the system, several of which nearly exceeded the national record. The Dee still retains the Welsh record, with a fish of 1.07kg caught in 1978.

From Bangor down to the tidal limit at Chester the river is typically a lowland plain coarse fishery which over the years has produced good quality roach *Rutilus rutilus* (L.), dace *Leuciscus leuciscus* (L.), bream *Abramis brama* (L.), chub *Leuciscus cephalus* (L.) and pike *Esox lucius* (L.) stocks, but not necessarily all during the same period (Pearce, 1983a). Whatever fish have been in prominence at any one time have dictated its status as a non-salmonid fishery, though the species occurring have not always been the preferred choice of the competition angler.

In the early 1960's there was a dominant roach and perch population, with a developing dace and chub stock initiating from the upper limits of the Cheshire plain (Pearce, 1983a). By the mid 1970's the situation had changed markedly as both roach and perch had suffered a serious decline, while there had been considerable expansion of the dace but less so of the chub (Ray and Haram, 1969).

Anglers by choice consider roach as their preferred species for competition angling in lowland rivers (Hodgson et.al 1988), probably because of their high abundance and widespread distribution. The loss of the roach population was therefore of serious concern to the anglers and although the expansion of dace, did to some extent, redress the situation, the void left by the roach generally lowered the Dee's status as a match angling centre (Pearce, 1983a).

In management terms a number of aspects need to be considered when requests are made to adjust and re-create a community structure that has roach as the prominent or dominant species of the coarse fish stock.

This study examines the ecology of the lowland section of a regulated river, the changes that have occurred and considers the problems and pressures of the system and how they interrelate with the coarse fish that are present. It examines aspects of the relationship between different species and investigates ways in which stock recruitment could be improved.

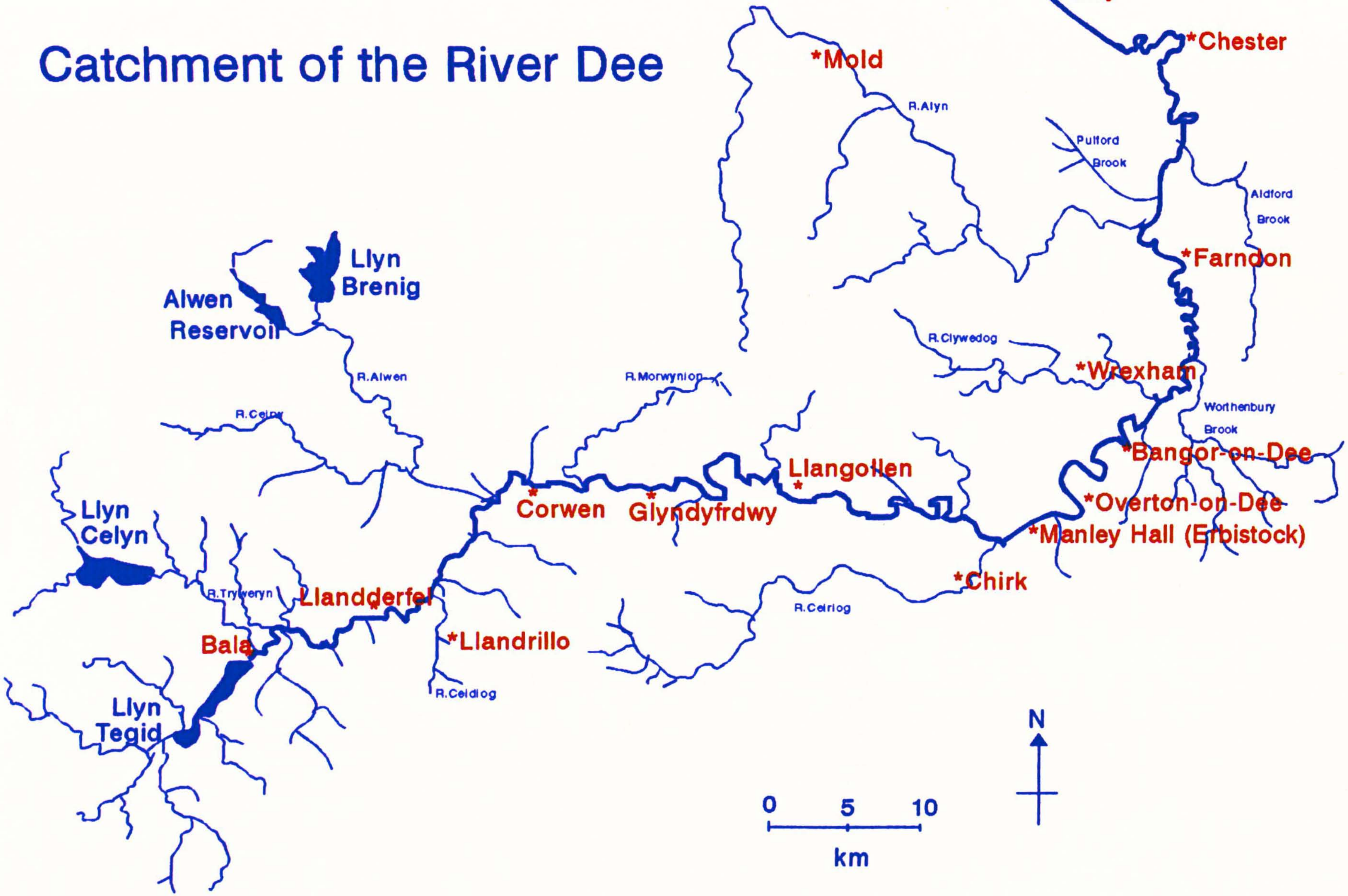
The practical objective of the research was to produce a management plan for the lower Dee from Ironbridge to Chester to enhance the coarse fish stocks for the angler, but also to improve the amenity, wildlife and landscape value of the river, in an area which is not only important to the angler but also to the general public and local tourist industry.

1.2 The Study Area

The study area extended from the Dee confluence with the River Clywedog down to Chester Weir, although influences outside this area were also considered. Plans of the catchment and the study area are given in Fig 1.1 and 1.2.

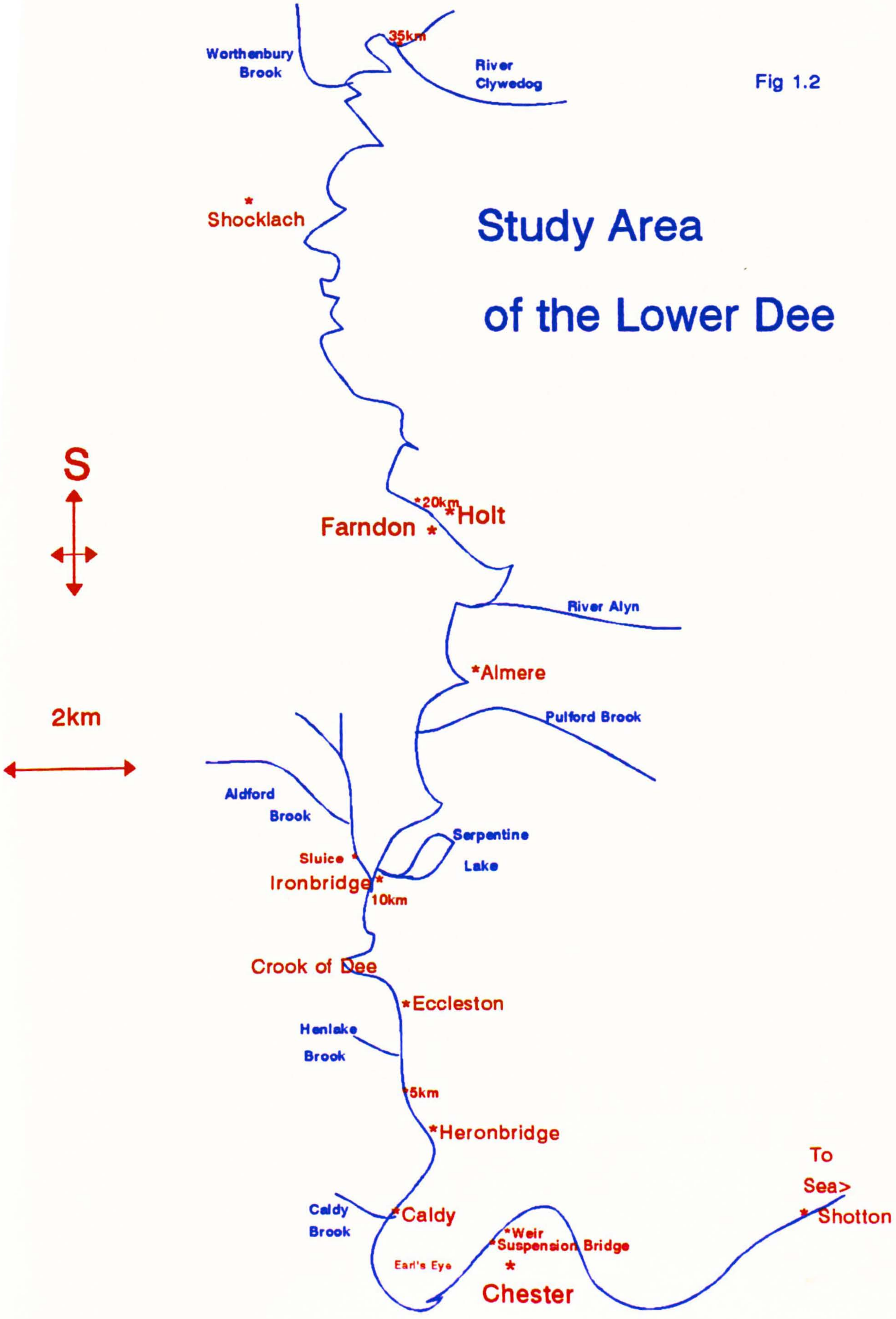
For the proposed management plan it was important to limit the length of river studied to one for which it would be feasible to develop specific plans. Therefore the section of the river between Ironbridge and Chester Weir was selected. This encompassed the area where greatest concern on fish catches had been expressed by anglers, but also it was the area of greatest importance in the wider context of amenity interest. If effective management change is to be pursued in the future for all users, then co-operation with other bodies will be essential for financial assistance to advance the proposals. Eaton Estates, in their management plan of 1983, sought guidance from the Welsh Water Authority (now National Rivers Authority) on improvements to the length of river in their ownership. More recently, Chester City Council have advanced amenity proposals with a special emphasis on enhancing conservation interests on land adjoining the Dee at Chester. A composite plan which centres on the areas of greatest need will have the best chance of success. It was the aim of this study to prepare a management strategy to integrate with other interests on the river, so that practical improvements can be introduced.

Fig 1.1



Catchment of the River Dee

Fig 1.2



Study Area of the Lower Dee

1.3 The Catchment of the Dee

The Welsh Dee rises in the Snowdonia National Park above Bala from where it drains into the largest natural lake in Wales, Llyn Tegid, at an elevation of 160 metres above sea level. This five hundred hectare water created during the last ice age still carries today some vestiges of this period in the form of the gwyniad Coregonus lavaretus (L.), a whitefish that thrives in this deep lake.

From Bala, the River Dee initially meanders through a deep section with shallow gradient, down to Corwen where it is joined by the largest tributary of the system, the River Alwen, which also drains the Brenig catchment. Below Corwen the gradient gradually increases, moving from a typical moderate flowing grayling zone, as defined by the classification system developed by Huet (1959), to a faster trout zone (Fig 1.3). Here the river has typical features of a large upland tributary with alternating fast flowing riffles and deep pools, down to Llangollen, (O'Hara, et al 1983). At this point the river passes through a gorge where there are the remains of a historic weir which was removed in 1965 to allow the free passage of migratory fish. There is little obstruction below this point until the river flows over Erbistock Weir, at which point the environmental change is most noticeable. The landscape becomes predominantly agricultural as the Cheshire plain replaces steep banks and the flow regime slows within a deep, meandering channel, protected by man-made flood embankments.

The geology of the area also changes, with the limestone escarpment above Llangollen being replaced by the Triassic Sandstone of the valley floor, overlain with glacial boulder clay and alluvium (Fig 1.4). The flood embankments are obtrusive between Bangor and Farndon as they constrain the channel and prevent the water movement on to the flood plain. Downstream of Farndon the need for flood embankments reduces as the carrying capacity of the channel increases by becoming deeper and wider. Increases in bankside trees also changes the character of the river in this area, with a mixture of alder Alnus glutinosa and willow Salix sp increasing the level of shade over the river channel to as much as two thirds of the water surface in areas (Eaton, Hodgson & Pearce,

Fig 1.3

Gradient Profile of the River Dee

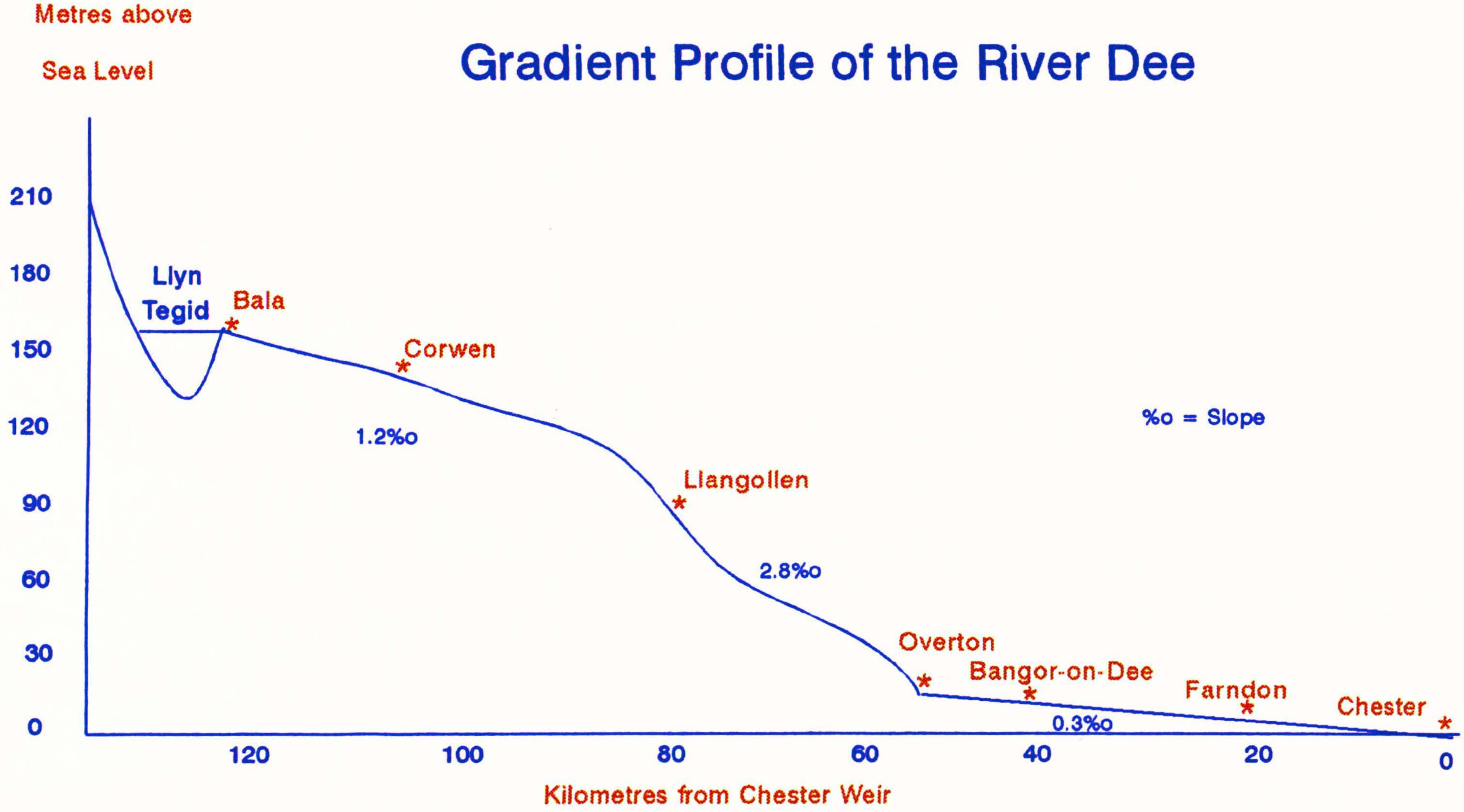
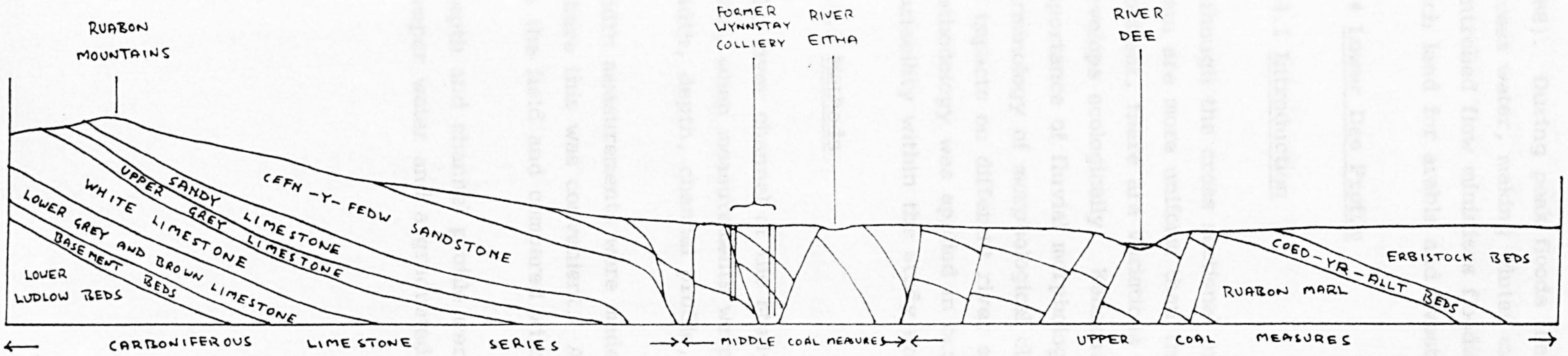
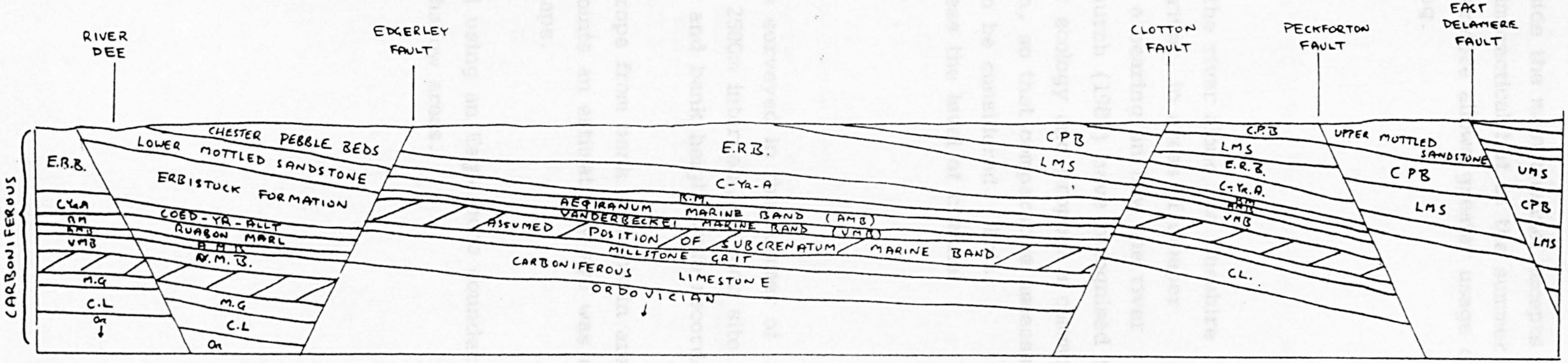


Fig. 1.4.

Upper Cheshire Plain



Lower Cheshire Plain



General Relationship of the Geology

1988). During peak floods the land outside the main channel accepts excess water, making winter cultivation impractical but in the summer the controlled flow minimises flooding and therefore allows greater usage of such land for arable and livestock farming.

1.4 Lower Dee Profile

1.4.1 Introduction

Although the cross sectional profiles of the river along the Cheshire Plain are more uniform than they are upriver, in areas of steeper gradient, there are variations that have a bearing on how the river develops ecologically. Kellerhals and Church (1989) have recognised the importance of fluvial morphology in river ecology and propose a common terminology of morphological classification, so that comparative assessment of impacts on different river systems can be considered. This methodology was applied in order to assess the level of channel variability within the study area.

1.4.2 Methods

The river channel of the study area was surveyed in the summer of 1988, when measurements were taken at 2500m intervals, at each site the width, depth, channel profile, sinuosity and bank height were recorded.

Width measurements were made using a rope from bank to bank in areas where this was convenient. At wider points an estimate by eye was made in the field and compared with 1:2500 maps.

Depth and channel profile were obtained using an Eagle echo sounder in deeper water and a graduated pole in shallow areas.

Sinuosity was calculated from 1:2500 maps by the direct measurement of length between two consecutive points on the river, 2.5km apart, and then calculated from the formula:

$$Sn = \frac{1}{L} \quad (Sn = \text{sinuosity};\ L = \text{Length})$$

Bank height was measured at the waters edge using the graduated pole.

1.4.3 Results

Channel dimensions are given in Table 1.1 below and Fig 1.5

Table 1.1

Channel Dimensions of the study area
(River Clywedog/Dee confluence to Chester Weir)

Distance from Chester Weir (km)	Width (m)	Depth (m)	Bank Height (m)	Sinuosity
35	22	1.5	6.2	0.61
32.5	21	1.2	6.2	0.59
30	29	2.6	6.1	0.43
27.5	27	2.4	4.9	0.63
25	27	3	3.6	0.3
22.5	30	3.1	3.5	0.5
20	35	2.4	4	0.1
17.5	34	3.9	3.2	0.18
15	32	3	3	0.55
12.5	35	5.2	3	0.43
10	36	4.1	3.2	0.06
7.5	42	5	2.8	0.1
5	45	4.2	3.2	0.05
2.5	50	3.7	1.5	0.13
0	58	4	1.5	0.05

Profiles of River Dee at 2.5km intervals

Fig. 1.5.

(Dee/Clywedog confluence - Chester Weir)

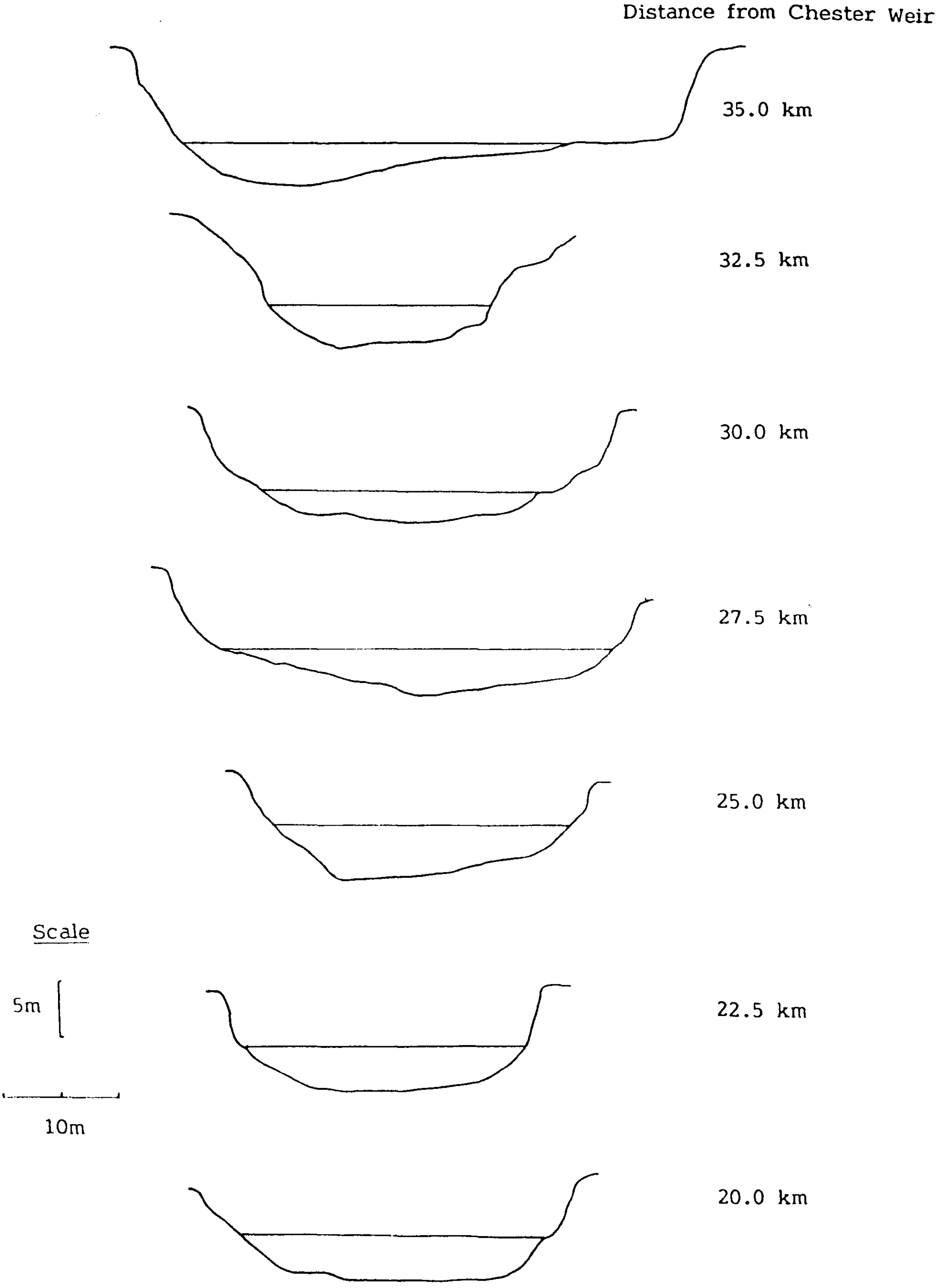
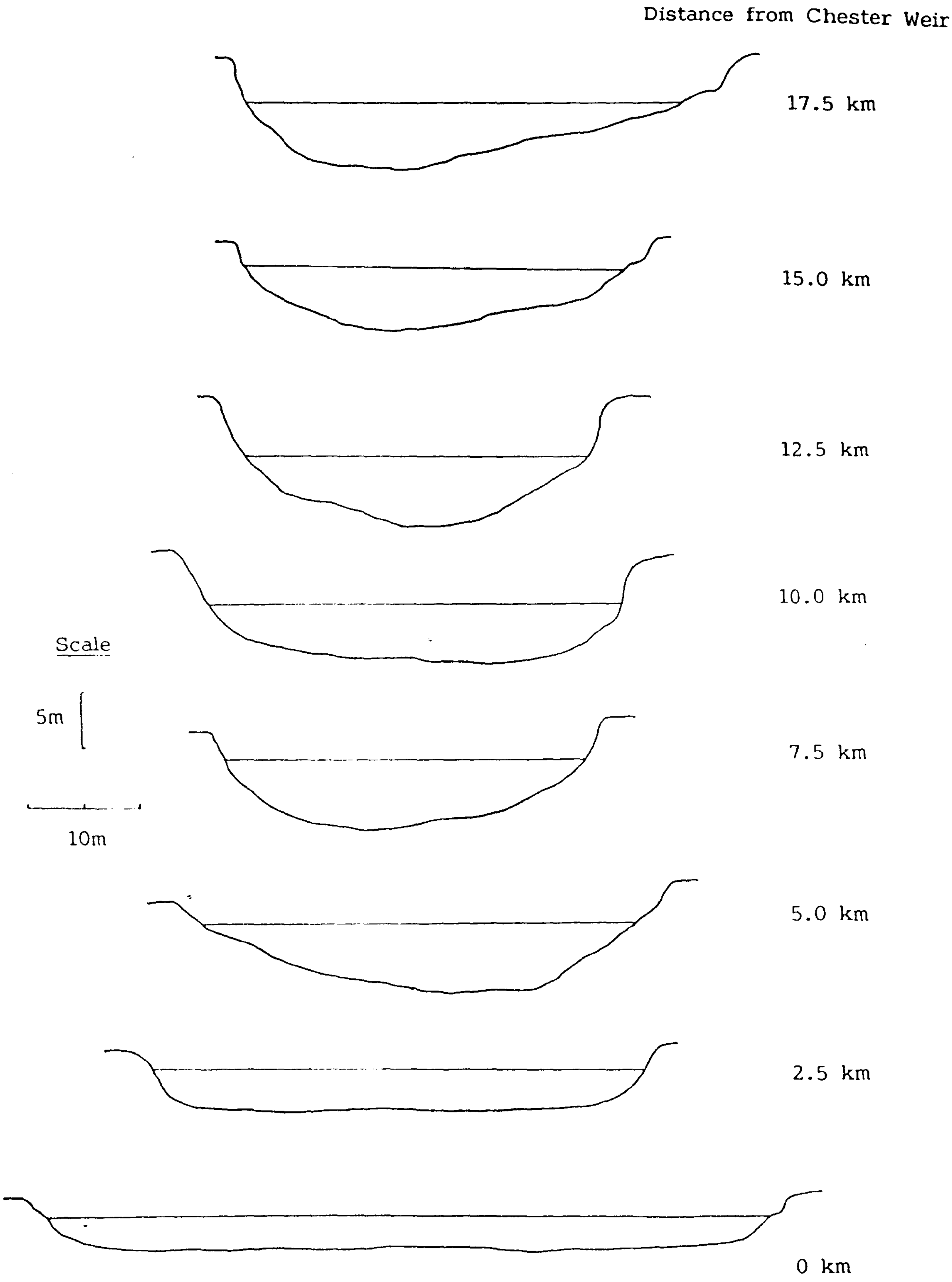


Fig. 1.5 (Cont)

Profiles of River Dee (Continued)



The mean channel width along the section was 35m and progressively increased downstream. There was more width variation at the upper sites, brought about by the greater level of scouring occurring on the outer edges of bends in the meandering channel. The non-uniform channel at this point creates a pool and riffle profile, which in places caused the development of islands. As the river straightens the level of variation both in flow velocity and channel shape decreases, with a consequence that at Chester the widths are fairly uniform and the channel configuration consistent.

The Thalweg or line of maximum depth was also more variable in sections in the upper reaches, with deeper water being found on the outside of bends. As the channel straightened the Thalweg moved towards the centre and a more canal shaped profile developed. The mean depth of 3.3m increased towards Chester but the deepest points were located at the sharpest turns in the river at the lower end, as for example, at Crook-of-Dee (15km from Chester) where the depth was 7.2m.

The mean bank height was 3.7m, with a considerable range from 6.2m at the upper limit of the study area, down to 1.5m at Chester. Heights progressively decreased downstream as channel depth increased. From Farndon to Eccleston, bank heights remained constant but below this point they quickly became shallow and low and, whereas man-made flood embankments were apparent at this point, they were difficult to distinguish from a natural profile at Chester. Bank height and stability has been affected by land drainage and flood prevention schemes over the years, particularly at the upper end where the embankments were 2-3m above the natural level of the flood plain (Rofe and Rafferty, 1961).

1.4.4 Discussion

Under the classification of Kellerhals and Church (1989), the study area on the Dee has three types of channel pattern, namely 'tortuous meanders' between the Clywedog confluence and Farndon, 'irregular meanders' from Farndon to Ironbridge and 'irregular wandering' downstream to Chester. This indicated that as the river advanced seawards the sinuosity became less severe, but whether this was a natural development or one brought about by man's influence on the system is difficult to establish.

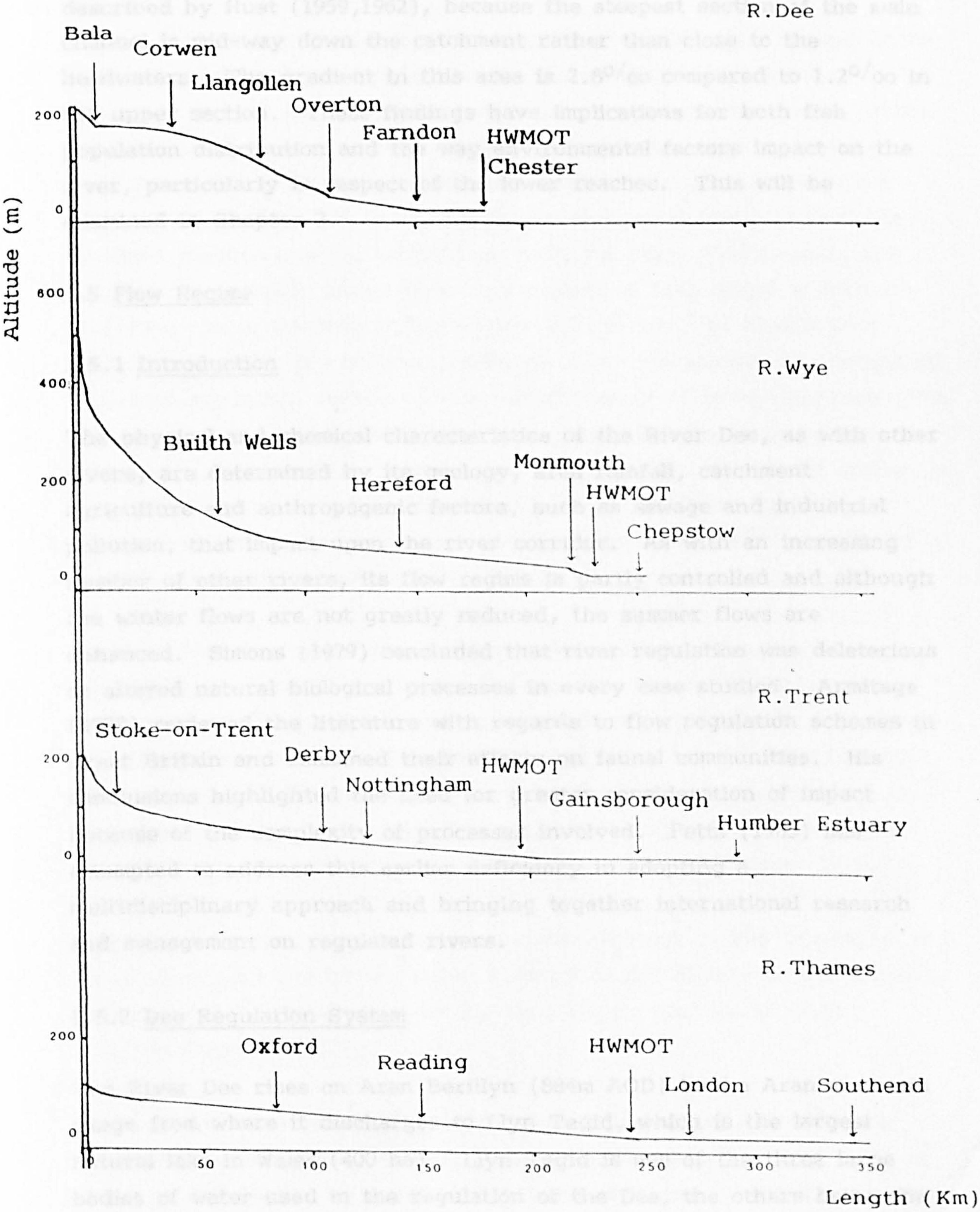
The presence of high banks and man-made flood embankments in much of the study area, as shown in Table 1.1, largely prevents the flood plain operating as it did historically. The concentration of flows within the channel causes flow erosive properties to impact on the banks and the ecology of the channel, particularly during periods of higher flows. This effect will be discussed in Chapter 3.

As the river progresses towards Chester the height of the embankments gradually decreases and the flood plain becomes inundated with water more frequently with severe winter spates. As the carrying capacity of the channel enlarges and becomes deeper and wider the extent of flooding is usually short in duration. The sandstone outcrop at Chester however, also constricts the channel and at peak flows is unable to carry the same volumes as the channel immediately upstream, with a consequence that back-flooding takes place along 'The Meadows' close to Chester. Lambert (1988) indicated that the channel at Chester is only capable of passing 12mm of runoff from the catchment per day when at full capacity.

The slope in the study length is also minimal with a gradient of just 0.3^{o}/oo for the length from Bangor-on-Dee to Chester (Fig 1.3). This is reflected in the sectional profiles indicated in Fig 1.5.

Geographically the River Dee is further north and therefore colder than most of the large, productive, coarse fishing rivers in the British Isles, such as the Thames, Trent and Wye, with which it is often compared by anglers. When considering the gradient profile of the Dee with these rivers (Fig 1.6), it can be seen that with the Trent, Thames and much of the Wye, the overall gradients along the catchments are less steep and the length of lowland section, or typical roach/bream zone as defined by Huet (1959,1962), is much greater.

Fig. 1.6.



Profiles of the Rivers Dee, Trent, Thames and Wye showing

upper tidal limit (HMWOT) and major towns

Adapted from Mann (1989)

The Dee also does not conform to the typical slope profile of rivers described by Huet (1959,1962), because the steepest section of the main channel is mid-way down the catchment rather than close to the headwaters. The gradient in this area is 2.8^{o}/oo compared to 1.2^{o}/oo in the upper section. These findings have implications for both fish population distribution and the way environmental factors impact on the river, particularly in respect of the lower reaches. This will be examined in Chapter 3.

1.5 Flow Regime

1.5.1 Introduction

The physical and chemical characteristics of the River Dee, as with other rivers, are determined by its geology, area rainfall, catchment agriculture and anthropogenic factors, such as sewage and industrial pollution, that impact upon the river corridor. As with an increasing number of other rivers, its flow regime is partly controlled and although the winter flows are not greatly reduced, the summer flows are enhanced. Simons (1979) concluded that river regulation was deleterious or altered natural biological processes in every case studied. Armitage (1979) reviewed the literature with regards to flow regulation schemes in Great Britain and examined their effects on faunal communities. His conclusions highlighted the need for greater consideration of impact because of the complexity of processes involved. Petts (1989) has attempted to address this earlier deficiency in adopting a multidisciplinary approach and bringing together international research and management on regulated rivers.

1.5.2 Dee Regulation System

The River Dee rises on Aran Berillyn (884m AOD) in the Aran mountain range from where it discharges to Llyn Tegid, which is the largest natural lake in Wales (400 ha). Llyn Tegid is one of the three large bodies of water used in the regulation of the Dee, the others being the man-made reservoirs of Llyn Celyn (325ha) and Llyn Brenig (370ha). The catchments of the three waters control 17% of the whole Dee

catchment and 35% of the average run off to Chester Weir (Lambert, 1988).
Thomas Telford introduced the first regulation of the Dee's natural cycle at the beginning of the 19th Century. He constructed a simple adjustable weir at the outlet of Llyn Tegid to store excess floods, which could be released later in dry weather to supplement the low natural river flows and guarantee a supply of water to the Shropshire Union Canal at Llangollen. However, the first major regulation to affect the Cheshire reaches was not undertaken until the early 1950's, when the Dee and Clwyd River Board increased control of Llyn Tegid sufficiently to reduce winter flooding and to assure 2.7 $m^3.sec^{-1}$ of abstractions along the river in dry summer conditions. In 1956 works were completed to extend regulation control with a limited amount of flood mitigation, this time allowing the top few metres of storage in Llyn Tegid to be used to hold back catchment flood water. Not only did this control the discharge from Llyn Tegid but, by a simple diversion of the River Tryweryn upstream of the newly constructed sluice gates, it was also possible to control this catchment as well.

Demands for water progressively increased and by 1964 a new large regulating reservoir, Llyn Celyn, was constructed in the Tryweryn headwaters. This reservoir was to be used conjuctively with Llyn Tegid to support the additional Dee abstraction of 3.4 $m^3.sec^{-1}$ but, for the first time, extra allocations were made available to improve residual flows below the abstraction points and to provide special releases for fishery and environmental protection purposes (Blezard and Lambert, 1979).

Llyn Celyn drains an acidic catchment and although it was developed as a trout fishery by the former Water Authorities it was largely unsuccessful because of its fluctuating water line and oligotrophic water quality. (Hunt and Jones, 1972)

Demands for water regionally continued to increase and, to meet the projected demands until the year 2010, a further reservoir was built at the head the Alwen catchment on the Denbigh Moors. Llyn Brenig was completed in 1976 and reached top water line in 1979 and created a further 60 $m^3 \times 10^6$ of water for domestic supply purposes, although its catchment area of 22 km was much smaller than that of Celyn (60 km). The higher productivity of the catchment, together with the reservoir's more stable water line, enabled it to be developed as a recreational centre and upland trout fishery (Hodgson, 1978).

Since 1979, summer flows in Cheshire have normally been maintained at a minimum of 11 $m^3.sec^{-1}$, to permit increased abstractions for public supply in the Chester area and allow a sufficient minimum flow of 4.2 $m^3.sec^{-1}$ over Chester weir. This was sufficient to dilute effluent in the tideway and to protect salmonids ascending the river by maintaining a good water quality in the estuary. A typical annual flow profile for Eccleston Ferry is given in Fig 1.7a for the dry summer of 1984 and Fig 1.7b the wet summer of 1988. Flow duration statistics and average daily flows are given in Tables 1.2 and 1.3.

Alwen Reservoir which lies in the adjacent valley to Llyn Brenig was built in the 1920's as a direct supply reservoir of 0.5 $m^3.sec^{-1}$ to Birkenhead. Although, at the present time, it does not form part of the regulation system, its conjunctive use with Llyn Brenig may well be advanced in the 1990's, if water demands increase at the rate predicted. A breakdown of abstractions is given in the Table 1.4 below:

Table 1.4. Licenced Abstractions on the River Dee

Abstractor	Authorised		Actual (1991)		Abstraction Points
	mgd	$m^3.sec^{-1}$	mgd	$m^3.sec^{-1}$	
Welsh Water	5.2	0.27	3.38	0.18	1
North West Water	156.0	8.21	132.4	6.97	5
Wrexham Water Co.	8.0	0.42	6.35	0.33	2
Chester Water Co.	7.5	0.40	6.23	0.33	1
British Waterways	6.2	0.33	6.2	0.33	1
TOTAL	189.9	9.63	154.56	8.14	10

River Dee Flow Duration Statistics
(Eccleston Ferry - 1977-1991)

Table 1.2

Flow exceedance for given percentage of time ($m^3 sec^{-1}$)

Tens % \ Units %	0	1	2	3	4	5	6	7	8	9
0	199.7	142.9	128.9	121.2	115.4	111.1	106.9	101.3	97	93.5
10	89.7	86	81.7	77.8	74.7	71.9	69.1	67.2	65	63
20	61.1	59.3	58	56.2	54.4	52.6	50.7	49.5	48	46.3
30	44.9	43.4	42.3	41	39.8	38.1	37.1	35.9	34.6	33.7
40	32.4	31.4	30.4	29.5	28.6	27.9	27.2	26.4	25.7	25
50	24.3	23.7	23.2	22.5	22.1	21.6	21	20.3	19.7	19.1
60	18.5	18.1	17.5	17	16.5	16	15.6	15.2	15	14.6
70	14.4	14.1	13.8	13.5	13.3	13.2	13.1	12.9	12.7	12.6
80	12.5	12.4	12.3	12.2	12.1	12	11.9	11.8	11.7	11.6
90	11.5	11.4	11.3	11.2	11.1	11	10.8	10.7	10.4	10.1

Average Daily Flow
1974-1989

Table 1.3

	Jan	Feb	Mar	April	May	June	July	August	Sept	Oct	Nov	Dec
Monthly Mean ($m^3 sec^{-1}$)	63.71	54.9	54.9	34.82	21.7	17.74	13.66	18.54	21.79	36.96	57.26	67.42
Monthly Minimum	18.07	11.35	12.54	10.12	9.69	9.71	9.33	6.8	8.07	8	10.68	10.76
($m^3 sec^{-1}$)	1985	1986	1986	1984	1977	1978	1980	1986	1977	1987	1983	1989

Fig 1.7a

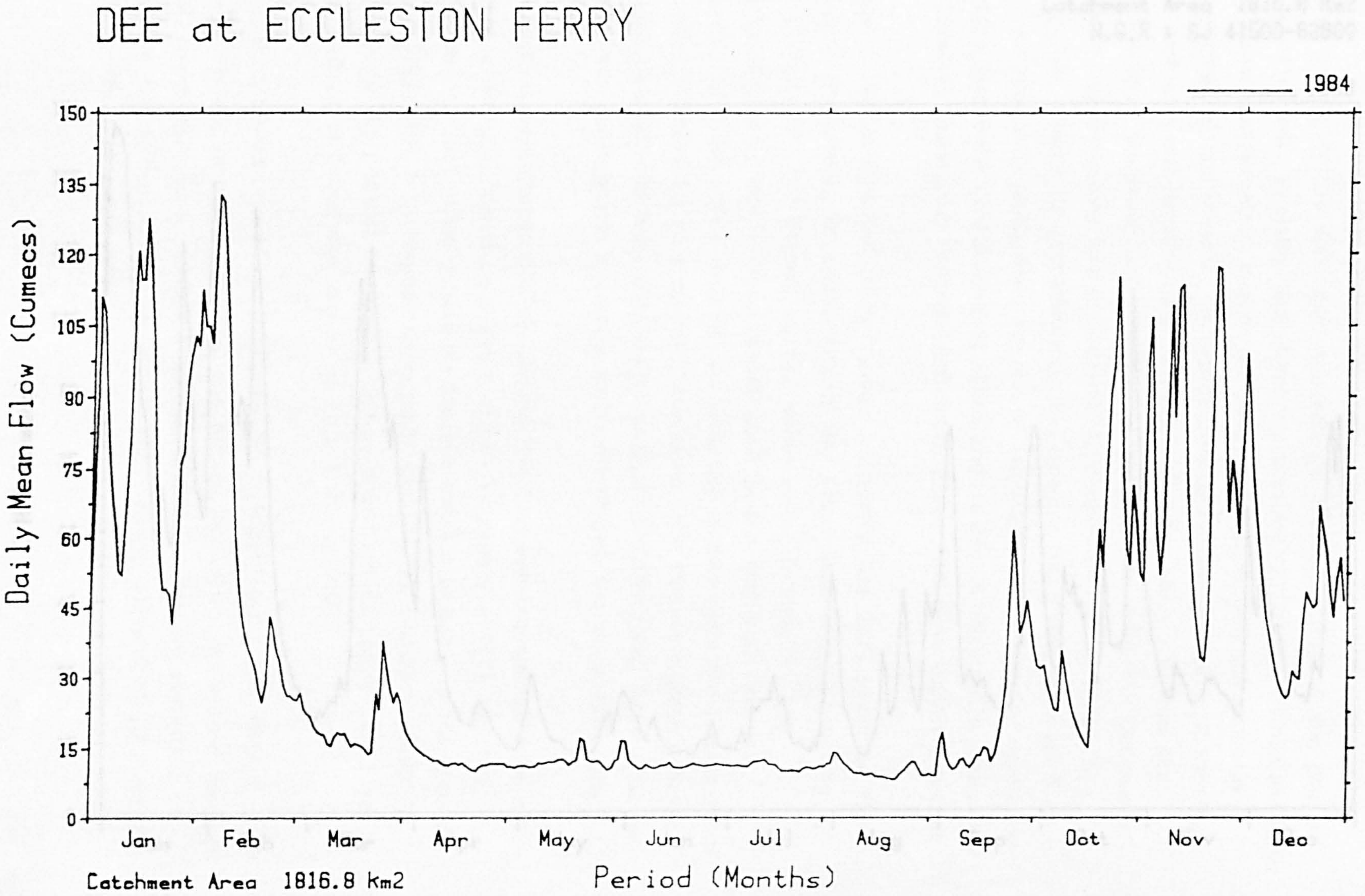
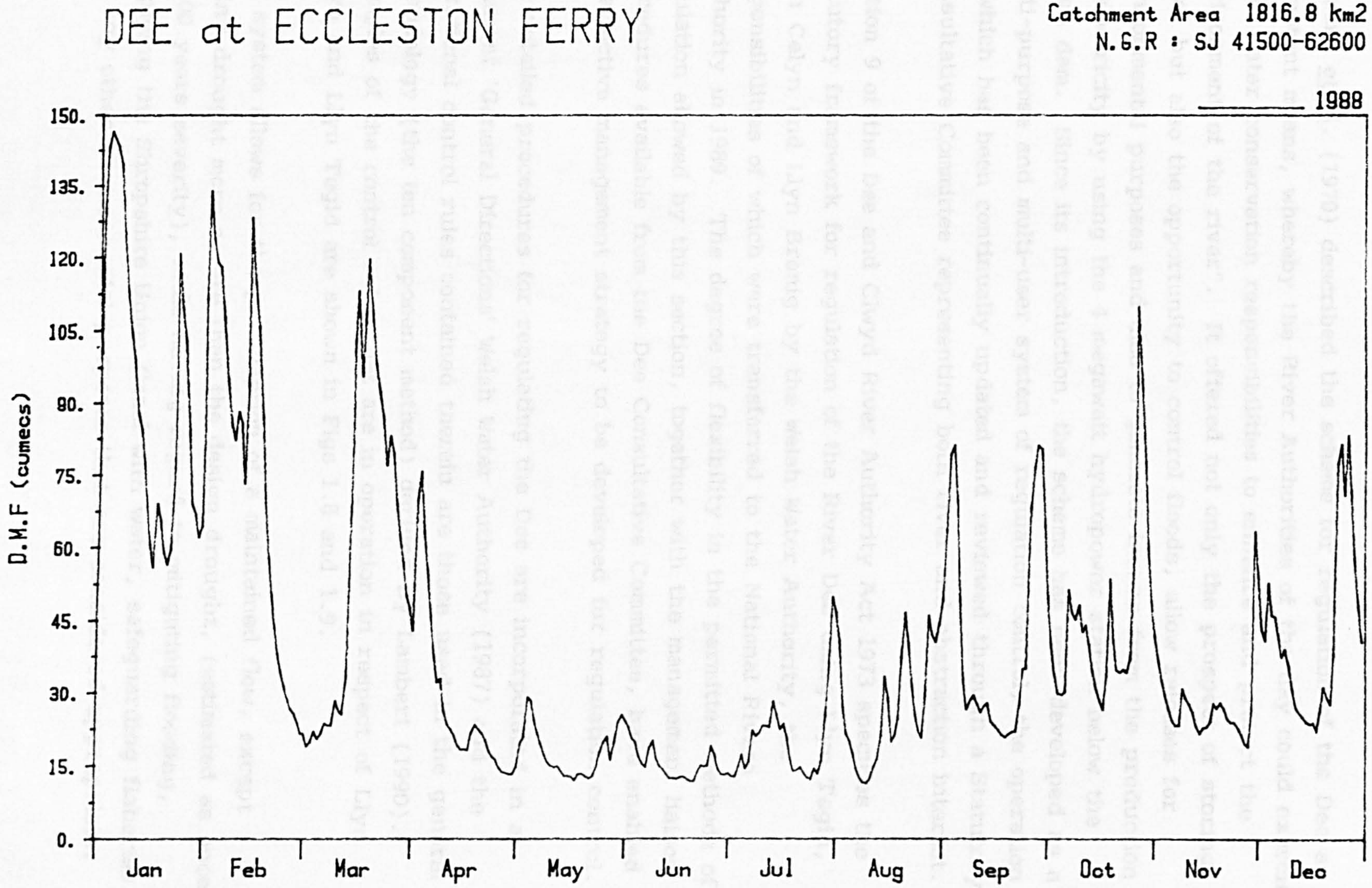

DEE at ECCLESTON FERRY
1984
Daily Mean Flow (Cumecs)
150
135
120
105
90
75
60
45
30
15
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Period (Months)
Catchment Area 1816.8 km2

Fig 1.7b


DEE at ECCLESTON FERRY
Catchment Area 1816.8 km2
N.G.R : SJ 41500-62600
1988
D.M.F (cumecs)
150.
135.
120.
105.
90.
75.
60.
45.
30.
15.
0.
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

1.5.3 Management of the System

Blezard et.al. (1970) described the scheme for regulation of the Dee as "a potent means, whereby the River Authorities of the day could exercise their water conservation responsibilities to enhance and protect the environment of the river". It offered not only the prospect of storing water but also the opportunity to control floods, allow releases for environmental purposes and also to generate income from the production of electricity by using the 4 megawatt hydropower station below the Celyn dam. Since its introduction, the scheme has been developed as a multi-purpose and multi-user system of regulation control, the operation of which has been continually updated and reviewed through a Statutory Consultative Committee representing both river and abstraction interest.

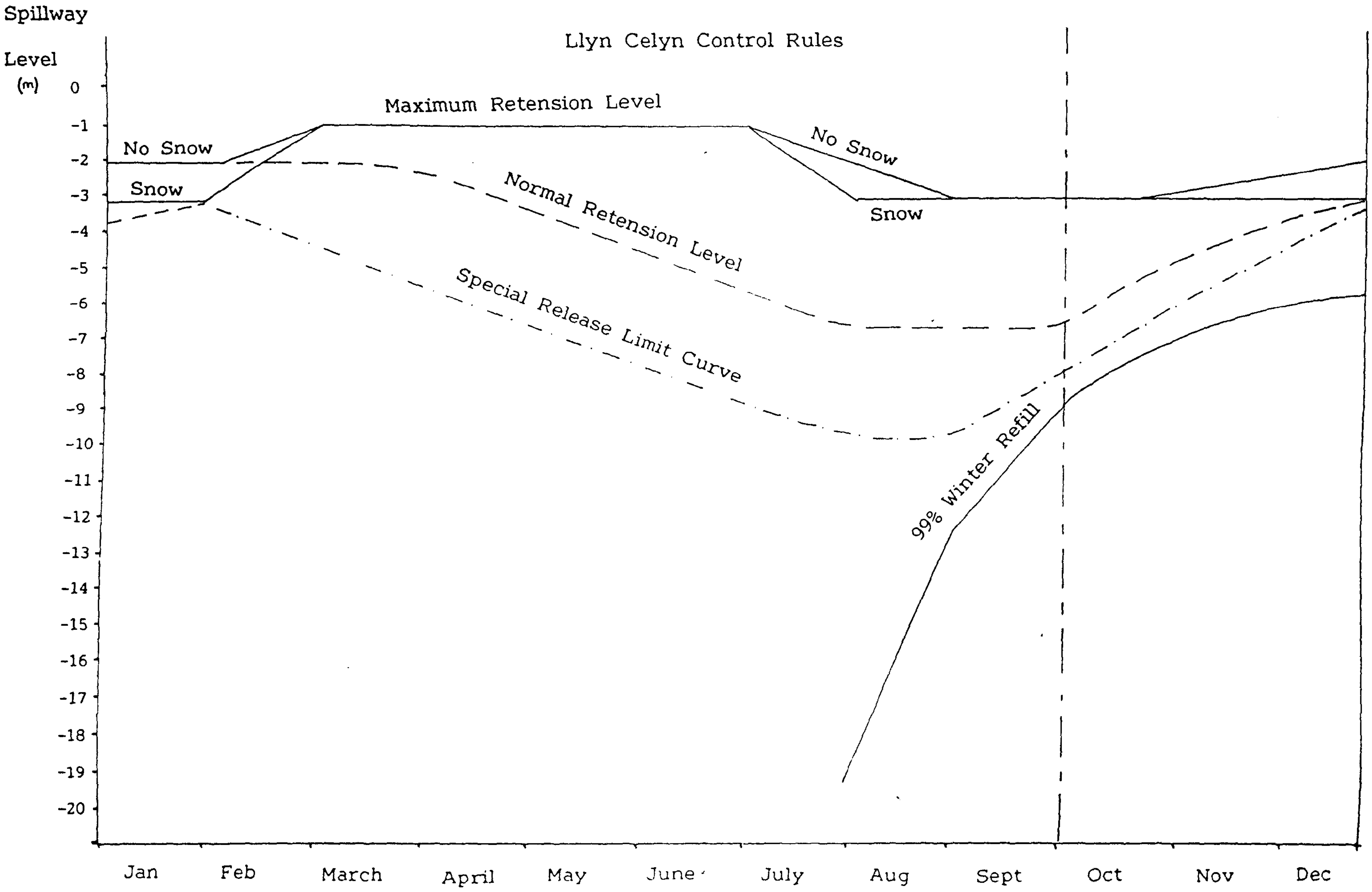
Section 9 of the Dee and Clwyd River Authority Act 1973 specifies the statutory framework for regulation of the River Dee using Llyn Tegid, Llyn Celyn and Llyn Brenig by the Welsh Water Authority, the responsibilities of which were transferred to the National Rivers Authority in 1989. The degree of flexibility in the permitted methods of regulation allowed by this section, together with the management liaison procedures available from the Dee Consultative Committee, have enabled an effective management strategy to be developed for regulation control.

The detailed procedures for regulating the Dee are incorporated in a document 'General Directions' Welsh Water Authority (1987) and the operational control rules contained therein are those used in the general methodology (the ten component method) derived by Lambert (1990). Examples of the control rules that are in operation in respect of Llyn Celyn and Llyn Tegid are shown in Figs 1.8 and 1.9.

The system allows for the prescription of a maintained flow, except during drought more severe than the design drought, (estimated as once in 100 years severity), while having regard to mitigating flooding, supplying the Shropshire Union Canal with water, safeguarding fisheries and any other environmental purposes that are considered appropriate.

Dee General Directions

Fig. 1.8.

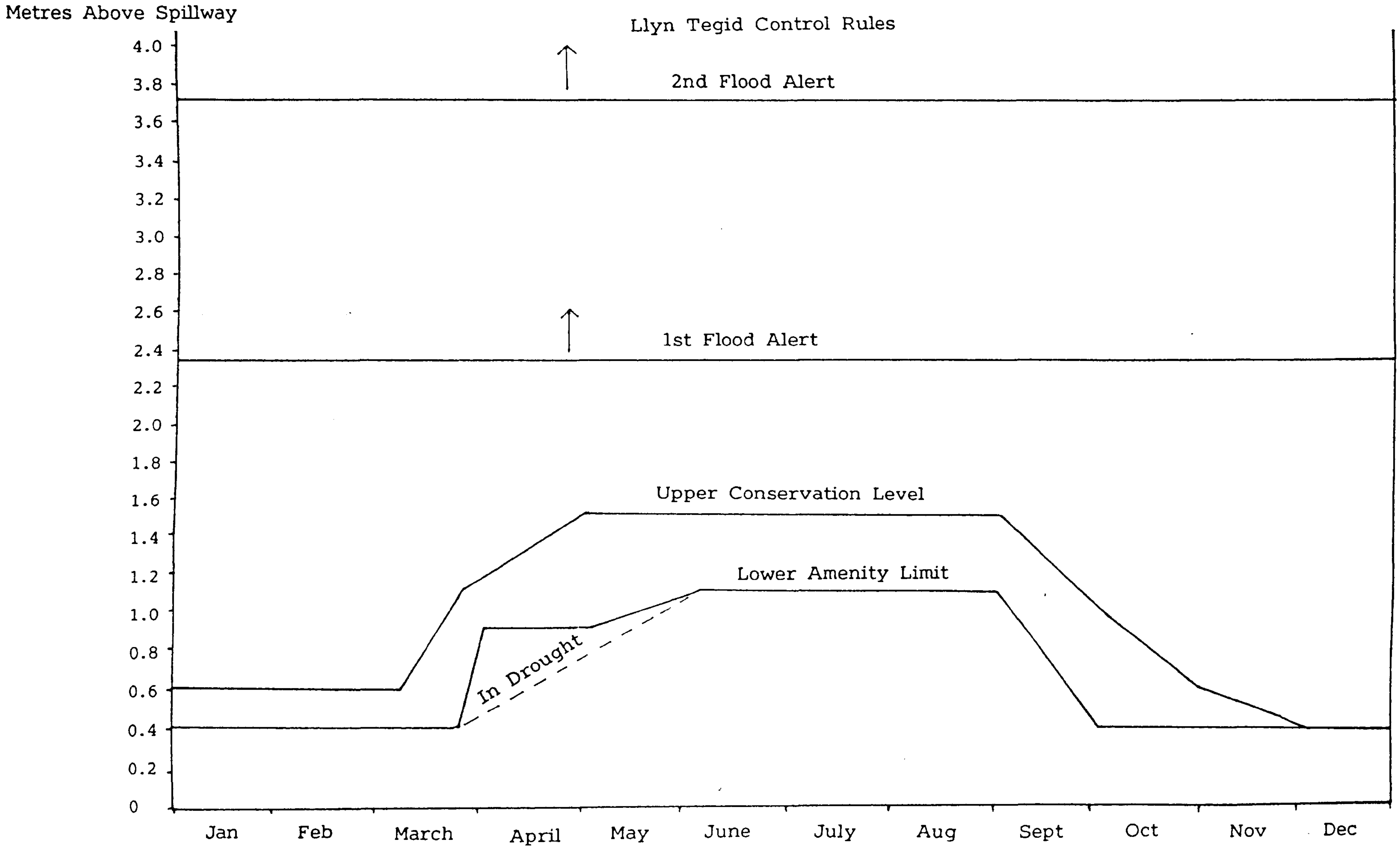


Llyn Celyn Control Rules

Fig. 1.9.

Dee General Directions

Llyn Tegid Control Rules



In brief, Llyn Celyn is the centrepiece of the system where flow regulation, flood alleviation and hydrogeneration are reconciled. Llyn Tegid has limited storage potential, but allows temporary storage of Celyn releases in the summer and some flood alleviation during the winter. Llyn Brenig, being a slow refilling reservoir, provides water in severe drought, although phased usage with Llyn Celyn maximises refilling characteristics of both reservoirs in normal rainfall years.

The current yield of the system is 14.3 $m^3.sec^{-1}$ which comprises the 9.6 $m^3.sec^{-1}$ of allocated licenced abstractions as detailed in Table 1.4, the residual flow over Chester Weir and a further 0.5 $m^3.sec^{-1}$ of unlicensed or spare yield. Chester Weir is currently the only point where a minimum flow is maintained, therefore a flow of around 14 $m^3.sec^{-1}$ has to be provided in the lower Dee to satisfy both abstraction and river flow requirements below the Huntington intake point, 6km upstream of Chester Weir. In spate this volume naturally occurs but at other times the natural flow is supplemented by regulated releases.

The Dee Regulation System encompasses a number of potential benefits in addition to those of water supply, flood mitigation and power generation. These benefits are directed towards improvement of the aquatic environment, including provision of sufficient water to enhance the upstream migration of salmonids from the tideway in times of drought.

On any river system, good water quality is of high importance for maintaining fish stocks and ecological diversity (Swales, 1980) and the ability to release water to minimise impact at times of pollution emergency is a useful aspect of the system. A special release volume of water is retained for just this purpose and on the 1st May each year a total of 119 $m^3.sec^{-1}$. for a 24hr period is specifically available for this purpose, so long as the reservoirs in the system are at top water line. This amount has been calculated as the spare yield after all designated abstractions have been accounted for and the volume of storage available will satisfy those abstractions in a one in a hundred year drought. Depending upon the time of the year and the rainfall in the catchment this amount can increase as the summer progresses. Wider use of spare water for recreation is another option which can help to develop sports such as canoeing, both on the Dee itself at Llangollen and on the River Tryweryn above Bala. The way water is used to benefit recreational pursuits can lead to conflict between sports such as canoeing and angling, so discussion and compromise are necessary requirements in the management process.

The system is, however, a flexible one and the framework of management control has been structured in a way that allows a continuing process of examination in order to achieve improvements in the light of experience. It has also accommodated changes in management responsibility, notably the privatisation of the Water Industry in 1989. The system, for the first time, had public and a private sector management involvement and although the direct control remained with the National Rivers Authority, the ownership of the reservoirs and power generation facility passed to the new water company, Welsh Water PLC. At the time of the Water Industry split a Dee Operating Agreement (NRA/WW.Plc, 1989) was produced and management control was transferred to a Dee Consultative Group which comprised 2 representatives from Welsh Water PLC and 2 from the National Rivers Authority. In undertaking their duties, the Consultative Group produced an operating manual applying the principles contained in the Dee Operating Agreement but, subject to the over-riding framework of the Dee and Clwyd River Authority Act 1973. By this means the proper and efficient operation of Alwen Reservoir, Llyn Brenig, Llyn Celyn and Llyn Tegid could continue as part of the Dee regulation scheme to protect the interests of all users.

1.5.4 Flow Conditions in the Lower River

Rainfall in the catchment varies considerably, from about 250cm/year over the mountainous regions of Snowdonia, down to around 80cm/year in the lower reaches. Severe storms in the valley cause flood flows, despite regulation control, and occasionally initiate emergency flood alerts to allow farmers to remove livestock from low-lying ground. Heavy snowfalls can also create flood conditions, but under these circumstances there is a delayed response until the thaw occurs.

Under normal summer conditions, 30-35 hours is allowed for released water to travel from the headwater reservoirs to Chester Weir. During low flow the time taken to travel along the study length, from Bangor-on-Dee to Chester (35km), almost equals the flow time from Bala to Overton-on-Dee (ie 65km). The slower flow in the study length which can be as much as 15 hours is indicative of its shallow gradient (Fig 1.3). During spates the time can be reduced to less than 5 hours, although expansion over the flood plain invariably increases the time during extreme floods.

Since the late 1960's flow conditions have been directly monitored in the lower Dee and over the past 10 years the average daily flow (ADF) over Chester Weir has been 36 $m^3.sec^{-1}$. The designed minimum summer flow at this point is 4.2 $m^3.sec^{-1}$ but, by agreement of the Dee Consultative Committee, can be allowed to fall to predicted natural dry weather flows of 2.8 $m^3.sec^{-1}$ or less in drought years. Flows in winter are much more variable but can be as much as 180 $m^3.sec^{-1}$ during severe floods. The monthly mean flows at Eccleston Ferry are given for 1990 in Fig 1.10 and although a dry summer occurred in this year, the flow conditions are still fairly typical because natural flows were enhanced to satisfy requirements for abstraction at Chester. The velocity along the study area, during a typical summer flow, is demonstrated in Fig 1.11.

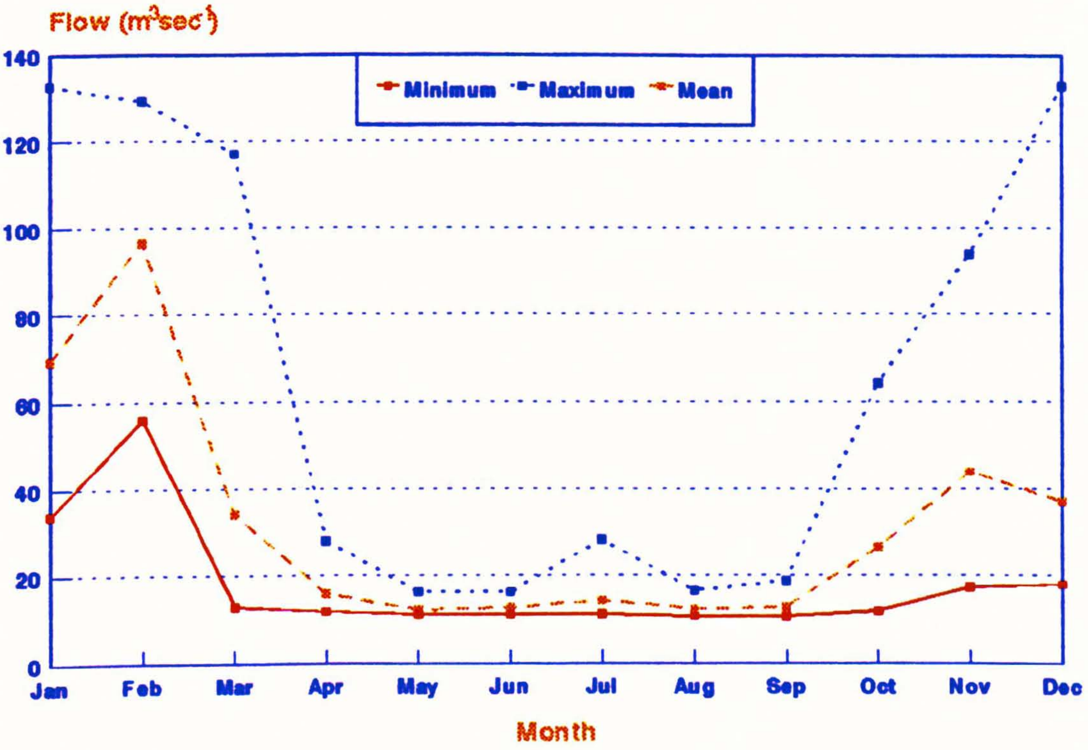
The residual flow over Chester Weir was calculated as the minimum flow that would avoid mortalities of both coarse fish and salmonids in the tideway section below the weir (Hodgson et al, 1980). This was necessary because river quality could deteriorate at times of discharge from Chester Sewage works, particularly during hot summers, low flow and small tidal sequences.

1.5.5 Tidal intrusion

Historical changes in the Dee Estuary have altered the flow regime in the Chester area. In 1737, in the tidal reach immediately below Chester, a new cut was constructed which confined a once meandering river into a straight man-made channel. This was an attempt to deepen the tidal channel and reverse the siltation of the navigable section up to the port

River Dee (Eccleston Ferry)
Monthly Flows

Fig 1.10.



1990

Current Velocity at Low Summer Flow
River Dee (Clywedog confluence-Chester Weir)

Fig. 1.11.

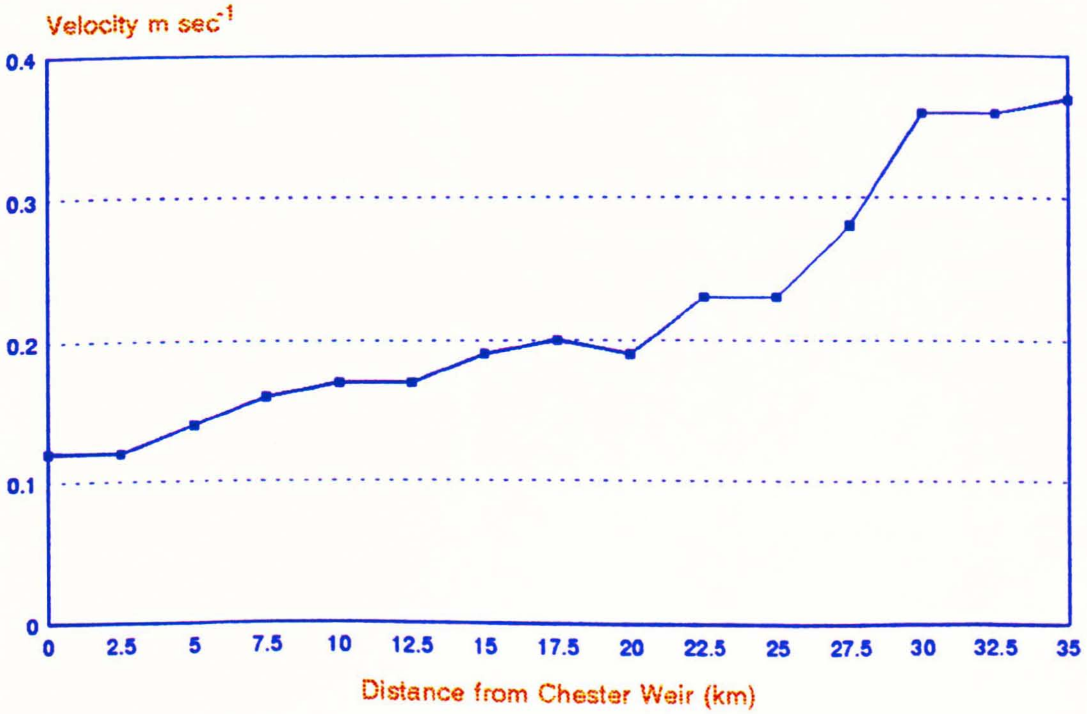


Fig. 1.12.

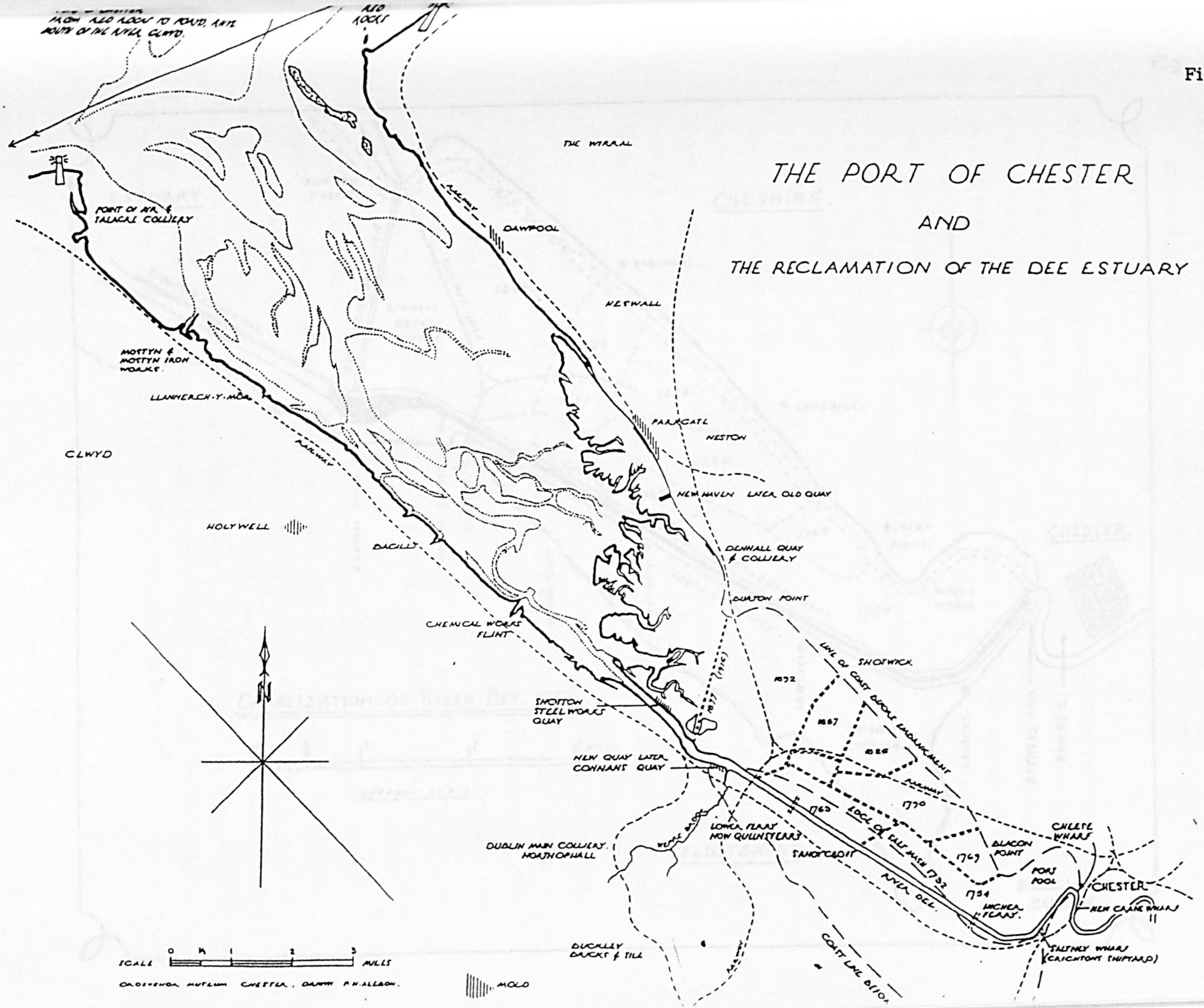
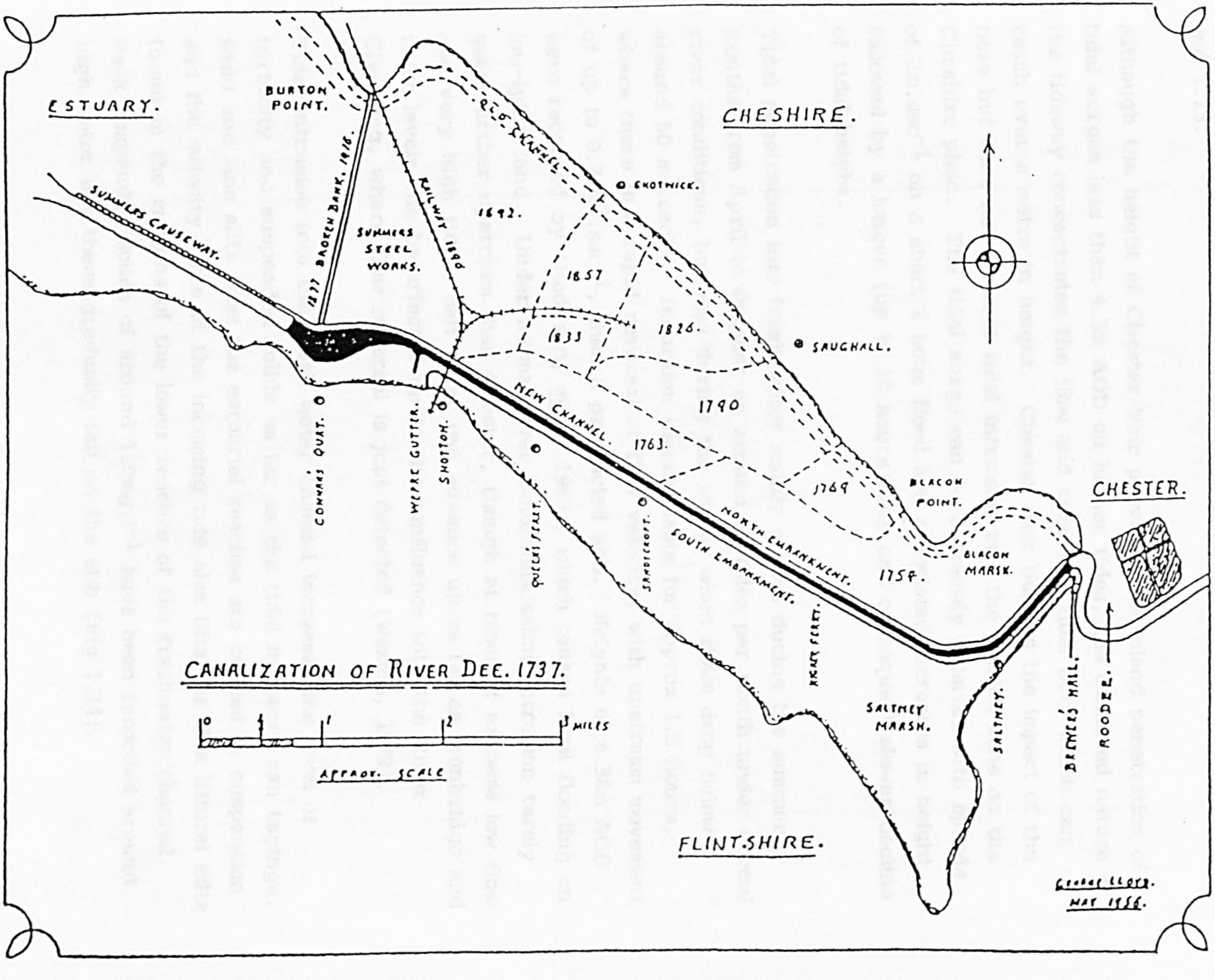

THE PORT OF CHESTER
AND
THE RECLAMATION OF THE DEE ESTUARY
FROM RED ROCKS TO POINT, ACROSS MOUTH OF THE RIVER CLWYD.
RED ROCKS
POINT OF AYR & TALACRE COLLIERY
THE WIRRAL
RAILWAY
DAWPOOL
HESWALL
MOSTYN & MOSTYN IRON WORKS.
LLANNERCH-Y-MOR
CLWYD
RAILWAY
PARKGATE
NESTON
NEW HAVEN LATER OLD QUAY
HOLYWELL
BAGILLT
DENHALL QUAY & COLLIERY
BURTON POINT
CHEMICAL WORKS FLINT
LINE OF SHOTWICK
LINE OF COAST BEFORE EMBANKMENT
1877 (1916)
1892
SHOTTON STEEL WORKS QUAY
1857
1826
NEW QUAY LATER CONNAHS QUAY
RAILWAY
1770
1763
EDGE OF SALT MARSH 1732
RIVER BROOK
LOWER FERRY NOW QUEENSFERRY
DUBLIN MAIN COLLIERY. NORTHOPHALL
SANDYCROFT
1769
BLACON POINT
CHESTER WHARF
PORT POOL
1754
RIVER DEE.
HIGHER FERRY.
CHESTER
NEW CRANE WHARF
SALTNEY WHARF (CRICHTONS SHIPYARD)
COAST LINE D110A
BUCKLEY BRICKS & TILE
RAILWAY
SCALE 0 ½ 1 2 3 MILES
GROSVENOR MUSEUM CHESTER. DRAWN P.H. ALLSOP.
MOLD

Fig. 1.13



ESTUARY.
BURTON POINT.
CHESHIRE.
SUMMERS CAUSEWAY.
1877 BROKEN BANK. 1916.
SUMMERS STEEL WORKS.
RAILWAY 1890
OLD CHANNEL
1692.
 o SHOTWICK.
1857
1833
1826.
o SAUGHALL.
1790
1763.
1769
NEW CHANNEL
NORTH EMBANKMENT.
SOUTH EMBANKMENT.
1754.
BLACON POINT.
BLACON MARSH.
CHESTER.
CONNAHS QUAY.
WEPRE GUTTER.
SHOTTON.
QUEENSFERRY.
SANDYCROFT.
KNAPS FERRY.
SALTNEY MARSH.
SALTNEY.
BRETTON'S HALL.
ROODEE.
CANALIZATION OF RIVER DEE. 1737.
0
1
2
3 MILES
APPROX. SCALE
FLINTSHIRE.
GEORGE LLOYD.
MAY 1956.

of Chester. Despite the work, the accretion of sand continued and today large ships are unable to navigate up to the city. Details on the extent of historical channel changes below Chester Weir are given in Fig 1.12 and 1.13.

Although the height of Chester Weir prevents the inland penetration of tidal surges less than 4.3m AOD on higher tides, the canalised nature of the tideway concentrates the flow and creates a tidal bore which can reach over a metre in height. Chester Weir buffers the impact of the bore but does not prevent tidal intrusion into the ponded zone on the Cheshire plain. The tidal surge can be extremely erosive, with speeds of $2m.sec^{-1}$ on a short 2 hour flood and associated increases in height, followed by a longer (up to 10 hours) ebb and consequent slower decline of tidal height.

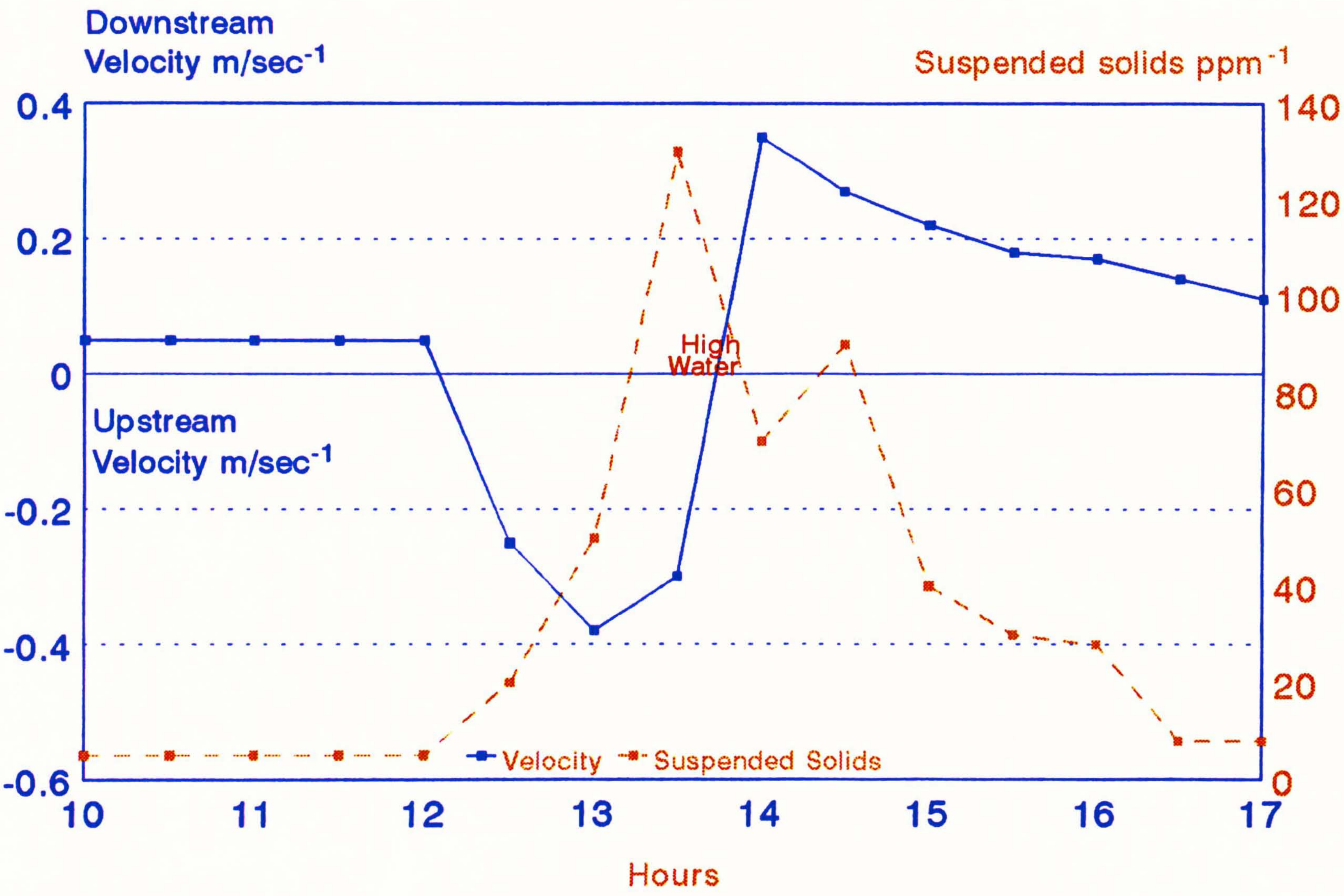
Tidal penetration into fresh water mainly occurs during the summer months from April to October on around 10 tides per month under normal river conditions, but also during the winter when flows drop below around 50 $m^3.sec^{-1}$. Incursion usually lasts for approx 1.5 hours, where there is a rapid reversal of flow velocity, with upstream movement of up to 0.7 $m^3.sec^{-1}$, then a protracted ebb. Heights of 6.38m AOD were recorded by (Hodgson, et.al. 1980), which caused local flooding on low-lying land. Under normal river conditions saline intrusion rarely goes further upstream than Chester, though at times of extreme low flow and very high tides, salt water can advance up as far as Ironbridge and river levels can be affected up to the confluence with the River Clywedog, where flow reversal is just detected (Weston, 1979).

Tidal intrusion into the fresh water channel increases the level of turbidity and suspended solids as far as the tidal influence can impinge. Sand and fine silts from the estuarial reaches are carried in suspension and the velocity force of the incoming tide also lifts the fine littoral silts found in the margins of the lower reaches of the freshwater channel. Peak suspended solids of around $120mg.l^{-1}$ have been recorded around high water but these gradually fall on the ebb (Fig 1.14).

River Dee - Spring Tide Effects

Caldy,Chester

Fig 1.14.



10.1 metre tide

Electrical conductivity levels also vary according to the concentrations of salt that enter the river from the estuary on the tide. Weston (1979) determined that the greater viscosity of salt water meant that it followed the bed of the river until the resistance from the freshwater prevented it from progressing further. Peak chloride levels, above Chester Weir, can be in excess of 3000 mg.l^{-1} and evidence from (Hodgson et.al. 1980) indicated that when such levels are reached the salinity at Chester Weir does not disappear between successive tides.

During periods of extreme drought, when special conditions are advanced by the Dee Consultative Committee, pulsed releases are made from the headwater reservoirs to reduce penetration of the tides at Chester Weir, to protect potable water abstraction points, close to Chester, from salt contamination.

Although the tidal effects are relatively short, their impact on river ecology should not be overlooked, as not only does the current velocity and salinity change but also the turbidity and residual sedimentation on vegetation can attenuate light long after the tidal episode (Hodgson, et.al. 1980).

1.6 Water Chemistry

The physico-chemical characteristics of the catchment are strongly determined by catchment geology, rainfall, flow regime and rate of run-off. The Dee has a fairly typical pattern of increasing downstream ionic and nutrient loading, as the river progresses from its source in the largely unproductive mountainous region of Snowdonia (North, 1988). Table 1.5 shows a typical chemical analyses of the water quality at four points of the river.

A general assessment of the water quality is that it is wholesome and supplies reliable drinking water for people residing in the catchment and also to many thousands of households in Cheshire, Merseyside and South Lancashire. Supporting evidence of its good quality lies in its standard of recreational fishery, being predominantly salmonid from the headwaters down to the Cheshire plain.

Table 1.5

Typical Water Analysis of the River Dee at Four Locations

Parameter	Glyndyfrdwy	Erbistock	Ironbridge	Shotton
Colour (Hazen Units)	18	17	18	20
Turbidity (As Fullers Earth)	21	27	53	92
Conductivity (mmhos/cm)	83.3	183.2	308	469
pH	6.9	7.2	7.4	7.4
Temperature %C	9.9	10.1	10.3	10.4
Dissolved Oxygen	11.3	11.2	10.3	9.6
Dissolved Oxygen (%Sat)	101	101	93	87
BOD	1	1.2	1.7	3.9
Permangenate Value	3.8	4	4.4	6.1
COD	10.2	9.1	11.7	14.4
Nitrogen (NH)	0.05	0.09	0.23	0.58
" (NO)	0.004	0.014	0.029	0.041
" (Tot)	0.5	0.9	1.4	1.5
Chloride	11	21	30	66
Solids (Dissolved)	58	114	184	280
" (Suspended)	7	10	19	42
Hardness (Total)	23	44	89	113
" (Calcium)	16	34	68	76
" (Magnesium)	6	11	21	36
Alkalinity	16	30	60	71
Sulphates	7	21	36	45
Phenols	<0.002	<0.002	<0.002	0.03
Silicates	2.6	3	3.8	3.9
Phosphates (Total)	0.16	0.27	0.52	0.72
" (Ortho)	0.05	0.14	0.34	0.49
Iron (Total)	0.49	0.56	0.89	0.96
" (Soluble)	0.23	0.22	0.24	0.23
Manganese (Total)	0.05	0.04	0.08	0.13
" (Soluble)	0.03	0.02	0.04	0.05

Expressed as mg/l^{-1} unless otherwise stated.

The river water for the most part lacks obvious colour but at times has a brown tinge up to 125 hazen units. The principal colouring matter is dissolved organic matter from the peaty headwater areas.

The natural taste of river water has been described as musty and rather earthy, which is possibly related to the peaty nature of the upland catchment and geosmin production by actinomycetes levels which accumulates as the river crosses the Cheshire plain.

The Dee drains from a slightly acidic catchment but does not possess the same acidification problems as neighbouring rivers to the west, which also drain the Snowdonia range (Milner and Jones, 1985). Only parts of the Tryweryn and Alwen catchment, together with a few tributaries entering Llyn Tegid, have the potential to produce discharges with the environmentally damaging combinations of high acidity and high aluminium with low buffering capacity (Heller, 1992). These extreme conditions are infrequent but any harmful effects are satisfactorily diluted well before they enter the main Dee (Cane, 1974 and Woolland, 1972). They do however create problems in the headwater tributaries (N.R.A. Juvenile Salmonid Report, 1991) and consequently some of these fisheries are suffering locally in a comparable way to those larger waterbodies where serious acidification problems have developed eg, Llyn Brianne (Edwards et.al., 1990).

For much of the year, pH in the main river remains relatively constant within the range 6.5-7.5 and only falls to a lower level after periods of heavy snowfall in the catchment.

Problems from groundwater sources have been encountered in the middle reaches of the Dee where dissolved iron from old tips and mine workings discharged to the river via Trefnant Brook near Newbridge (Water Research Centre, 1979). This caused an avoidance reaction in salmonids which resulted in decreased catches from the local fishery. Steps were taken to alleviate the problem by oxygenating the mine discharge to bring the iron out of solution quickly. This reduced the problem, but the case highlighted the potential threat of leachates from similar historical tipping grounds that could affect the quality of the river.

Although the Dee is an upland river of generally low productivity (Weatherley, 1985), it is naturally well oxygenated throughout its length and the permanantly regulated flow ensures that there is little variation from this condition. Only some of the lowland tributaries and canalised sections of the tideway experience periodic low dissolved oxygen levels that can threaten fish life. Such situations really only occur during a periods of very warm weather in mid summer (Hodgson, et.al., 1980). Oxygen concentrations vary between 5-12 $mg.l^{-1}$ and usually are in excess of 90% although, in the tideway and occasionally at Chester, supersaturation can develop in warm weather, when algal activity increases as a result of nutrient enrichment by phosphates released in the effluent from Chester Sewage Works (Mills, 1980).

Suspended solids are generally low (< 20 $mg.l^{-1}$) in the mid and upper river, apart from times of flood run-off when they can exceed $200 mg.l^{-1}$. In the lower river there are other factors, such as tidal intrusion and disturbance of marginal substrates by recreational traffic, that can cause further variations and these will be examined in more detail with respect to their effects on the aquatic environment.

1.7 Water Quality Control

1.7.1 River Protection

The National Rivers Authority has a statutory obligation to monitor the quality of river water and discharges made to rivers throughout its area of jurisdiction (Water Act, 1989).

On the Dee, an active programme of routine sampling is undertaken with respect to river water, which include outfalls from sewage works, industrial premises, waste disposal sites and any other discharge that is likely to be made to any stream or river.

In order to make a discharge to a watercourse, a formal consent of the National Rivers Authority is required and if ignored can lead to legal proceedings under the Control of Pollution Act 1974 or the Environmental Protection Act 1991. When a consent to discharge is issued under the above Acts, certain conditions are imposed, both on the volume and the quality of the discharge, to ensure that it does not have a detrimental effect upon the receiving watercourse. If the discharge falls outside the consent conditions laid down, then an offence is committed and again legal action can be taken against the discharger. Penalties for illegal discharges to the Dee, because of its importance to water supply, have been up to £7000.

A register of all discharge consents is held by the National Rivers Authority and under defined procedures public access to this information is available. This measure has been introduced to ensure an openness to the general public, of the procedures adopted to protect water bodies. Under the former Water Authorities there was a vested interest in maintaining confidentiality, as in some cases the Authorities themselves were the polluters and therefore the system was subject to public criticism.

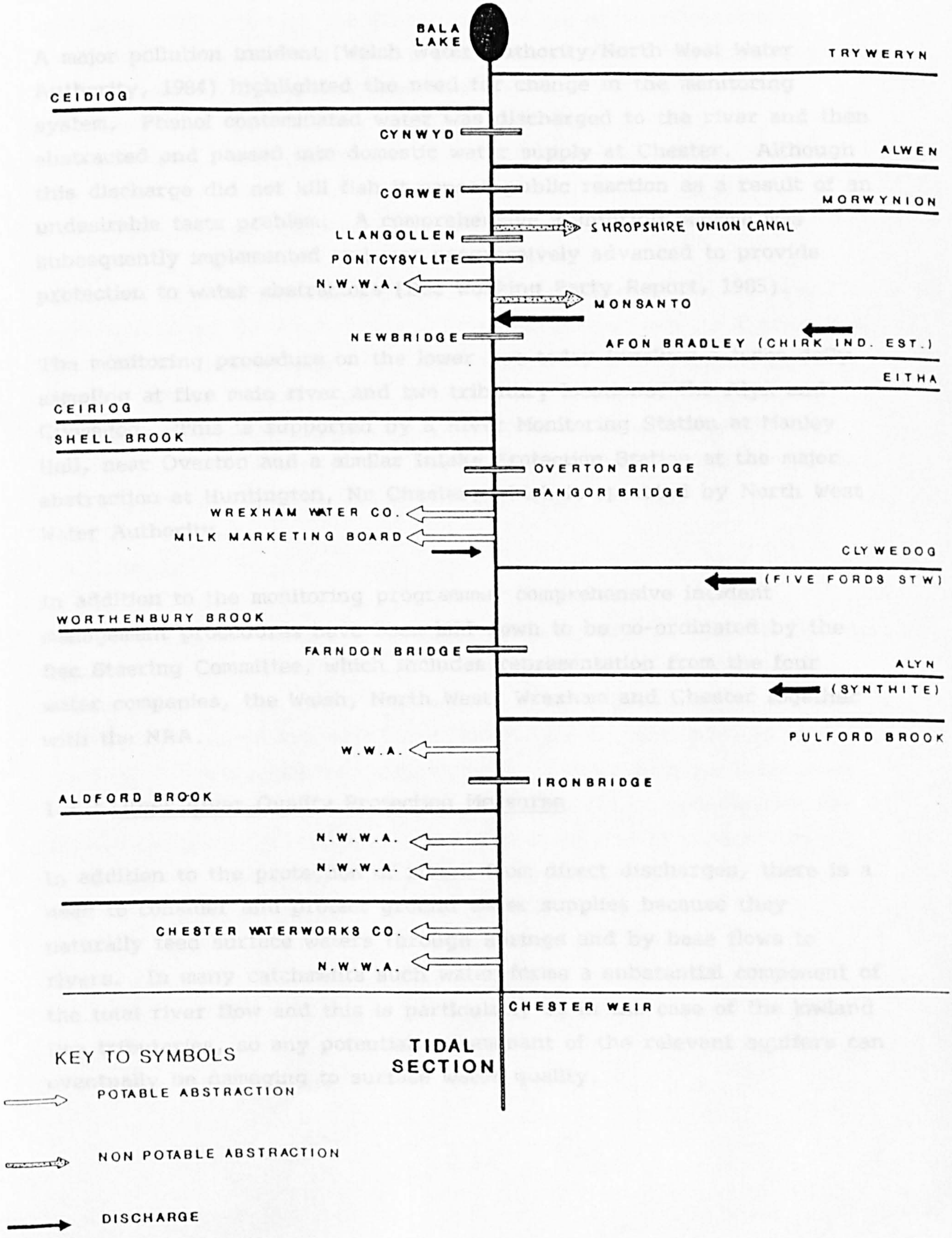
In addition to the standards imposed on discharges, the River Authority also designates major rivers into various classes namely 1A, 1B, 2, 3 and 4 which range from very clean in 1A to highly polluted in Class 4. (National Rivers Authority, 1991). The objective of the Authority is to improve water quality in all major rivers to Class 2 or better.

The River Dee is classified as 1A from its source above Bala down to its confluence with the River Clywedog near Wrexham. Downstream of this point it falls to a Class 1B but this is still considered a very high quality which commands conditions suitable for a salmonid fishery. The principal reason for the change below this point is the variable quality of some of the tributaries that drain the Cheshire Plain. These rivers include the Alyn, Class 2; Clywedog, Class 3; Worthenbury Brook, Class 3; Pulford Brook, Class 3 and Aldford Brook, Class 3.

Although the Dee is classified as of good quality, it is still unavoidably subject to occasional pollution incidents within the catchment, from agricultural activities, sewage effluent or industrial discharges (Fig 1.15). The industrial developments at Ruabon, Chirk, Wrexham and Mold have historically been the source of the most serious problems associated

Fig. 1.15.

Main Tributaries, Abstractions and Discharges along the River Dee
(Bala Lake to Chester Weir)



with poorer quality effluents or actual acute pollution discharges. It is for this reason, and the inherent risks to the water supply system, that stricter monitoring procedures have been adopted (Westwood, 1985 and Welsh Water Authority, 1985).

A major pollution incident (Welsh Water Authority/North West Water Authority, 1984) highlighted the need for change in the monitoring system. Phenol contaminated water was discharged to the river and then abstracted and passed into domestic water supply at Chester. Although this discharge did not kill fish it caused public reaction as a result of an undesirable taste problem. A comprehensive monitoring scheme was subsequently implemented and was progressively advanced to provide protection to water abstractors (Dee Working Party Report, 1985).

The monitoring procedure on the lower Dee today involves a twice daily sampling at five main river and two tributary locations, the Alyn and Clywedog. This is supported by a River Monitoring Station at Manley Hall, near Overton and a similar Intake Protection Station at the major abstraction at Huntington, Nr Chester, which is operated by North West Water Authority.

In addition to the monitoring programme, comprehensive incident management procedures have been laid down to be co-ordinated by the Dee Steering Committee, which includes representation from the four water companies, the Welsh, North West, Wrexham and Chester together with the NRA.

1.7.2 Other River Quality Protection Measures

In addition to the protection of rivers from direct discharges, there is a need to consider and protect ground water supplies because they naturally feed surface waters through springs and by base flows to rivers. In many catchments such water forms a substantial component of the total river flow and this is particularly so in the case of the lowland Dee tributaries, so any potential contaminant of the relevant aquifers can eventually be damaging to surface water quality.

The National Rivers Authority under the provisions of the Water Act 1989 (Section 3) is advancing a proposal to introduce an exclusion zone along the River Dee, to prohibit or restrict the storage of materials that could pose a threat to water supplies and this would include both groundwater and river water. Under the scheme all storage of listed substances would need to be consented and proper safety precautions would need to be set in place. Already a register of premises storing potentially hazardous chemicals has been compiled, which would assist the implementation of any procedures under this proposal.

1.8 Vegetation and its Distribution

A diverse flora encompassing a wide variety of species (See Chapter 5), is present along the study length of the lower river and the distribution and species found is dictated by the range of habitats that are present (Haslam, 1978). Taxonomically the flora encompasses algae, mosses, vascular cryptograms (fern) and larger numbers of monocotyledons and dicotyledons, the latter two in almost equal proportions which is typical in lowland rivers like the Dee (Haslam, 1982).

1.9 Summary

The River Dee is managed as a multipurpose facility, but principally, the changes that have taken place in recent years have been directed at developing and protecting it as a water supply source and, to minimize its impact on human settlement and farming by the alleviation of flooding. Concern, however, had been expressed by anglers that the lower river had deteriorated as a coarse fishery and therefore an investigation was advanced to establish the extent of the problem and to suggest ways improvements could possibly be achieved.

Chapter 2 The Coarse Fishery of the Lower Dee

2.1 Introduction

The Welsh Dee is better known for its salmonid rather than its coarse fishery (Grimble, 1913), as it supports good populations of salmon *Salmo salar* (L.), sea trout *Salmo trutta* (L.) and brown trout *Salmo trutta fario* (L.). In Wales, management attention and expenditure has mainly been directed to further the interests of the salmonid resource, with high expenditure particularly directed to the control of illegal exploitation. There are over 70 rivers in the principality extending in total length to around 5700km, the majority of which are solely salmonid fisheries.

The coarse fishery of the Dee is important however, because it is one of very few rivers in Wales where competition angling of coarse fish can take place and as the majority of anglers in the British Isles are coarse fishermen (55% or 1.9 million), (NOP, 1980) demand is high for this type of angling. As the river has a most picturesque setting, particularly in the historic city of Chester, it also attracts large numbers of tourist anglers as well as the regular fishermen, especially during the summer months. The main fishing area extends from Overton-on-Dee to Chester.

Methods of fish population monitoring in watercourses can be problematical. Hodgson (1974) satisfactorily applied electrofishing techniques to sample fish for population estimates on the Leeds/Liverpool canal while Ayton (1976) used creel census on a Midlands canal.

There have been a number of studies undertaken on the ecology and biology of adult fish populations on lowland rivers. Age, growth and diet have been investigated by Hartley (1947); Cragg-Hine (1964); Hellawell (1969), and Mann (1973,1974). In particular Sillah (1981) has looked at older dace and Hellawell (1972) at roach. In respect of assessing population densities, including production estimates, notable studies include those of Williams (1965); Mann (1967,1971 and 1975); Matthews (1971); Wilkinson (1974); Hunt and Jones (1974a, 1974b and 1975); Starkie (1976) and Hickley and Bailey (1982).

The Dee is a large river and despite its importance for angling, little attention has been directed to its coarse fish population size and structure in the lower reaches. O'Hara (1976) and Johnson (1981) examined the age and growth relationships for certain fish species in the river, although they concentrated on the population changes and movements associated with the estuarial areas. Barnabus (1971) also examined aspects of feeding relationships of adult coarse fish and Wilkinson (1974) investigated the fish colonisation of some lowland tributaries.

To establish fish population information on a large river system, methods of sampling for adult fish are often more problematical because of difficulties of application. Many techniques, such as electrofishing, seine and gill netting and angler census, have been variously attempted but none totally satisfy the requirements for assessing all aspects of fish populations structure, size, distribution and seasonal variation (Kell, 1991). Various workers (Axford, 1979; North, 1980; Cooper and Wheatley, 1981) and more recently Cowx, Fisher and Broughton (1986), Cowx (1990 and 1991) and North and Hickley (1989) have attempted to overcome the difficulties of sampling in large river systems by utilising anglers' catches as a means of fish population assessment. They have indicated that the sample obtained is more representative of fish population size in a river system than other more direct and selective methods, such as netting.

In the study area, the flow is typically slow with a deep and wide channel having a steep profile towards the banks which make it difficult to sample by netting techniques. On account of the problems outlined, in the present study a programme of monitoring anglers catches was used in co-operation with the local angling associations. Fish acquired from these events were used to assess species presence and in respect of roach and dace, growth rates, year class strengths and, by a system of tagging, movements patterns within the study area.

2.2 Methods

2.2.1 Coarse Fish of the River Dee

i) Species present

During the course of the study a listing of the different species was undertaken from a number of different sources which included direct sampling from the study area, anglers catches and angling match reports in local newspapers. This was compared with historical records from the Dee and Clwyd Fisheries Reports (1950-91) and species records detailed in earlier fisheries research studies on the river. These included O'Hara (1976) and Johnson (1981) from the lower river and tideway, Barnabus (1971) and Pearce (1983b) from the lower Dee from Farndon to Chester, Wilkinson (1974) from some of the tributaries of the Cheshire plain and Woolland (1972) who sampled the higher reaches between Bala and Llangollen.

ii) Restocking of Coarse Fish

An historical compilation of stocked species was made by abstracting information from the Dee and Clwyd Fisheries Reports (1950-91) and also in more detail from the stocking consent register held by the National Rivers Authority which is a record of all authorised fish introduction to the area of jurisdiction. This is a statutory procedure under Section 30 of the Salmon and Freshwater Fisheries Act, 1975.

2.2.2 Size and Distribution of the Roach and Dace Population

Investigations were undertaken to establish the composition of the adult population of roach and dace and their movements within the study area, by using anglers catches during competition events.

i) Roach and Dace Population from Anglers' Catches

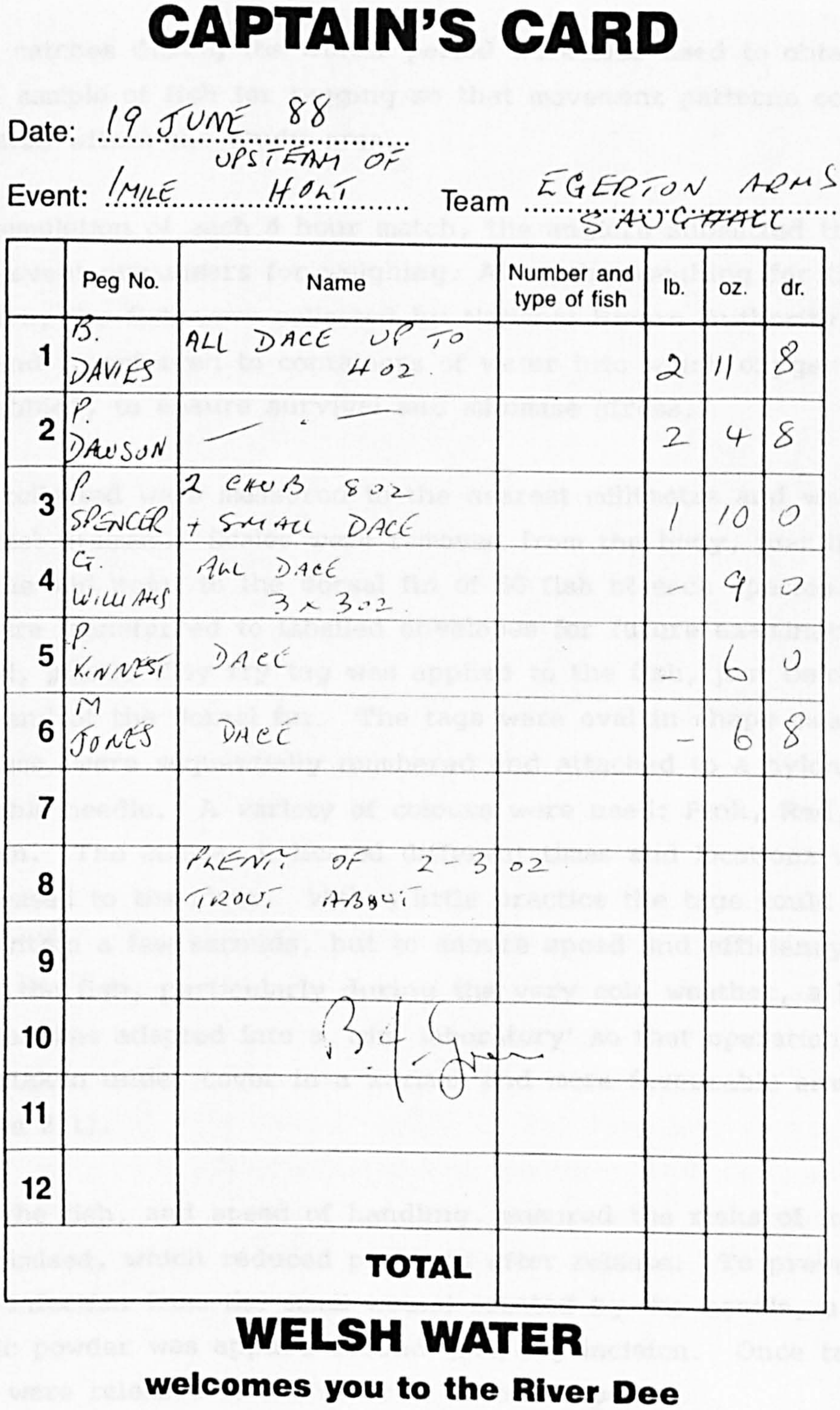
As there were two main areas for match angling at Farndon and Chester, a programme was advanced that took account of the catches made in these two locations. Catch return cards (Fig 2.1), similar to those used by Cowx and Broughton (1986) on the Trent, were disseminated to the secretaries of angling clubs and other bodies which controlled the seasonal match programme on the Dee. The census established the number of anglers fishing in events and also the top three catch weights made. Initially, it was considered that the total match weight in the competition would be more suitable to acquire and would enable comparisons with other river systems, but as this was difficult to obtain and also the individual match weights were quite small and frequently the poorer catches not declared, it was considered that more consistent representation was established from the top weight figures. This also allowed the data from local press reports, which covered more fishing matches than were submitted, to be amalgamated with information acquired from the club secretaries. This allowed a larger sample to be compiled.

The Chester Chronicle produces weekly reports on angling matches, which are conveniently separated into the two main fishing locations selected ie. Farndon and Chester. They include the individual top three weights for each named match. The data were extracted from the weekly paper which was stored on microfilm at the Chester Reference Library.

From fish acquired in selected supervised angling competitions the species distribution and the size structure of the fish caught by anglers was determined for the two fishing locations.

A Mann-Whitney test was applied to the data and comparisons were made between catches recorded at Farndon and those made at Chester. This included comparisons between seasons and also periods within each season between the two locations. The four seasons sampled extended from June to March in 1988/89 to 1991/92 and the periods examined in each year were June-September; October-December and January-March. These were separated because of the perceived changes that occurred in fish

Fig. 2.1.



CAPTAIN'S CARD

Date: 19 JUNE 88

Event: 1MILE UPSTEAM OF HOLT

Team EGERTON ARMS SAUGHALL

	Peg No.	Name	Number and type of fish	lb.	oz.	dr.
1	B. DAVIES	ALL DACE UP TO 4 OZ		2	11	8
2	P. DAWSON	—		2	4	8
3	P. SPENCER	2 CHUB 8 OZ + SMALL DACE		1	10	0
4	G. WILLIAMS	ALL DACE 3 x 3 OZ			9	0
5	P. KINNEST	DACE		–	6	0
6	M JONES	DACE		–	6	8
7						
8		PLENTY OF 2-3 OZ TROUT ABOUT				
9						
10						
11						
12						
		TOTAL				

WELSH WATER

welcomes you to the River Dee

movement at different times of the year. Comparisons were also made of catches taken in respective season periods at Chester and separately at Farndon.

ii) <u>Movements of Roach and Dace</u>

Anglers' catches during the winter period were also used to obtain the required sample of fish for tagging so that movement patterns could be investigated within the study area.

At the completion of each 4 hour match, the anglers submitted their catch to event organisers for weighing. After the weighing for the competition, the fish were collected by National Rivers Authority water bailiffs and transferred to containers of water into which oxygen was being bubbled, to ensure survival and minimise stress.

All fish collected were measured to the nearest millimetre and weighed to the nearest gramme. Scales were removed from the body, just below and behind the mid point to the dorsal fin of 50 fish of each species. These scales were transferred to labelled envelopes for future examination. A numbered, plastic Floy fry tag was applied to the fish, just below the forward end of the dorsal fin. The tags were oval in shape measuring 5mm X 3mm, were sequentially numbered and attached to a nylon tie with a removable needle. A variety of colours were used: Pink, Red, Blue and Green. The colours indicated different times and locations when fish were released to the river. With a little practice the tags could be applied within a few seconds, but to ensure speed and efficiency of handling the fish, particularly during the very cold weather, a horse box trailer was adapted into a 'mini laboratory' so that operations could be undertaken under cover in a warmer and more favourable environment (See Plate 2.1).

Care of the fish, and speed of handling, ensured the risks of injury were minimised, which reduced problems after release. To prevent the risks of infection from the small wound created by the needle, a little antiseptic powder was applied around each tag incision. Once tagged, the fish were released to the river at recorded points.

'Portable Laboratory' for sampling fish. Plate 2.1

The length of river that was used in the study, extended from Bangor-on-Dee to Chester and fish collections took place at Farndon and Chester. The main collection period was during the winter league competition programme, from October to March and was undertaken between October 1988 and March 1990. It was necessary to sample additional matches at Chester because it was more difficult to obtain sufficient fish at this location compared to Farndon. A number of extra mid week angling events were included in an effort to increase the number of roach available for tagging.

In order for the scheme to be succesful the co-operation of the anglers was necessary. Experience on the Thames by Butterworth (Pers comm), had indicated that obtaining reliable data from anglers on a regular basis was difficult to achieve and therefore considerable effort had to be directed to the public relations approach to ensure an adequate return.

This was accomplished by a variety of methods:

i) the scheme was promoted in the local and national angling press,

ii) presentations were given to angling associations which outlined the overall programme of work and the tagging scheme itself,

iii) literature describing the scheme was distributed on the river bank and at local tackle shops,

iv) local tackle shops were used as collection points for the tag returns from the anglers,

v) angling match attendance was undertaken on a regular basis and frequent bailiff patrols were arranged to encourage the submission of tags,

vi) a reward scheme and prize draw was introduced for tag returns.

The reward scheme involved a payment of £1 for each tag return and although this initially stimulated interest there was still complacency amongst some anglers and a positive reluctance with others to make returns. This necessitated continued publicity, liaison with anglers and also a further annual prize draw, which was sponsored by the National Rivers Authority, where a £100 worth of cash prizes were awarded.

iii) Fish Population of the River Clywedog

In addition to the anglers catches, a major fish kill on the Clywedog in November 1990 enabled the population structure to be accurately assessed for the lower 8km of this tributary.

2.2.3 Age and Growth Structure of Roach and Dace

The study of growth rings on the scales of a fish has long been used as a means of determining age, as well as being a measure of growth development between successive years. Comparisons between a single habitat or between a range of different habitats can be achieved, so giving a clearer understanding of the status of the fishery and thereby allowing application of management techniques for improvement as required.

Workers who have investigated the growth and age determination include Hartley (1947), Hellawell (1969), Cragg-Hine and Jones (1969) and Mann (1967,1971). All these workers have used the premise that fish scale checks or annulli are a result of annual growth of a species, from which the age of the fish can be accurately determined.

Fish scales cannot be used to determine the age of all fish species however, because in some cases annular ring formation can be inaccurate. For instance in perch Perca fluviatilis (L.) and pike Esox lucius (L.), the annular rings can be indistinct or even missing and therefore the scales can be, at best misleading or, at worst inaccurate (Segerstrale, 1933).

Where there are problems of scale age accuracy, an alternative method which can give more reliable results is the technique that uses the measurement of otolith growth. Otoliths, which are calcareaus structures found in the head of the fish, are made up of an opaque material which is laid down in the spring, summer and early autumn and a further hyaline layer is deposited in the winter. These two materials produce distinct rings which represent annual growth and which can be seen under ordinary light. With extrapolation, calculations of earlier years growth can be established. Blacker (1974) and Williams and Bedford (1974) variously describe the technique of using otoliths in the age determination of fish.

The practice of back calculation of scales or otiliths to assess the growth history of fish, has been well documented in the past and workers such as LeCren (1947), Frost and Kipling (1959), Penaz and Tesch (1970) and Mann (1973) contributed to its interpretation and advancement as a measurement in fisheries biology.

The procedure depends upon the principle that successive annual checks or annulli are laid down on the scales and these bear a relationship to the growth of the fish and more particularly to the growth in length of the fish. The method extends the more direct relationship of observed length with respective ages of fish, by allowing an examination of the growth history from time periods laid down.

Ricker (1958) and Gulland (1964) have expanded the methodology by fitting mathematical models or growth curves to data and established patterns of growth, or determined factors that actually influence growth. The best known growth model used in fisheries was that advanced by von Bertalanffy (1938), who based his assessments on physiological considerations. Methods of fitting observations have been variously described by Beverton and Holt (1957), Ricker (1958), Gulland (1964) and Allen (1966).

In this study only scales were used for age determination for two reasons:

i) in the case of both roach and dace, the detection of annual banding gave an accurate assessment of growth rate,

ii) all fish needed to be returned alive, this being a requirement of the anglers in return for their full support of the project.

Scales that had been collected during the course of sampling work were removed from their labelled envelopes and positioned in the central area of a 3in x 1in glass slide. Where the samples were in a clump they were carefully separated, washed and then cleaned between thumb and forefinger to remove surplus debris. Once arranged on the slide, a second slide was placed over the first and cellotape was affixed around each end. The scales were then numbered on each slide. It was found that setting the scales in this way allowed for quick and easy examination, while at the same time giving ease of reference for future study, if required.

The scales were examined under a Projectina Scale Projector which had a metric rule in two planes, which allowed accurate back calculations. A measurement of the radius was taken from the heart, or focus, of the scale, across the oral field to the anterior edge of the scale. The number of annulli were counted and a measurement of the radius to each succesive annullus was taken from the focus. These readings were retained for calculation of lengths for each succesive years growth indicated on the scales.

In order to establish that the back-calculated measurements from adult fish for the first year's growth were an accurate reflection of annual growth, a sample of fry caught at intervals from October to June was also used to check when the first annulus was formed.

2.3 Results

2.3.1 Coarse Fish of the River Dee

i) Species Present

During the course of the study the list of fish species in Table 2.1 were recorded and compared with historical data for the river. This showed that the range of species present had not materially changed over the previous 30 years. O'Hara (1976) listed the coarse fish which were present in the lower tideway between Chester and Queensferry which he showed to move seasonally between the tidal and non-tidal section above Chester Weir.

The only exceptions to this list were the bitterling *Rhodeus amarus* (Bloch.) which was recorded at Sandy Lane, near Chester, chub *Leuciscus cephalus* (L.) which was found in rod catches at Farndon and barbel *Barbus barbus* (L.), of which occasional fish were reported in local angling catches from the Worthenbury area.

The Fish Fauna of the Cheshire Dee and Tributaries Table 2.1

No	Species	Common Name	Freq	Introduced
	PETROMYZONIDAE			
1	Lampetra fluviatilis (L.)	River lamprey	2	Ind M
2	Lampetra planeri (Bloch.)	Brook lamprey	1	Ind
	CLUPEIDAE			
3	Alosa fallax (Lacepede.)	Twaite Shad	1	Ind
4	Sprattus sprattus (L.)	Sprat	1	Ind E
	SALMONIDAE			
5	Salmo salar (L.)	Salmon	3	Ind M
6	Salmo trutta (L.)	Sea Trout	3	Ind M
7	Salmo gairdneri (Richardson.)	Rainbow Trout	2	c1990
	COREGONIDAE			
8	Coregonus laveratus (L.)	Whitefish	1	Ind T
	THYMALLIDAE			
9	Thymallus thymallus (L.)	Grayling	2	Ind
	OSMERIDAE			
10	Osmerus eperlanus (L.)	Smelt	1	Ind E
	ESOCIDAE			
11	Esox lucius (L.)	Pike	3	c1805
	CYPRINIDAE			
12	Cyprinus carpio (L.)	Carp	1	1931
13	Cyprinus carassius (L.)	Crucian Carp	1	1970
14	Cyprinus auratus (L.)	Goldfish	1	c1920
15	Barbus barbus (L.)	Barbel	1	1970
16	Gobio gobio (L.)	Gudgeon	3	Ind
17	Tinca tinca (L.)	Tench	1	1937
18	Blicca bjoerkna (L.)	Silver bream	1	c1920
19	Abramis brama (L.)	Common bream	2	Ind
20	Phoxinus phoxinus (L.)	Minnow	4	Ind
21	Scardinius erythrophthalamus (L.)	Rudd	1	1927
22	Rutilus rutilus (L.)	Roach	3	Ind
23	Leuciscus cephalus (L.)	Chub	3	1955
24	Leuciscus idus (L.)	Orfe	1	c1920
25	Leuciscus leuciscus (L.)	Dace	4	Ind
26	Rhodeus sericeus amarus (Bloch.)	Bitterling	1	1978
	COBITIDAE			
27	Neomacheilus barbatulus (L.)	Stone Loach	2	Ind
	ANGUILLIDAE			
28	Anguilla anguilla (L.)	Eel	4	Ind M
	GASTEROSTEIDAE			
29	Gasterosteus aculeatus (L.)	3-spined Stickleback	3	Ind
30	Pungitius pungitius (L.)	10-spined Stickleback	1	Ind E
	PERCIDAE			
31	Perca fluviatilis (L.)	Perch	2	Ind
32	Gymnocephalus cernua (L.)	Ruffe	1	Ind
	GOBIIDAE			
33	Potamoschistus microps (Kroyer.)	Common Goby	1	Ind E
	COTTIDAE			
34	Cottus gobio (L.)	Bullhead	2	Ind
	PLEURONECTIDAE			
35	Platichthys flesus (L.)	Flounder	4	Ind E

1 = Rare 2 = Infrequent
3 = Common 4 = Abundant

E = Estuarine
M = Migratory
Ind= Indigenous

ii) Restocking of Coarse Fish

Fig 2.2 and 2.3 shows the extent of authorised stockings to the river in the period since 1955. Although roach figured predominantly in these additions, a shortage of available fish dictated that not only established species were stocked, but also non-riverine fish such as rudd, tench and both common and crucian carp were included.

Stocking of this kind peaked in the mid 1970's with the single largest amount being 50,000 small roach in 1973 (Dee and Clwyd Fishery Reports 1974). The fish came predominantly from inland sources ranging from small local ponds in Cheshire and large local waters like Llyn Tegid (Bala Lake).

2.3.2 Size and Distribution of the Roach and Dace Population

i) Roach and Dace Population from Anglers' Catches

From samples of fish caught in selected angling matches during the winter periods of 1988/89 and 1989/90, the ratio of species and size composition of fish caught by anglers was established. This detail is shown in Fig 2.4 where it can be seen that at Chester over the two season period the percentage of dace in catches was 82% and 73% respectively, while roach represented only 14% and 24% of the catch. Other fish landed included bream, pike, chub and perch, but they accounted for less than 4% in total in each year.

At Farndon the angling catch was totally dominated by dace, being 98% in each of the 2 years. The greatest number of chub were caught near to Overton-on-Dee rather than Farndon and therefore did not feature in the species composition data.

Stocking of Coarse Fish to the Lower Dee

1955-91

Fig 2.2

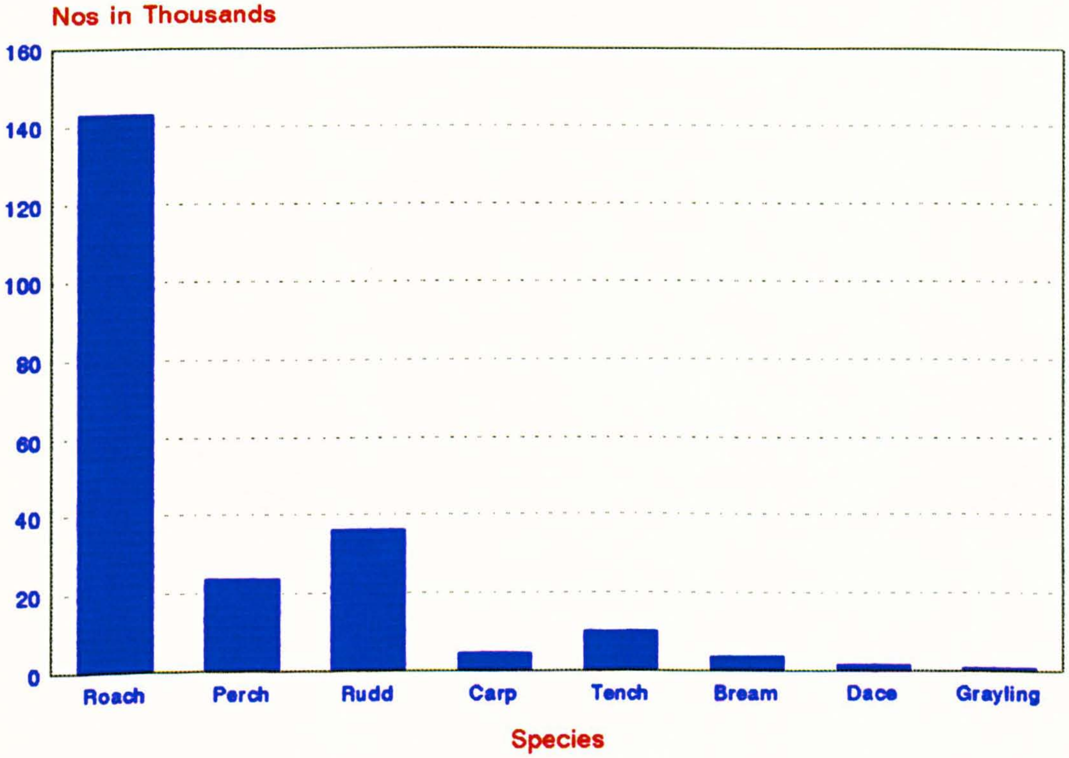


Fig 2.3

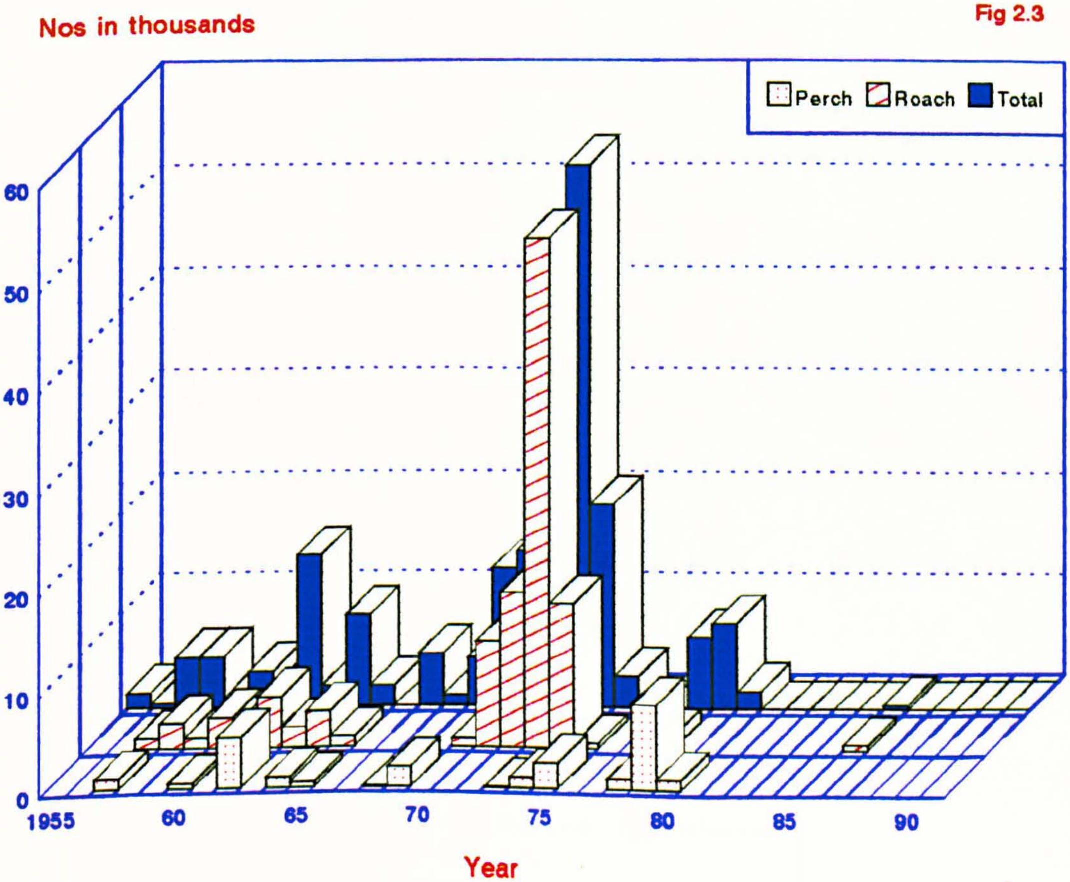
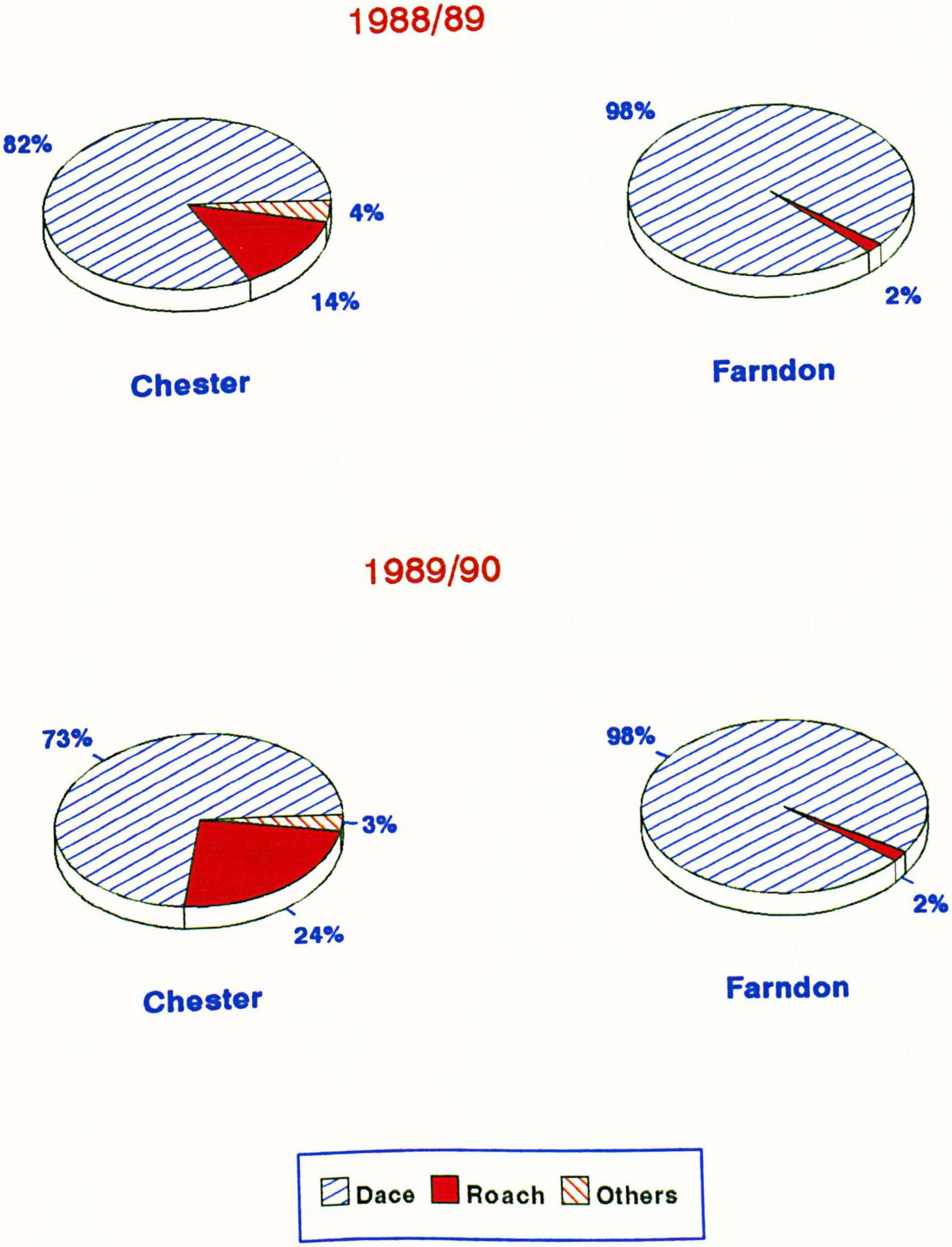


Fig 2.4

Match Angling Catches
Species Abundance



The results given in Tables 2.2-2.6 compile data from individual matches submitted by angling club secretaries and also the data acquired from local newspaper angling columns. The combination of the two sources enabled a wider coverage of competition events to be made.

-Table 2.2 shows the number of competitions surveyed at the two fishing locations of Chester and Farndon.

-Table 2.3 details the total number of anglers fishing at the matches sampled in 2.2.

-Table 2.4 gives the mean rod catch/week from the total weight for the top three anglers in each of the angling matches that took place.

-Table 2.5 summarises the data in Table 2.4 into monthly catagories.

-Table 2.6 expresses the mean monthly catch of the top 3 anglers shown in Table 2.5 as catch/angler expressed in gms/man.hr^{-1} for the 4 hour matches.

Figure 2.5 and 2.6 graphically display in three dimensions the mean weekly anglers catch from Table 2.4 for the two locations for a four season period 1988/89-1991/92. The weekly catches over four angling seasons are compared against river flow in Fig 2.7-2.10 for Chester catches and Fig 2.11-2.14 for Farndon.

From Table 2.3 the results revealed that the Chester area had greater angler usage which was an indication of its importance for match angling, particularly in the period October to January when the winter league programme took place. The good accessibility of the river and ideal bank profile in the area between Eccleston and Chester are probable reasons for it being favoured for staging competition events. At Farndon there was much more variability of fishing activity with the summer period being preferred for smaller club competitions.

Details on catches detailed in Table 2.5 show that between the two areas for match angling, Farndon is consistently a more productive fishery

Number of Angling Matches Sampled/Month

Table 2.2

Chester												
	June	July	August	September	October	November	December	January	February	March	Total	Mean
1988/89	1	5	6	9	16	17	19	15	7	1	96	9.6
1989/90	1	3	7	7	11	13	13	5	5	5	70	7
1990/91	2	6	5	4	11	8	13	8	3	-	60	6
1991/92	4	6	6	5	13	15	9	4	1	-	63	6.3
Total	8	20	24	25	51	53	54	32	16	6	289	
Mean	2	5	6	6.3	12.8	13.3	13.5	8	4	1.5	72.3	
Farndon												
1988/89	4	13	6	8	6	5	1	5	5	3	56	5.6
1989/90	2	6	12	3	7	3	2	8	1	5	48	4.8
1990/91	5	6	12	10	4	2	3	3	5	5	55	5.5
1991/92	7	10	9	6	6	4	5	11	7	3	68	6.8
Total	18	35	39	27	23	14	11	27	17	16	227	
Mean	4.5	8.8	9.8	6.8	5.8	3.5	2.8	6.8	4.3	4	56.8	

Number of Anglers competing in Matches Sampled

Table 2.3

	June	July	August	September	October	November	December	January	February	March	Total	No Events	Anglers/ Events
Chester													
1988/89	10	60	70	175	362	315	597	452	160	20	2221	90	22.78
1989/90	10	50	105	110	312	361	420	241	110	60	1779	78	26.56
1990/91	25	135	85	55	444	229	451	100	35		1559	64	28.7
1991/92	85	70	80	70	277	426	312	102	10		1432	69	21.09
Total	130	315	340	410	1395	1331	1780	895	315	80	6991		
Mean	32.5	78.8	85	102.5	348.8	332.8	445	223.8	78.8	40		75.3	
Farndon													
1988/89	55	190	95	130	132	65	15	130	95	45	952	55	15.85
1989/90	35	95	200	45	105	45	30	160	20	60	795	48	17.19
1990/91	80	125	220	155	55	55	85	60	95	70	1000	55	18.27
1991/92	85	150	125	80	70	55	95	180	105	60	1005	60	14.75
Total	255	560	640	410	362	220	225	530	315	235	3752		
Mean	63.8	140	160	102.5	90.5	55	56.3	132.5	78.8	58.8		54.5	

Table 2.4

Mean Rod Catch from Angling Club Matches

(Weight of Fish in kg)

	Chester					Farndon			
Week	Years				Week	Years			
	1988/89	1989/90	1990/91	1991/92		1988/89	1989/90	1990/91	1991/92
24					24	2.664			
25	0.794	0.142	0.652	1.219	25	1.276	0.765	10.319	1.984
26			0.482	1.039	26	3.175	0.936	4.791	1.588
27	2.948	1.36	1.077	2.088	27	3.374	2.807	7.626	2.315
28	0.992		2.551	1.739	28	3.288	3.005	8.42	3.409
29		5.33	3.401		29	3.742	2.013	12.445	1.191
30	1.191	7.739	2.41		30	1.417	3.289		1.758
31		1.162	1.049	4.167	31	2.267	3.203	3.005	
32	2.523	2.977	1.134	1.455	32	2.637	3.317	4.99	1.95
33	0.34	0.482		1.276	33	2.438	4.054	2.778	
34	2.324	4.252	2.637	1.446	34	0.964	2.722	3.374	2.062
35	1.758	2.381			35	1.503		1.984	
36	1.162	1.247	3.487	2.849	36	3.147	0.454	3.742	2.736
37			1.701		37	0.907		1.927	
38	1.758	4.536	0.482	1.71	38	1.673	3.6	1.616	1.467
39	2.948	2.665			39	4.196	2.098	4.337	
40	1.814	0.624	2.183	2.398	40	1.276	0.764	4.224	0.978
41	2.268	1.332	5.046	3.459	41	2.155	6.209	2.041	4.437
42	2.977	1.814	12.474	4.205	42	4.961	4.904		1.573
43	1.021	3.317	6.634		43		1.106	2.041	
44	2.296	5.443		14.146	44	3.941	4.706		2.14
45	2.977	3.235		1.396	45	3.033	0.312	10.092	
46	1.956	2.892	5.046	1.106	46	3.826	2.268	8.363	
47	2.098	5.67	3.203	0.85	47				2.835
48	3.884	3.969	2.353	5.16	48	1.247			8.93
49	3.26		4.054	4.89	49			3.997	3.231
50	2.608	6.379	4.564	1.573	50		1.758		5.415
51	4.763	3.374	4.451	2.476	51	2.154	1.786	11.113	11.141
52	1.36	0.85	2.098	0.936	52			9.724	5.812
1	2.325	8.108	0.652	4.876	1	8.59	4.649		5.811
2	4.053	2.268	1.106	2.013	2	9.214	6.322		6.903
3	1.871	4.706	0.198	0.567	3	4.763	4.196		3.033
4	1.474	2.495	1.212	0	4	2.807	9.781	12.578	6.473
5	5.557	3.969	0.936		5	1.332	3.544	11.954	7.371
6	3.033	0.737			6	6.69		12.247	6.506
7	1.531	1.134	0.68		7				9.54
8	2.07	1.417			8	0.482		21.602	2.75
9	0.113	0.964		0	9		5.925	0.17	9.072
10					10	6.492	8.505	11.198	10.348
11		1.7			11	5.5	10.574	1.134	4.111

Mean Rod Catch/Angling Match

(Top Three Weights in kg)

Chester											**Table 2.5**	
	June	July	August	September	October	November	December	January	February	March	**Total**	**Mean**
1988/89	0.794	1.71	1.736	1.956	2.075	2.729	2.998	2.431	3.048	0.113	19.9	1.959
1989/90	0.142	4.81	2.251	2.816	2.506	3.942	3.534	4.309	1.096	1.332	26.74	2.674
1990/91	0.567	2.097	1.886	1.963	8.051	3.534	3.164	0.863	0.68		22.81	2.281
1991/92	1.449	2.453	1.392	2.319	7.27	2.128	2.469	1.864	0		21.34	2.134
Total	2.952	11.07	7.265	9.054	19.902	12.333	12.165	9.467	4.824	1.445		
Mean	0.738	2.768	1.816	2.264	4.976	3.083	3.041	2.367	1.206	0.361		
Farndon												
1988/89	2.371	2.818	1.886	2.481	3.083	2.702	2.154	5.341	3.586	5.996	32.93	3.29
1989/90	0.851	2.804	3.324	2.051	3.538	1.29	1.772	5.698	5.925	9.54	36.79	3.68
1990/91	7.555	7.874	3.282	3.169	2.041	9.228	8.278	12.266	11.34	6.166	71.2	7.12
1991/92	1.962	2.119	2.006	1.724	2.717	5.883	6.4	5.918	6.967	7.23	42.93	4.29
Total	12.739	15.615	10.498	9.425	11.379	18.339	19.88	29.223	27.818	28.932		
Mean	3.185	3.904	2.625	2.356	2.845	4.585	4.97	7.306	6.955	7.233		

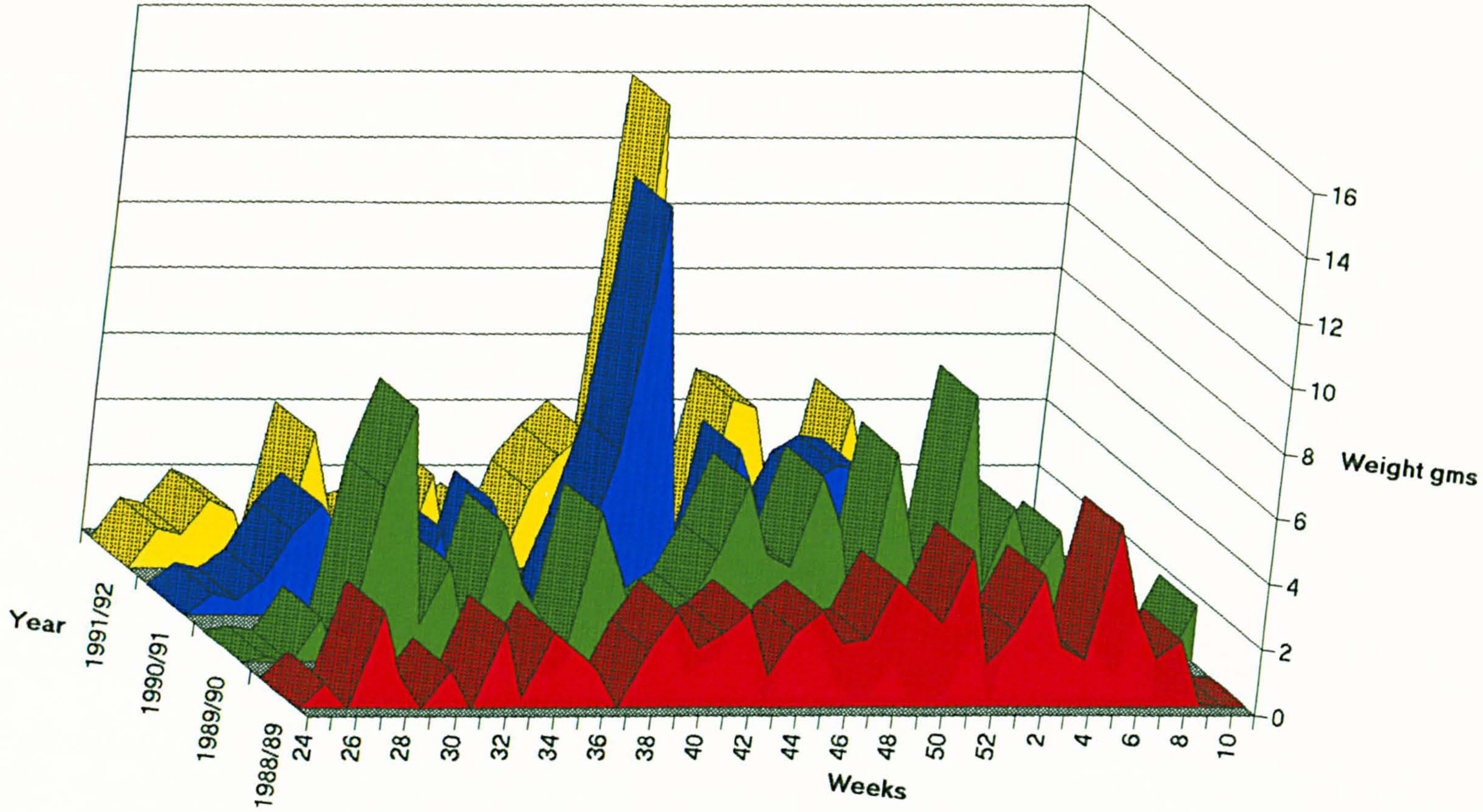
Mean Rod Catch of Top Three Anglers

(Catch Rate in gms/man hour)

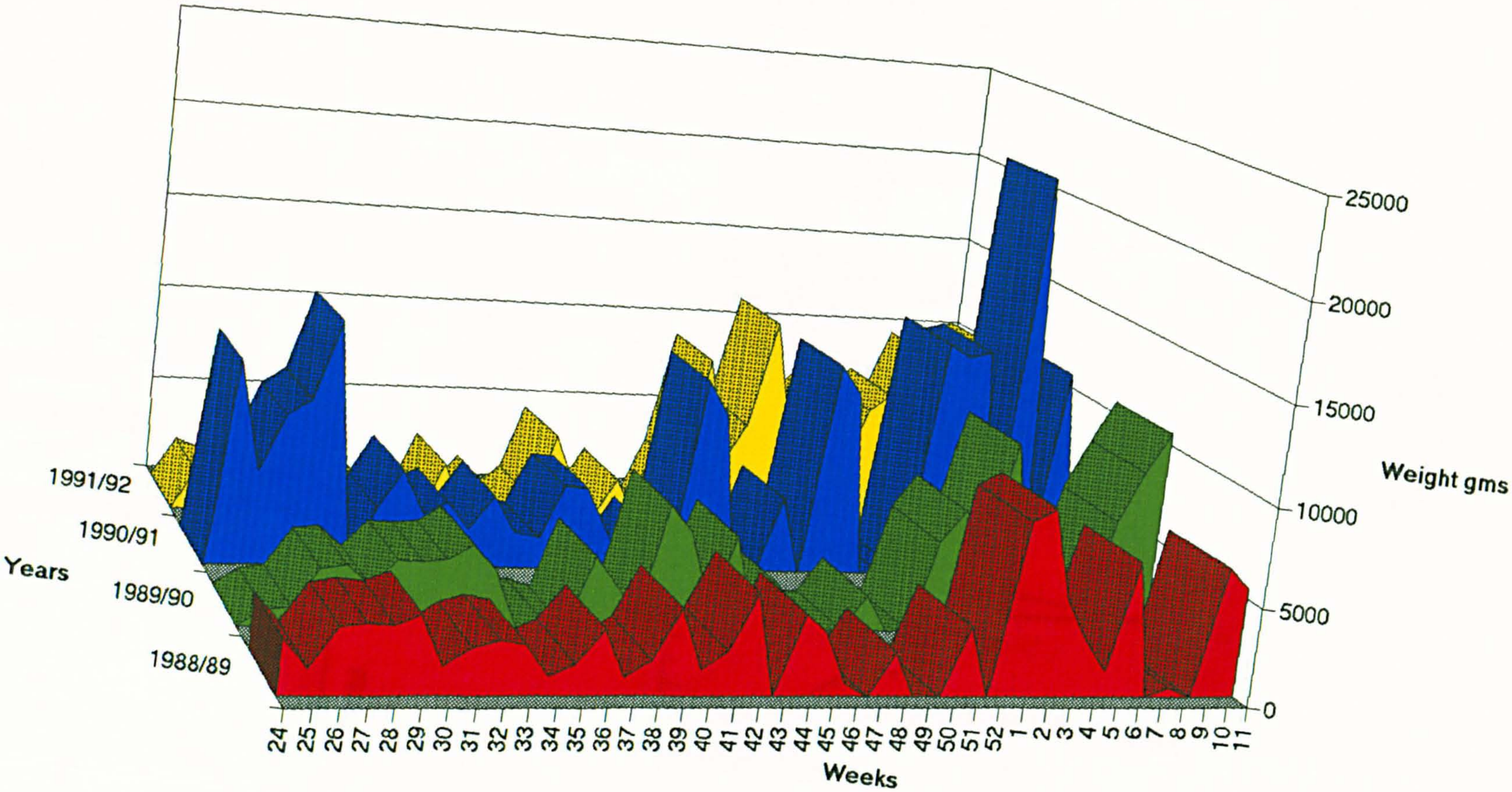
Table 2.6

	June	July	August	September	October	November	December	January	February	March	Total	Mean
Chester												
1988/89	66.2	142.5	144.6	163	172.9	227.4	249.8	202.6	254	9.4	1632.4	163.2
1989/90	11.8	40.1	187.6	234.7	208.8	328.5	294.5	359.1	91.3	111	1867.4	186.7
1990/91	47.3	174.8	157.2	163.6	670.9	294.5	263.3	71.9	56.7		1900.2	211.1
1991/92	120.8	204.4	116	193.3	605.8	177.3	205.8	155.3	0		1778.7	197.6
Total	246.1	561.8	605.4	754.6	1658.4	1027.7	1013.4	788.9	402	120.4	7178.7	
Mean	61.5	140.5	155.4	188.7	414.6	256.9	253.4	197.2	100.5	60.2		189.7
Farndon												
1988/89	197.6	234.8	157.2	206.8	256.9	225.2	179.5	445	298.8	499.7		
1989/90	70.9	233.7	277	170.9	294.8	107.5	147.7	474.8	493.8	795		
1990/91	629.6	656.2	273.5	264	170.1	769	689.8	1022.2	945	513.8		
1991/92	163.5	176.6	167.2	143.7	226.4	490.3	533.3	493.2	580.6	602.5		
Total	1061.6	1301.3	874.9	785.4	948.2	1592	1550.3	2435.2	2318.2	2411	15278.1	
Mean	265.4	325.3	218.7	196.4	237.1	398	387.6	608.8	579.6	602.8		382

Mean Weekly Rod Catch - Chester Fig 2.5

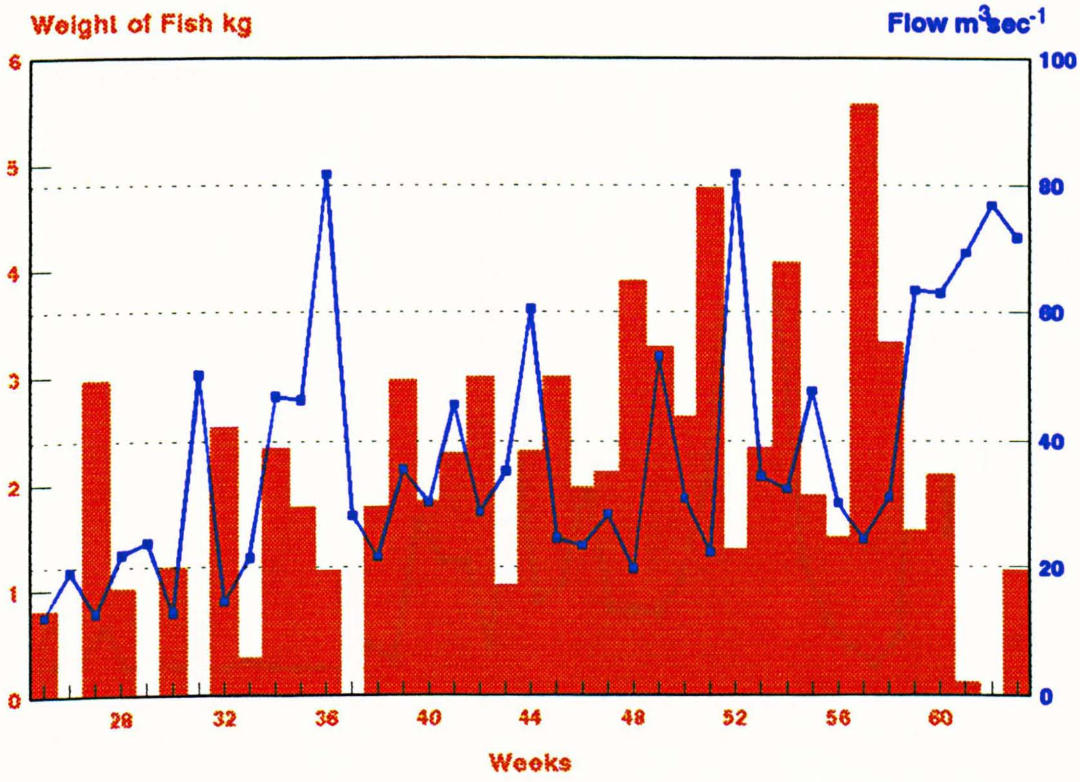


Mean Weekly Rod Catch - Farndon   Fig 2.6



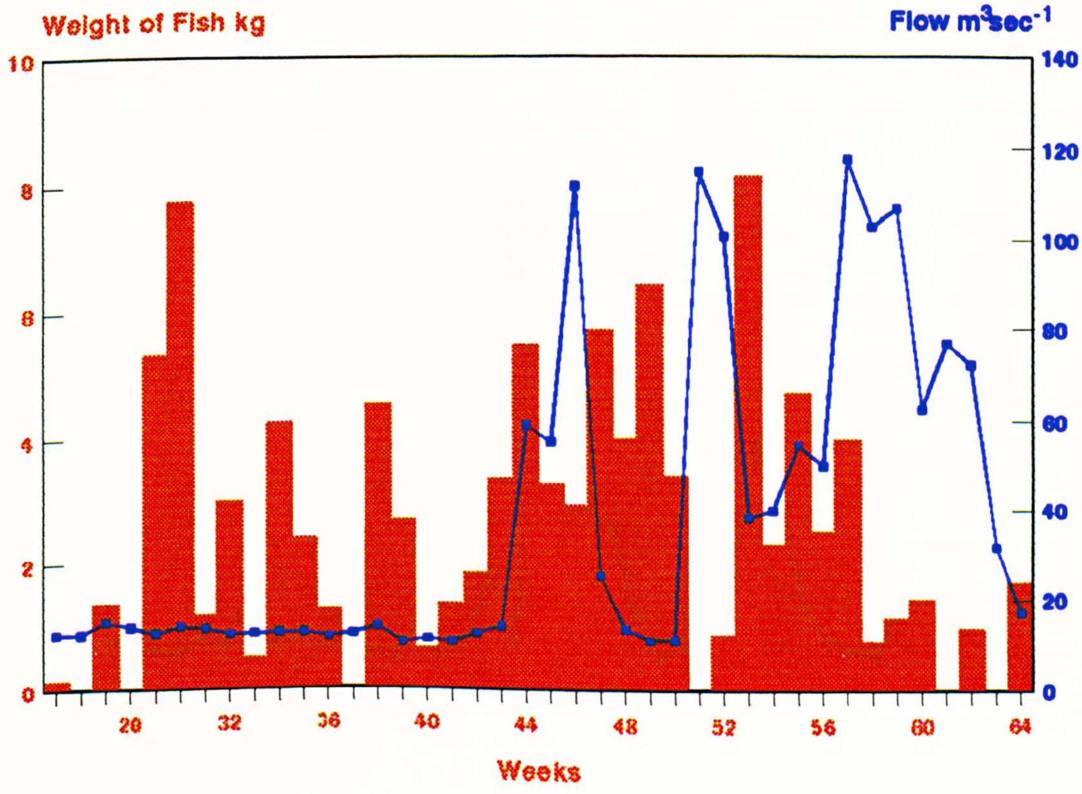
Anglers'Match Catches
River Dee-Chester 1988/89

Fig 2.7



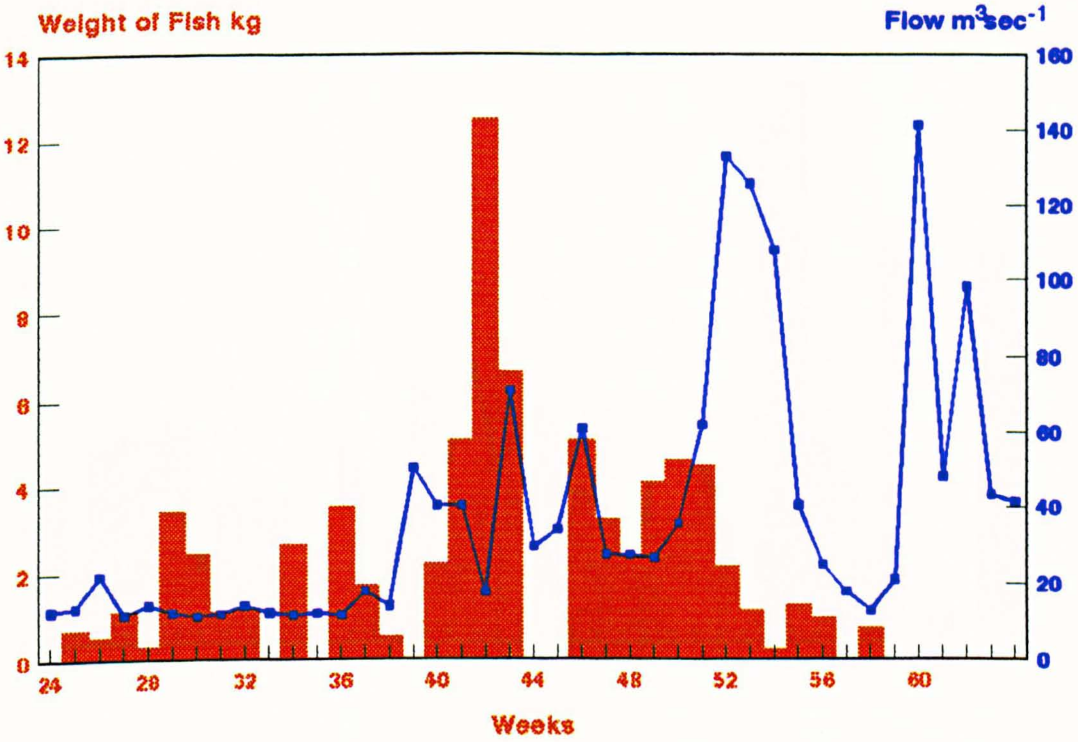
Anglers'Match Catches
River Dee-Chester 1989/90

Fig 2.8



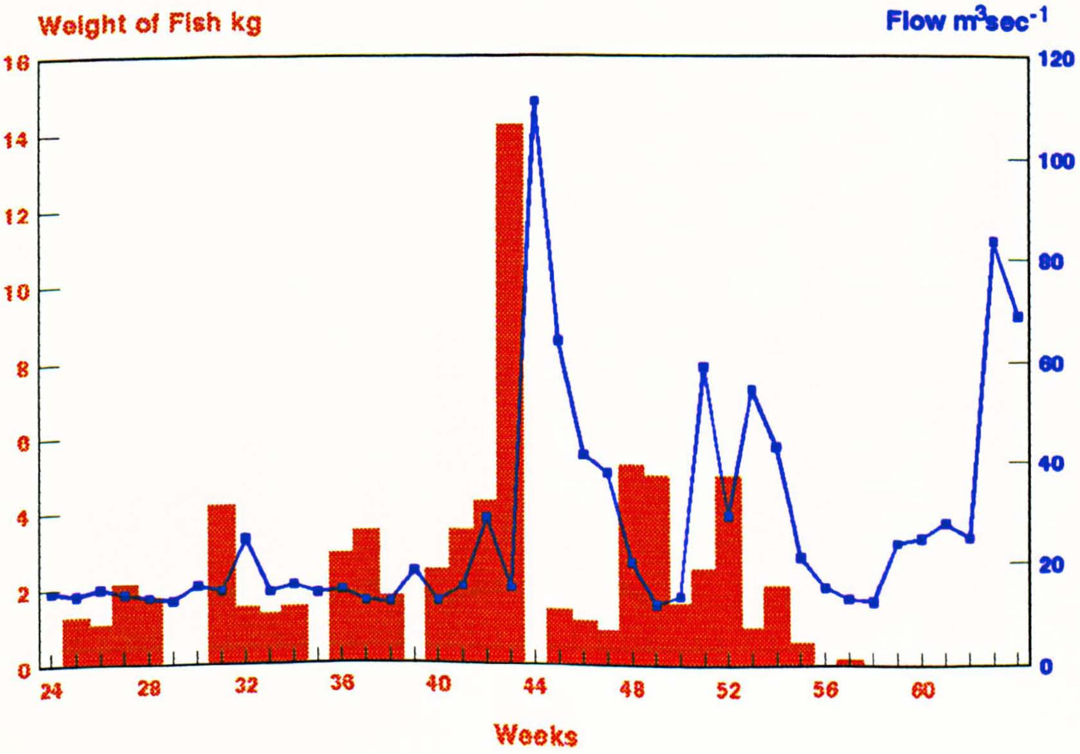
Anglers'Match Catches
River Dee-Chester 1990/91

Fig 2.9



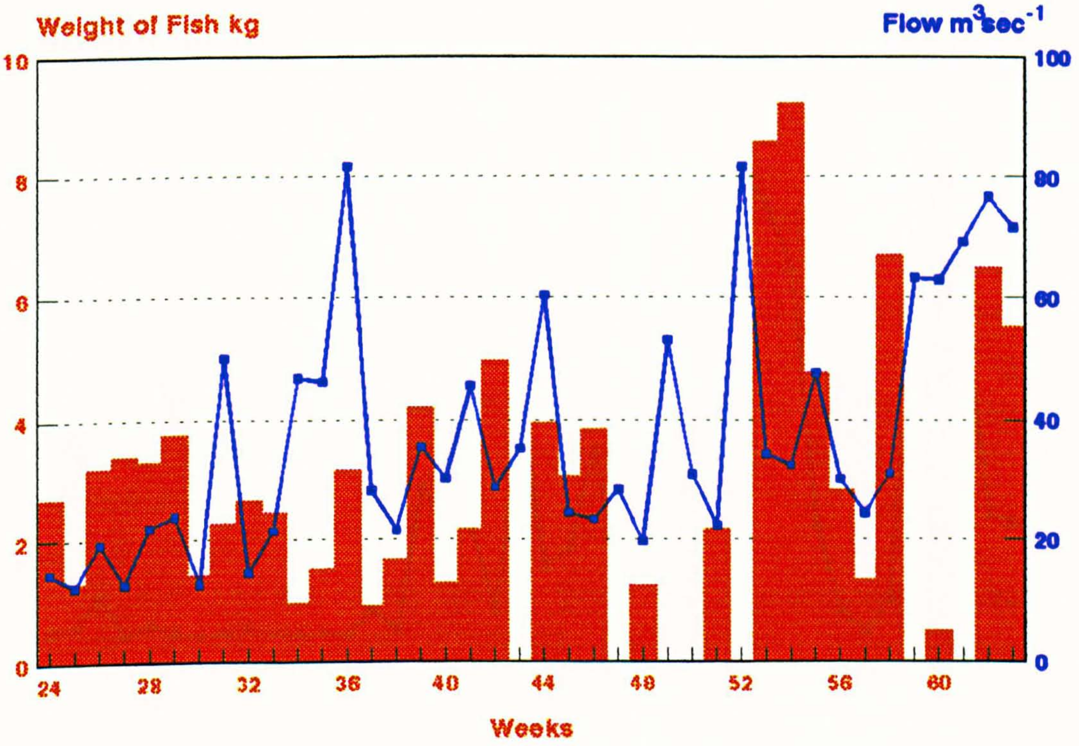
Anglers'Match Catches
River Dee-Chester 1991/92

Fig 2.10



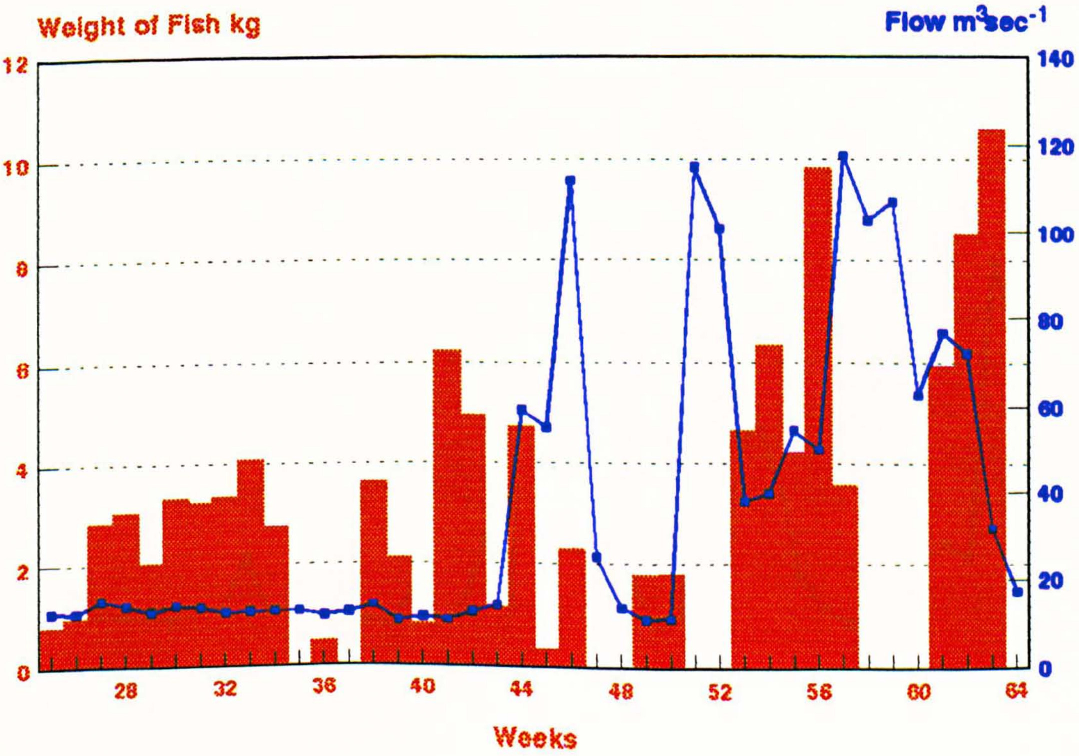
Anglers'Match Catches
River Dee-Farndon 1988/89

Fig 2.11



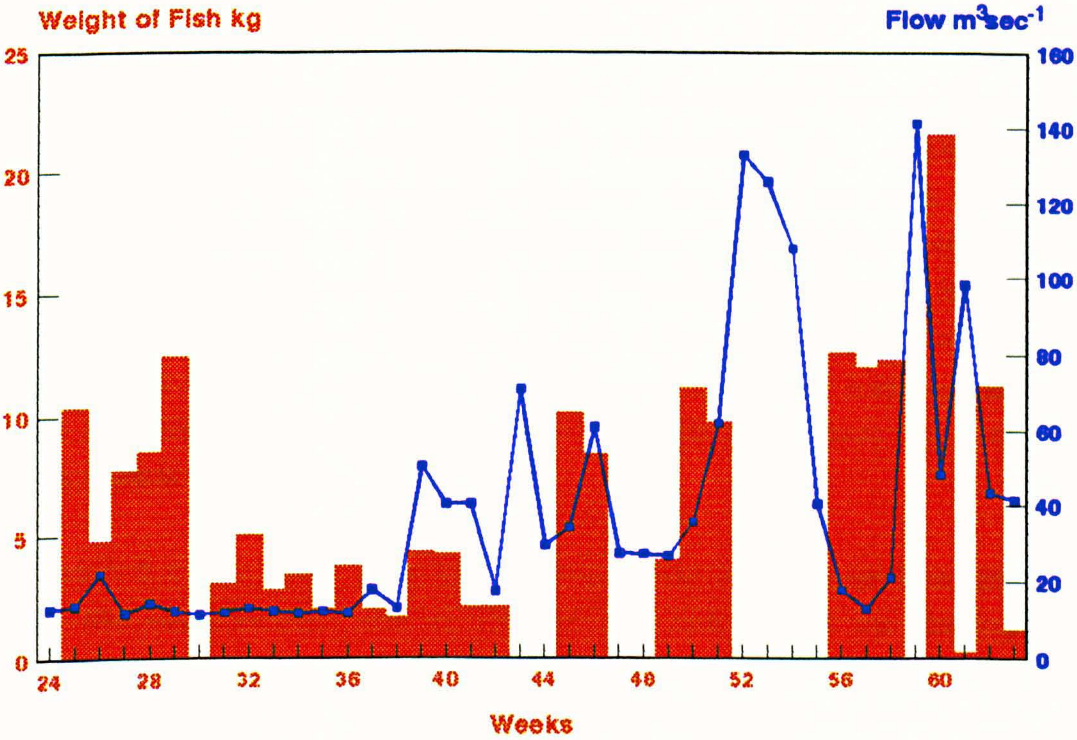
Anglers'Match Catches
River Dee-Farndon 1989/90

Fig 2.12



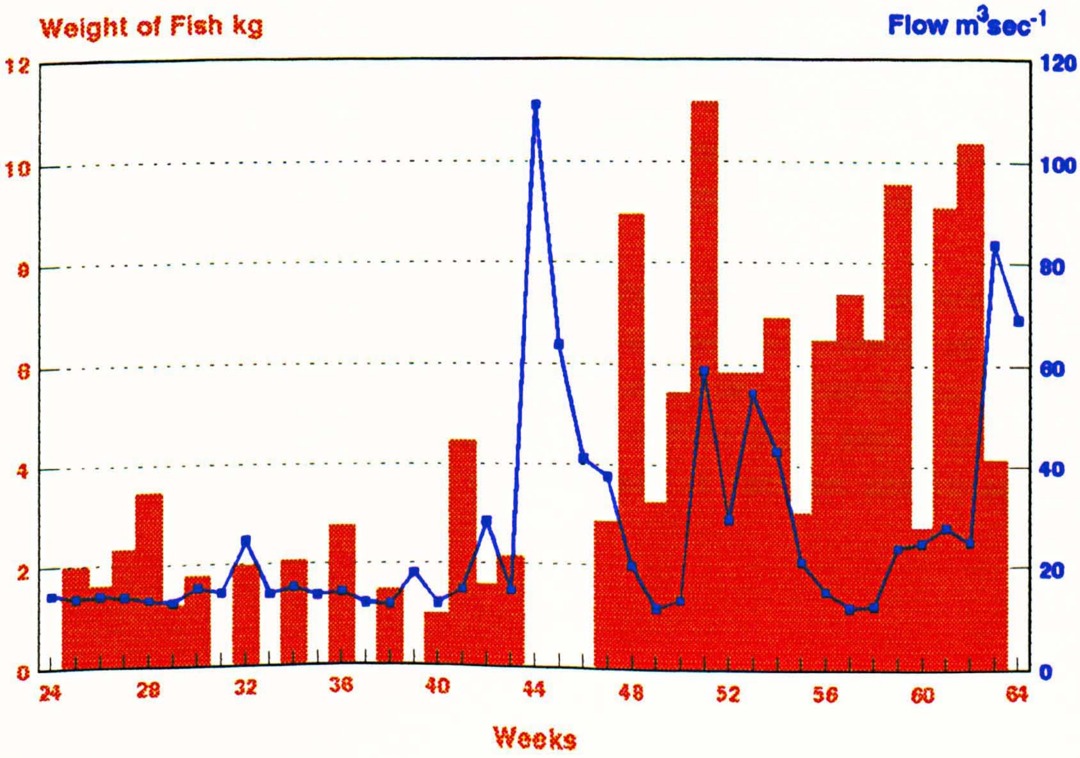
Anglers'Match Catches
River Dee-Farndon 1990/91

Fig 2.13



Anglers'Match Catches
River Dee-Farndon 1991/92

Fig 2.14



than Chester apart from two months of the fishing season. Over the period of four years, the mean annual total catch of the top three anglers in each event sampled at Farndon ranged from 3.29 kg/match at its lowest in 1988/89, up to a maximum of 7.12 kg/match in 1990/91. This compared to Chester with just 1.96 kg/match and 2.67 kg/match respectively.

Farndon was also a consistent fishery in the summer months of June to September with mean catches of 3.02^{+}0.8 kg/match, but as the winter months advanced this figure progressively increased to peak at 7.31 kg/match in January and was maintained at 7.09^{+}0.14 kg/match through to the end of the fishing season in mid March. At Chester however, much lower figures were recorded, from a low mean for the summer months of 1.90^{+}0.87 kg/match to a high in October of 5.00kg/match. After this time the catches decreased progressively down to just 0.3kg/match in March.

In Table 2.6 the catch rate for the two areas is expressed in gm/man.hr^{-1} for the two locations and at Chester the best period for fishing is indicated as between September and January and the latter month maintains catches for the top anglers at almost 200 gms/man.hr^{-1}. The results reveal that catches over four seasons were slightly better during the summer in the Farndon area than at Chester but a very marked reversal of trend takes place from November onwards with a severe decline at the lower part of the river which coincides with a period of increased activity by anglers. As angler activity increased at both locations the trend is likely to be as a result of natural fish movement from one area to the other rather than angler influence, although Ratt (1985) has shown that higher angler activity reduced catch rate following increased frequency of capture. Evidence from tag returns in 2.3.2.ii supports the theory that the dace stocks migrate upstream.

The results of the Mann-Whitney statistical test on the comparisons between seasons and periods of seasons at the two locations of Farndon and Chester are presented in Table 2.7 and 2.8. From Table 2.7 the results reveal that in three seasons out of four there was a highly significant difference between catches made at Farndon and those made at

Mann - Whitney Test on Mean Rod Catch by Top Three Anglers

Table 2.7

Comparison of Catches made at Chester with those made at Farndon

	Chester	Farndon			
	K'	K	n'	n	U
Season to Season					
1988/89	23	77	10	10	<0.05
1989/90	43	57	10	10	>0.20
1990/91	9	73	9	10	<0.002
1991/92	26	63	9	10	<0.10
Parts of a Season over a 4 Season Period					
	Chester	Farndon			
June to September	52.5	203.5	16	16	<0.002
October to December	75	69	12	12	>0.20
January to March	0	120	10	12	<0.001

Table 2.8

Comparison of Catches made between Periods at Chester and Farndon

June-Sept/Oct-Dec					
	June-Sept	Oct-Dec			
Chester	12	180	16	12	<0.001
Farndon	18	174	16	12	<0.001
June-Sept/Jan-Mar					
	June-Sept	Jan-March			
Chester	91	69	16	10	>0.20
Farndon	18	174	16	12	<0.001
Oct-Dec/Jan-Mar					
	Oct-March	Jan-Dec			
Chester	102	18	12	10	<0.01
Farndon	29	115	12	12	<0.02

Chester, with the former producing the best catches. With the season periods June-Sept and January-March again there was highly significant difference between the two locations with better fishing at Farndon but in the period October-December no significant difference was established.

The results therefore revealed that there was variable movement of fish at Chester and that the stock remaining outside of the October-December period did not produce catches that compared favourably with those made at Farndon.

In Table 2.8 the seasonal periods are compared by means of the Mann-Whitney test at both Farndon and Chester separately. At both locations there was high significance that greater catches were taken in the October-December period compared to June-September. At Farndon there was also high significance that greater catches were taken in January-March period compared to June-September, but at Chester no significance was established. This suggests that anglers catches at Chester in January-March are similar to those recorded in the summer period but at Farndon they remain high as occurred in October-December. When the October-December period is compared with January-March there are significant results at both locations but in respect of Farndon it is the January-March period that has higher catches whereas at Chester it is the reverse.

The results support the anglers' views that fish migrate from the Chester area during January and March and probably pass upstream to Farndon. This aspect was examined in the tagging programme on fish movement.

ii) Movements of Roach and Dace

In total 25 matches were used to acquire fish for tagging of which 18 were in the Chester area and 7 at Farndon.

Table 2.9 lists dates of the matches that were used to collect fish for tagging and shows the species abundance of those fish tagged. Table 2.10 gives a summary of the numbers of fish that were recaptured in the two winter fishing competition periods of 1988/89 and 1989/90.

Table 2.9

Dates of Matches and Fish collected for Tagging Programme

Showing Species Ratio

Chester	Dace	Roach	Total	%Roach	**Farndon**	Dace	Roach	Total	%Roach
08/10/88	65	14	79	17.7	22/01/89	209	2	211	0.9
16/10/88	18	14	32	43.8	29/01/89	182	2	184	1.1
30/10/88	41	2	43	4.7	05/02/89	118	2	120	1.7
30/10/88	21	5	26	19.2	12/02/89	35	3	38	8
06/11/88	53	17	70	24.3	12/03/89	13	0	13	0
14/11/88	112	53	165	32.1					
22/11/88	28	3	31	9.7					
27/11/88	13	1	14	7.1					
06/12/88	66	3	69	4.3					
18/12/88	13	38	51	74.5					
20/12/88	68	11	79	13.9					
1988/89	498	161	659		**1988/89**	541	9	55	
15/10/89	23	6	29	20.7					
05/11/89	101	7	108	6.5					
19/11/89	23	28	51	54.9					
26/11/89	39	18	57	31.6					
03/12/89	35	13	48	27.1					
10/12/89	4	16	20	80					
07/01/90	68	3	71	4.2	04/03/90	75	1	76	1.3
					11/03/90	186	5	191	2.6
1989/90	293	91	384	23.7	**1989/90**	261	6	267	2.2
Total	791	252	1043	24.2	**Total**	802	15	817	1.8

Table 2.10

Total Tag Returns

	Chester	Farndon	Total	%Return
Dace	46	38	84	5.27
Roach	11	0	11	4.12
Total	57	38	95	5.12

Unfortunately the numbers of roach tagged was too low to expect a reasonable return. 267 roach were tagged in total, of which 94% were originally caught in the Chester area. The 11 tag returns, or 4.12% of released fish, was lower than that for dace. The reasons for this probably reflected the small size of the roach population and the dilution of the available stock for the anglers to catch, compared with the abundance of dace in the area.

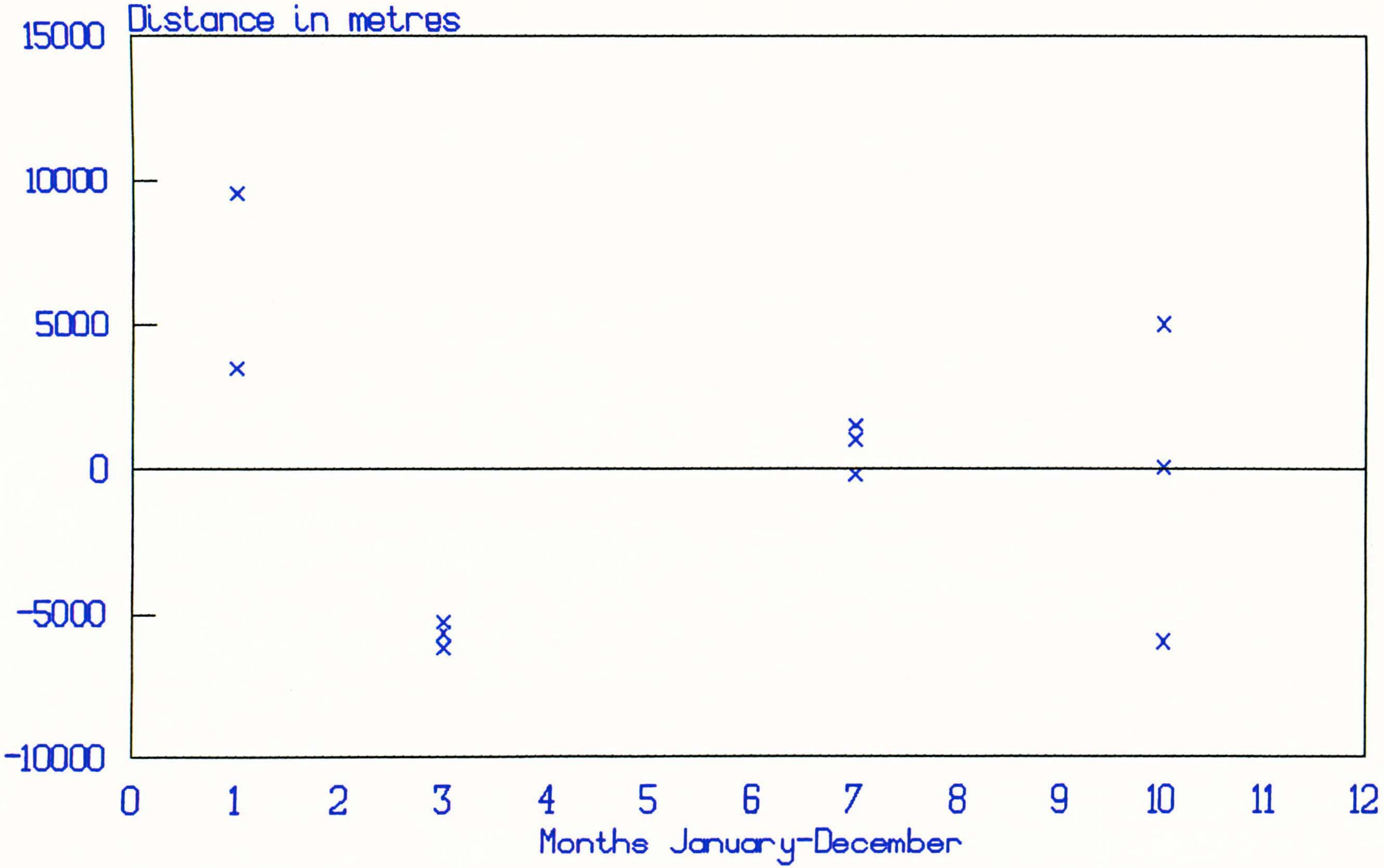
Even with the limited number of fish tag returns it was revealed in Fig 2.15 that the movements of the roach was greater than had been anticipated, with fish not only moving along the channel between Chester and Eccleston but also upstream as far as Aldford Brook, approximately 9km from Chester. No movements of roach were detected above Aldford Brook and none of the roach from Farndon were recaptured to establish if any movements took place at that location.

Over the two season period 1593 dace were tagged, of which 84 tags were returned from anglers, this represented 5.27% of released fish. The larger sample size established a clearer indication of movement pattern within the species. It showed that dace in the lower Dee moved great distances, both up and downstream and also, the speeds at which they progressed was, at times, very rapid. Individual fish indicated that movements exceeded 5km.day^{-1}, which represented a speed in excess of 208m.hr^{-1}. This figure was derived from a fish released in March which moved from Farndon to Bangor-on-Dee, some 20km upstream, in under 4 days. Another fish released in January, moved upstream from Eccleston to Farndon, a distance of 14.5 km, in under 9 days. These times were maximum figures as the precise time of recapture may not have coincided with the time the fish reached its new location.

From the recaptures it was shown that the probable upper limit of dace movement was Overton-on-Dee, some 50km upstream of Chester and the downstream limit was in the tideway, some 5km downstream of Chester Weir.

River Dee - Distance of Roach Movement
Release of Fish at Chester (October-December)

Fig 2.15



From Anglers' Recaptures

The movement in the dace population can be best summarised by Fig 2.16 and 2.19. It was found that, for fish released at Chester, there was movement of up to 5 km in both directions between Eccleston and Chester Weir between October and the end of the year. In January there was the first indication of extensive movements taking place which continued up until March. It was then that movement increased to 15 km in an upstream direction to the Farndon area of river.

Of the 52 dace recaptures that were originally released at Chester, some 9 fish were eventually caught outside the Chester area, 8 were taken at Farndon between the months of January and March, the remaining fish was landed at Bangor-on-Dee in August. Of the recaptures made at Chester only 4 were caught in the months between January and March, all of which were recaptured in the first two weeks of January.

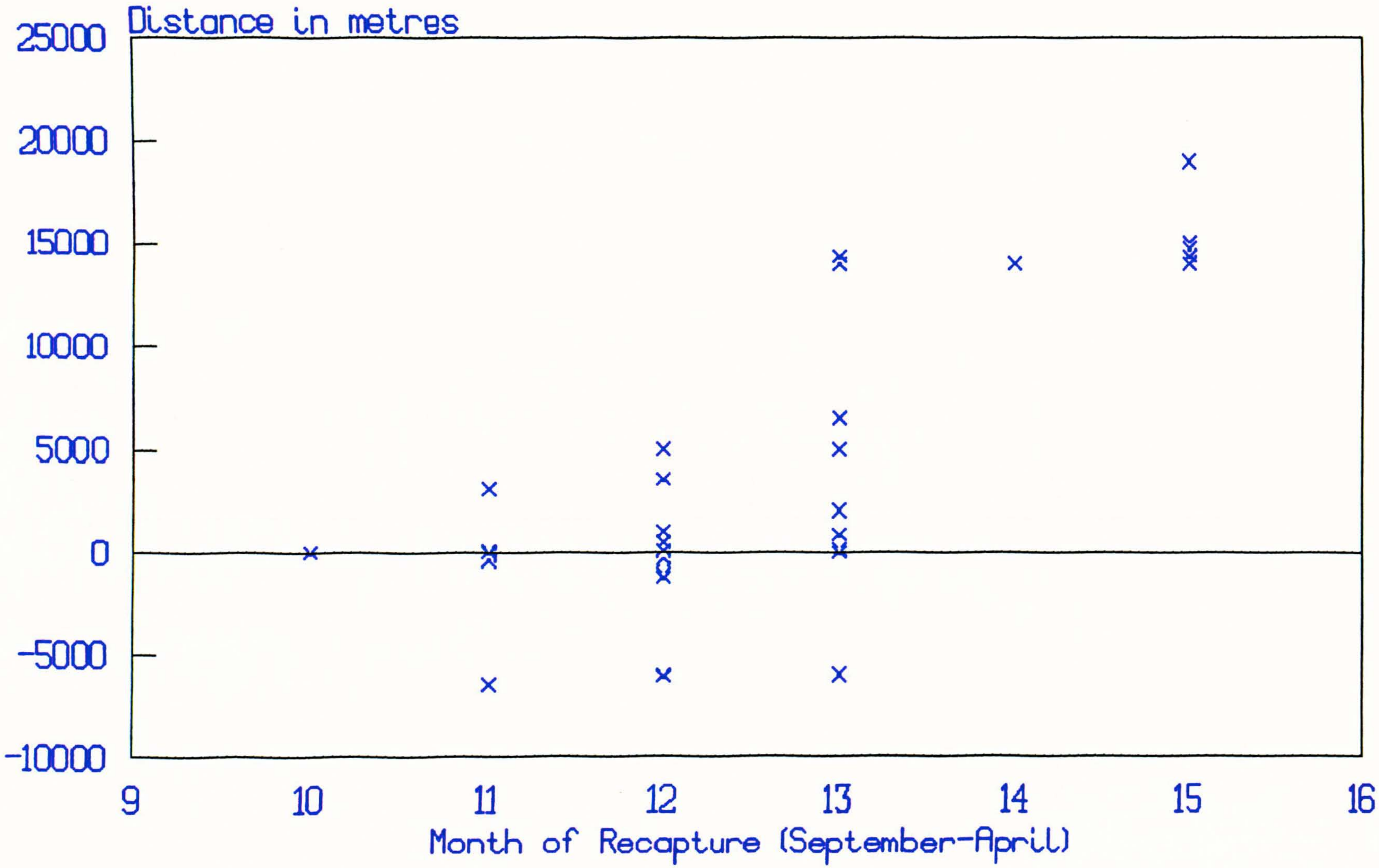
From the recaptures made from dace released at Farndon, it was established that little movement from the Farndon area took place between January and March. Of the 32 dace which were released at Farndon and eventually recaptured, 26 were caught within 2 km of Farndon even though the average period of liberty for the dace recaptured in the same season was 17 days, which would have given sufficient time for extensive dispersal. Between January and March there were matches upstream of Overton-on-Dee, but despite this only one fish released at Farndon was recaptured outside of the Farndon area, this being the one which travelled 20 km up to Bangor in 4 days.

iii) Fish Population of the River Clywedog

The fish species populating one of the major tributaries in the study area was established from a total fish mortality of an 8km lower section of the River Clywedog in November 1990. Data from this incident are given in Fig 2.20-2.22 which show that the fish population was predominantly dace and within that stock there were two year classes found with a strong dominance of adult fish rather than juveniles. This supported similar findings by Wilkinson (1974) working on three other tributaries of the lower Dee which suggested that 0-group dace numbers in the tributaries were limited. Sex ratio was evenly balanced with males being larger.

River Dee - Distance of Dace Movements
Release of Fish at Chester (October-December)

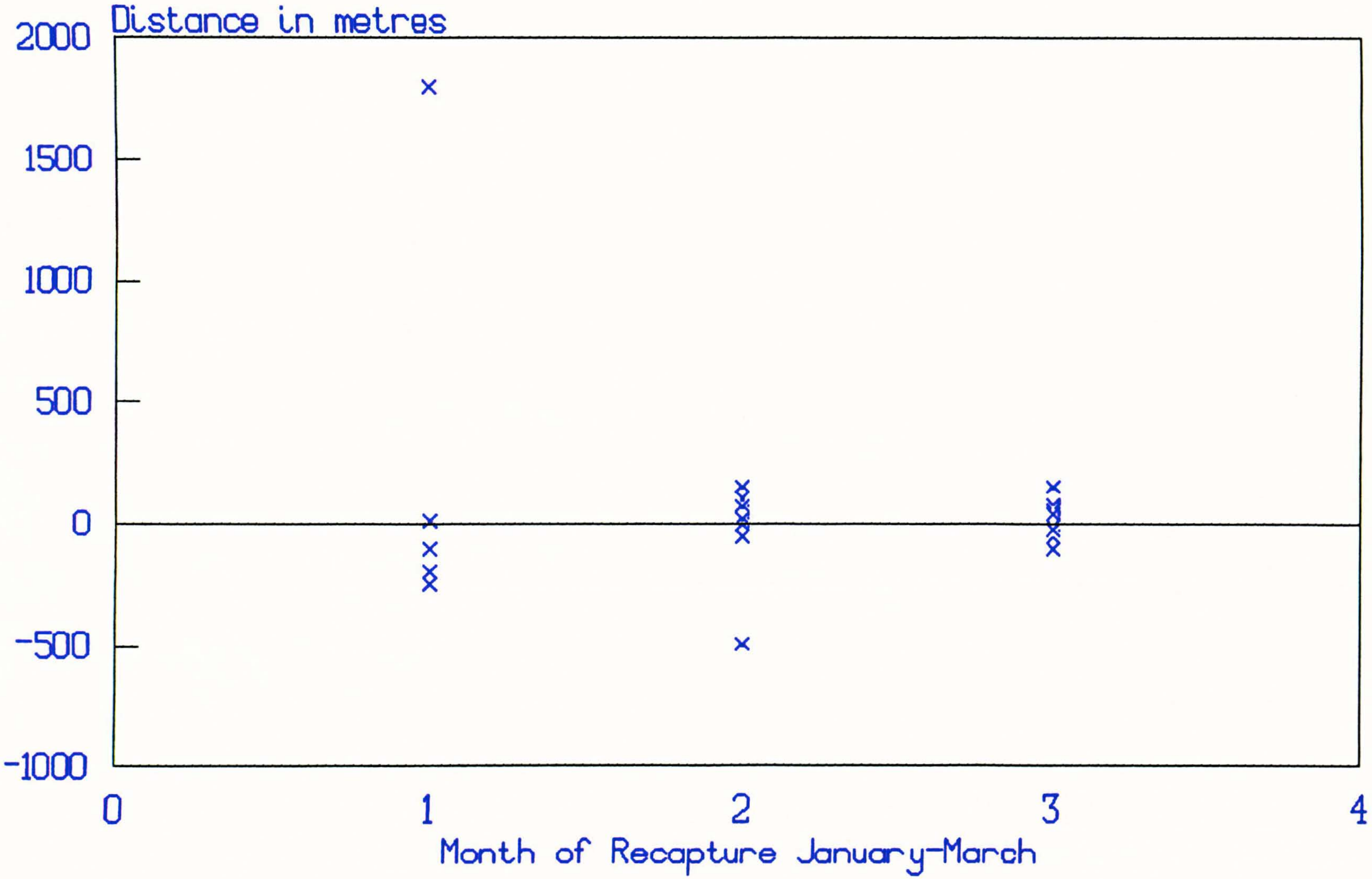
Fig 2.16



From Anglers Recaptures

River Dee - Distance of Dace Movements
Release of Fish at Farndon in January

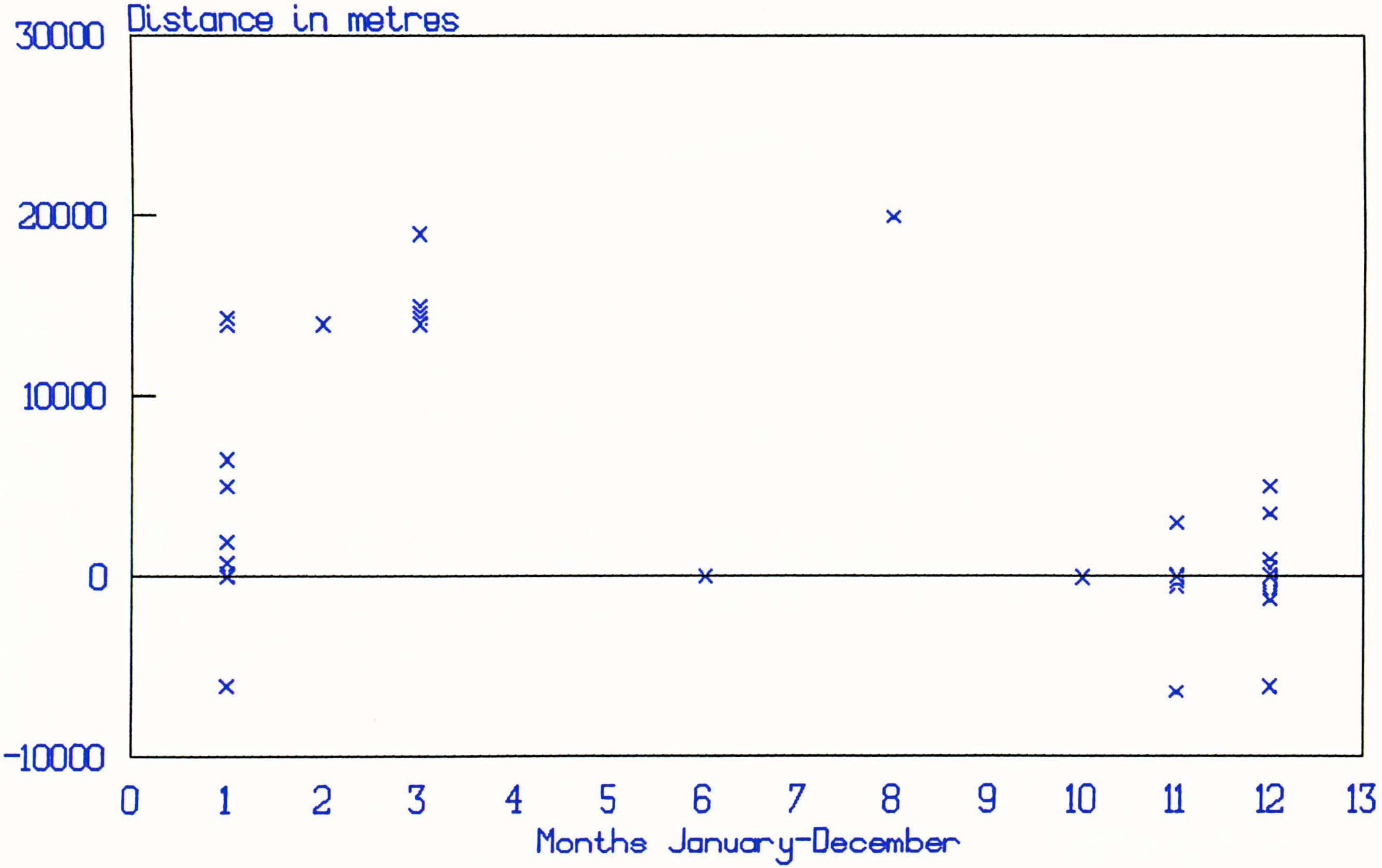
Fig 2.17



From Anglers Recaptures

River Dee - Distance of Dace Movements
Release of Fish at Chester (October-December)

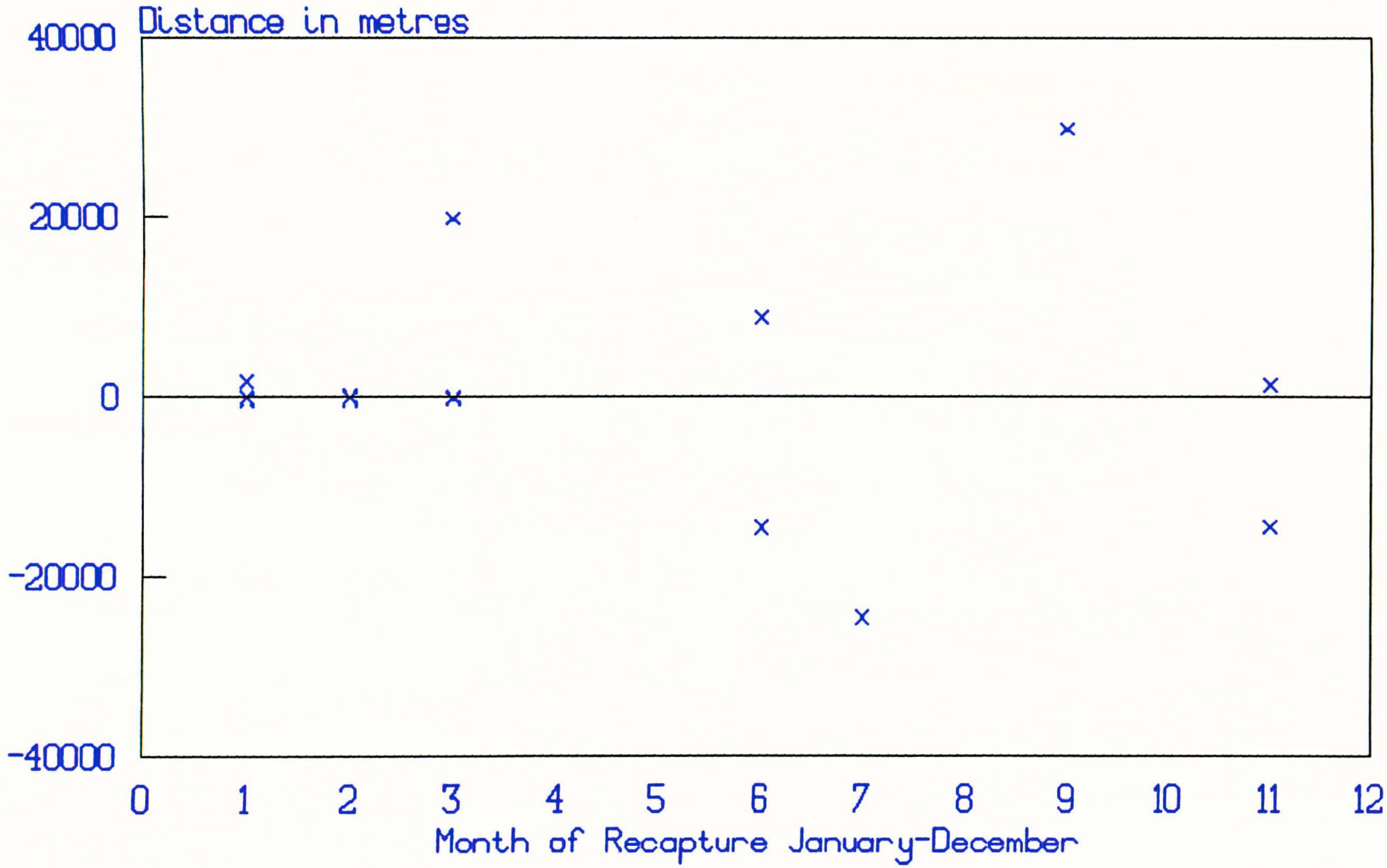
Fig 2.18



From Anglers Recaptures

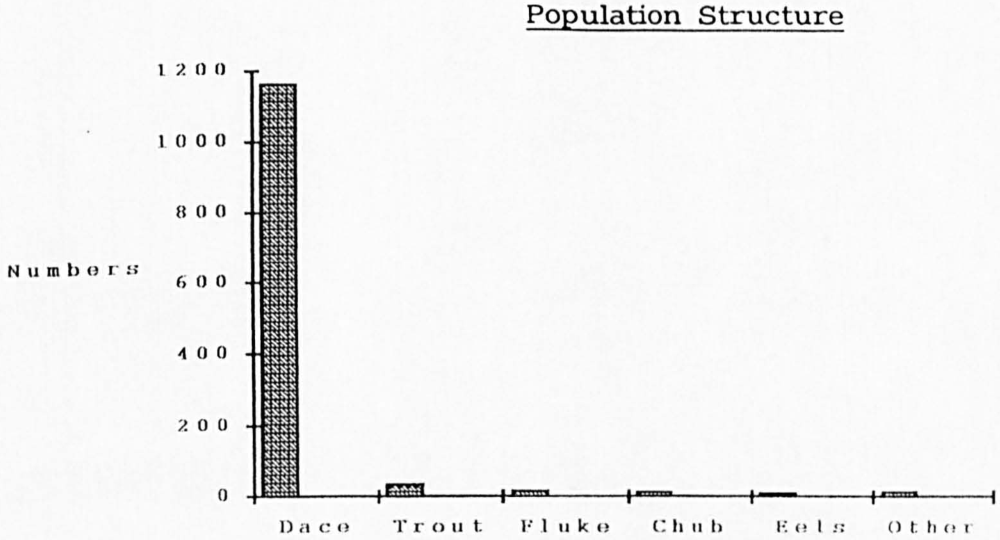
River Dee - Distance of Dace Movements
Release of Fish at Farndon in January

Fig 2.19



From Anglers Recaptures

Fig 2.20



2.3.3 Age and Growth Structure of Roach and Dace

Details on growth in length for roach and dace at Chester are included in Fig 2.23 and 2.24. Length/Weight relationship in Fig 2.25 and 2.26 and Age/Length relationship in Fig 2.27 and 2.28 are also shown for the two species.

The growth rate of both species are compared with other rivers in Fig 2.29 and the assessed year class strength in recent years is shown in Fig 2.30 and 2.31.

2.4 Discussion

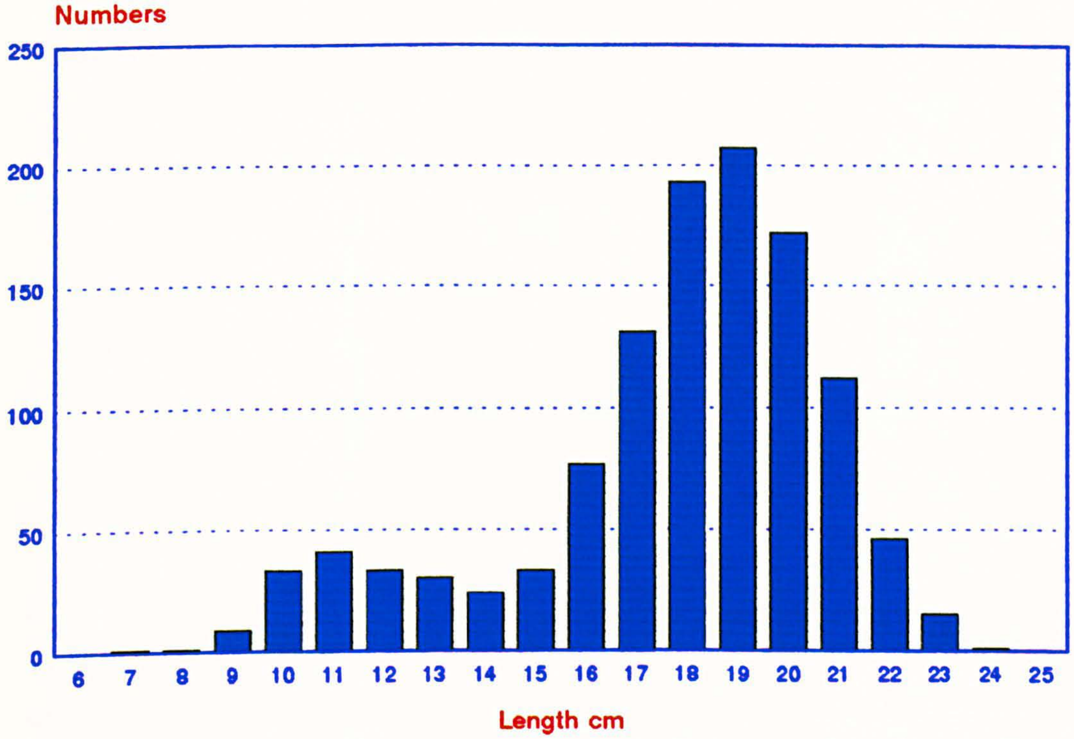
2.4.1 Coarse Fish of the River Dee

i) Species Present

There has been a considerable variation in species respective abundances over the years, to the extent that in the 1960's and early 1970's the Dee was predominantly a roach and perch river, with dace being very much a secondary species, (O'Hara, 1976). At the time of this study the

Size Distribution of Dace in the River Clywedog

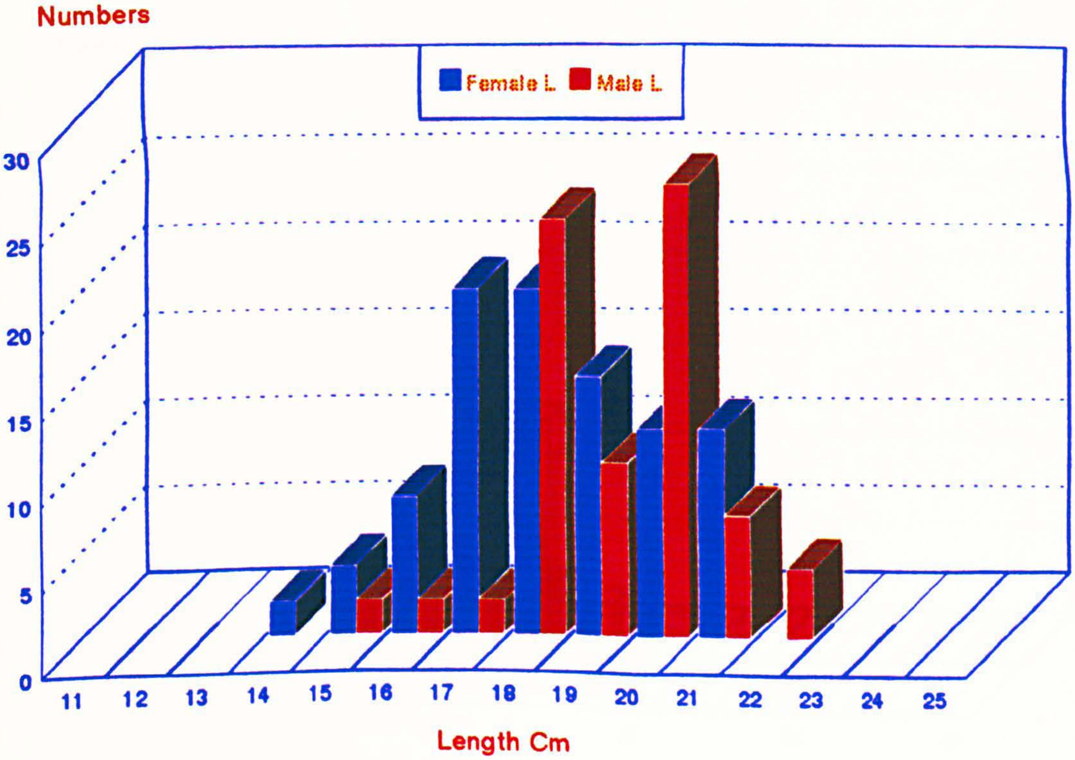
Fig 2.21



From Fish Kill
November 1990

Sex Size Range of Dace in the River Clywedog

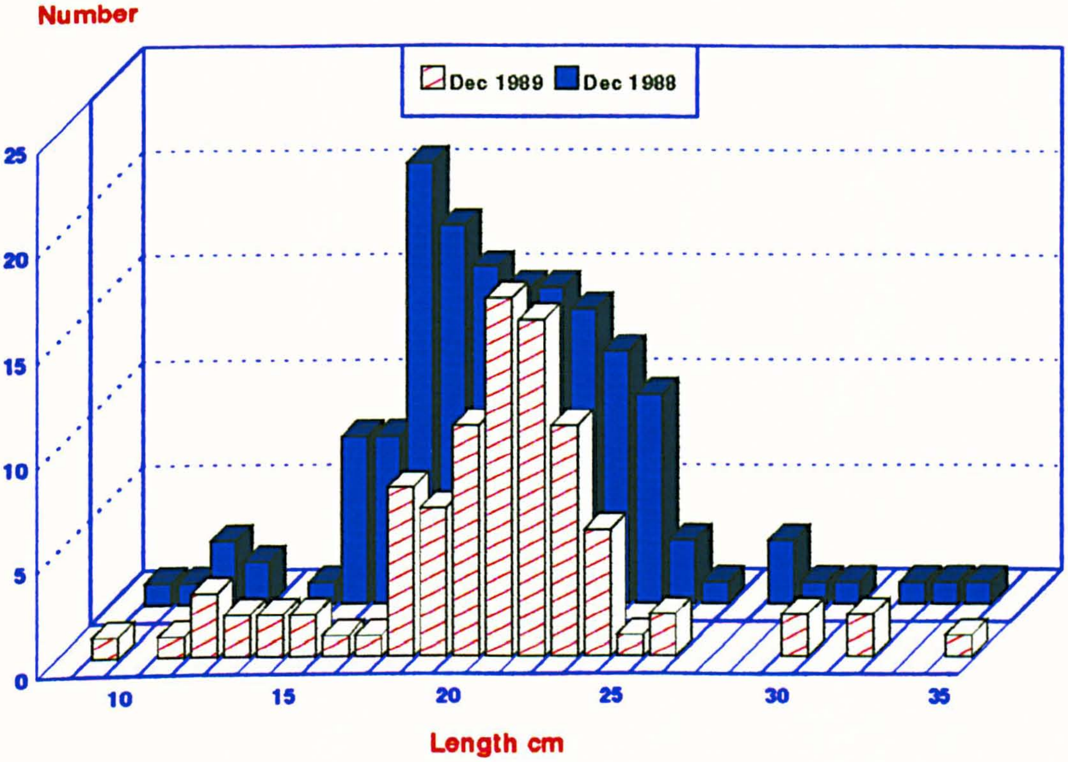
Fig 2.22



Length of Roach in Anglers'Catches

River Dee (Chester)

Fig 2.23



Length of Dace in Anglers' Catches

River Dee (Chester)

Fig 2.24

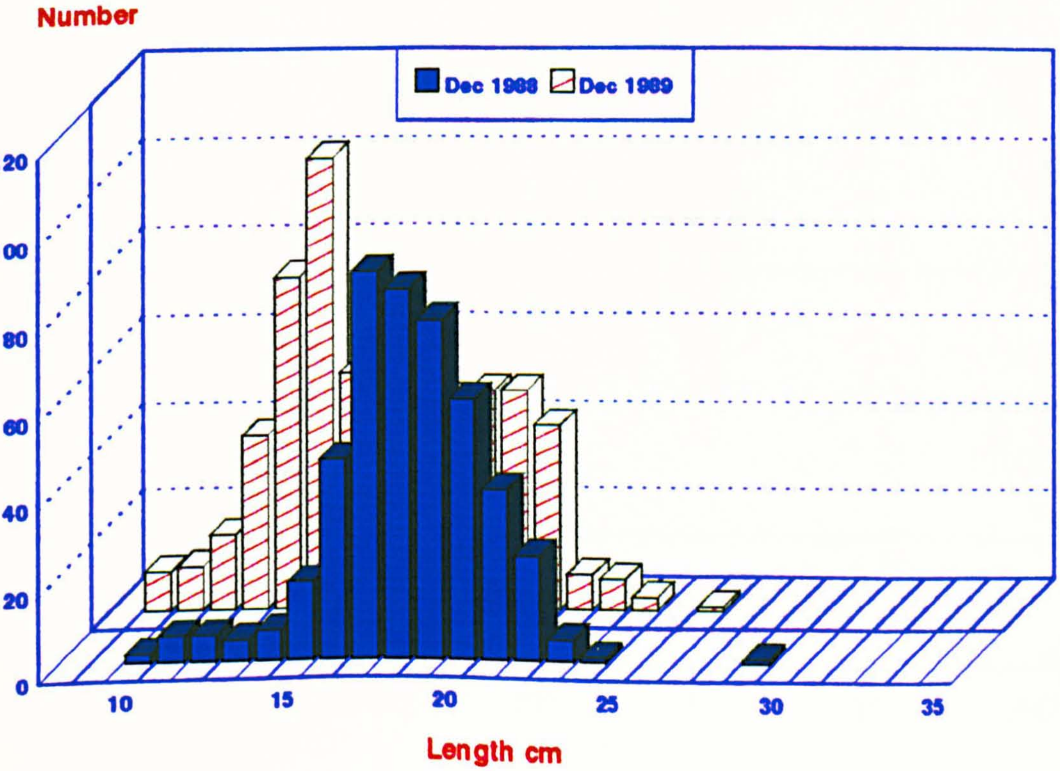


Fig 2.25

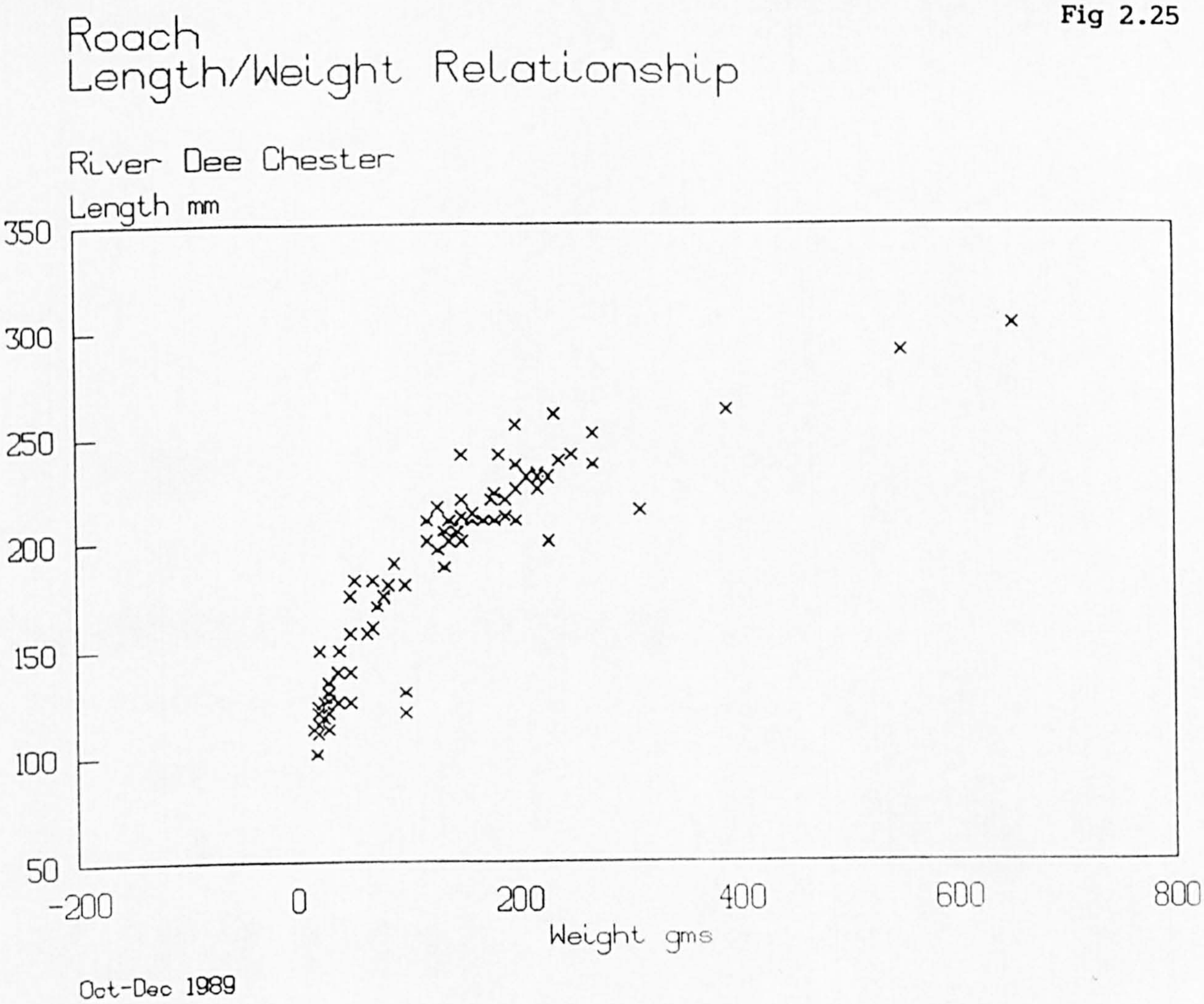


Fig 2.26

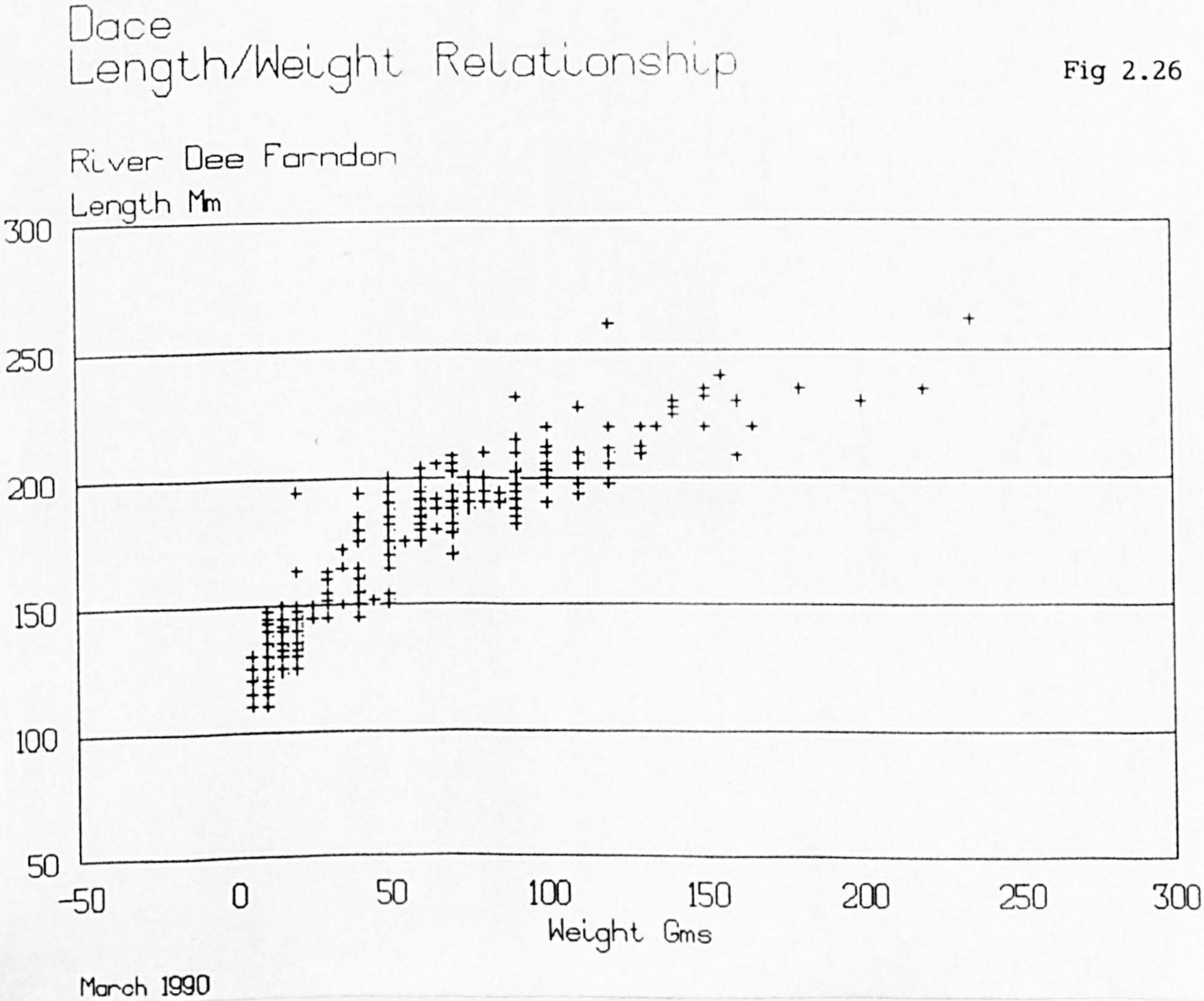
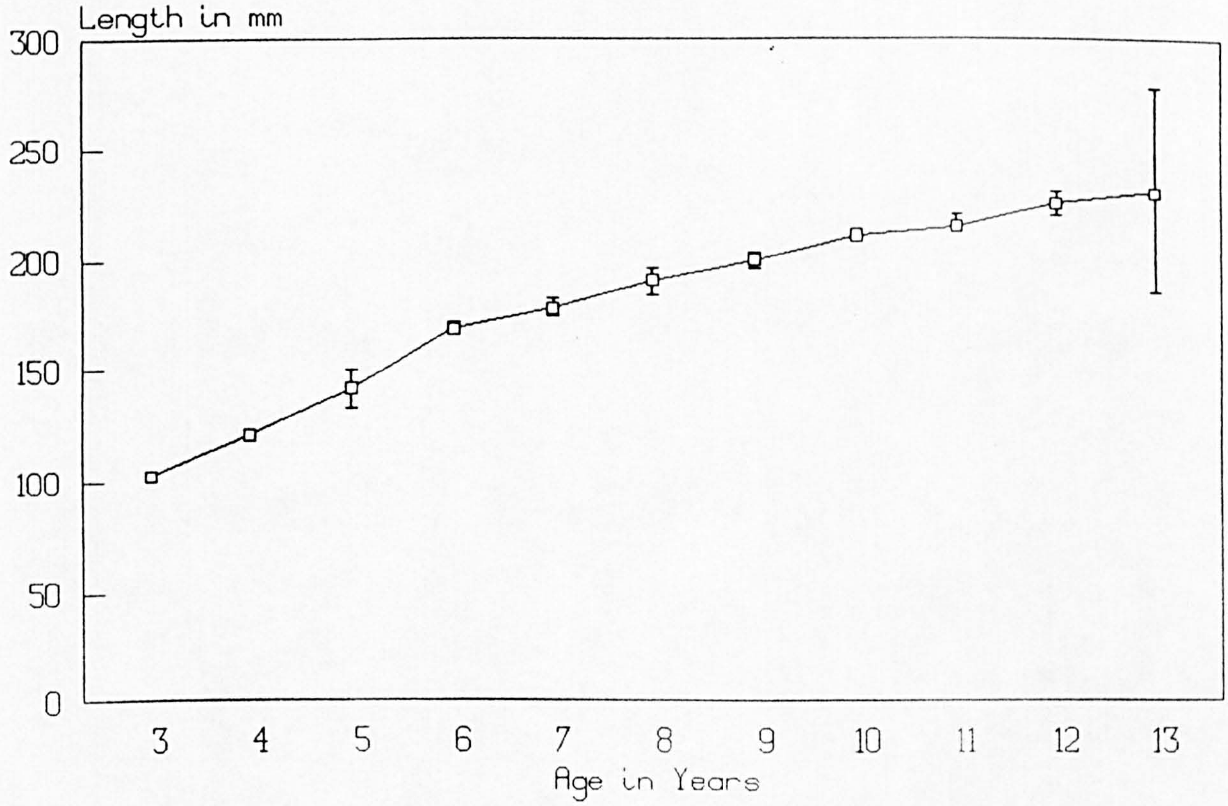


Fig 2.27

River Dee - Roach
Age/Length Relationship

From Angler's Catches in 1988 and 1989

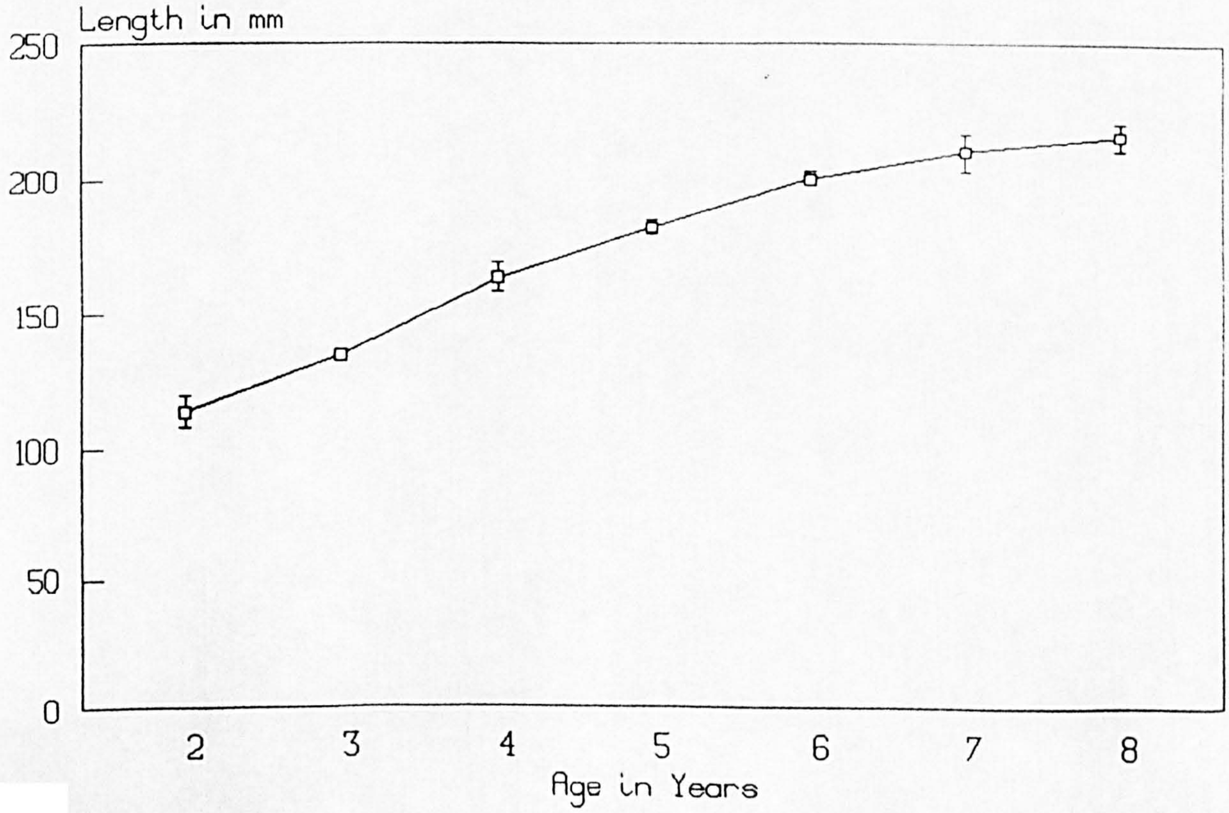


With 95% Confidence Limits

Fig 2.28

River Dee - Dace
Age/Length Relationship

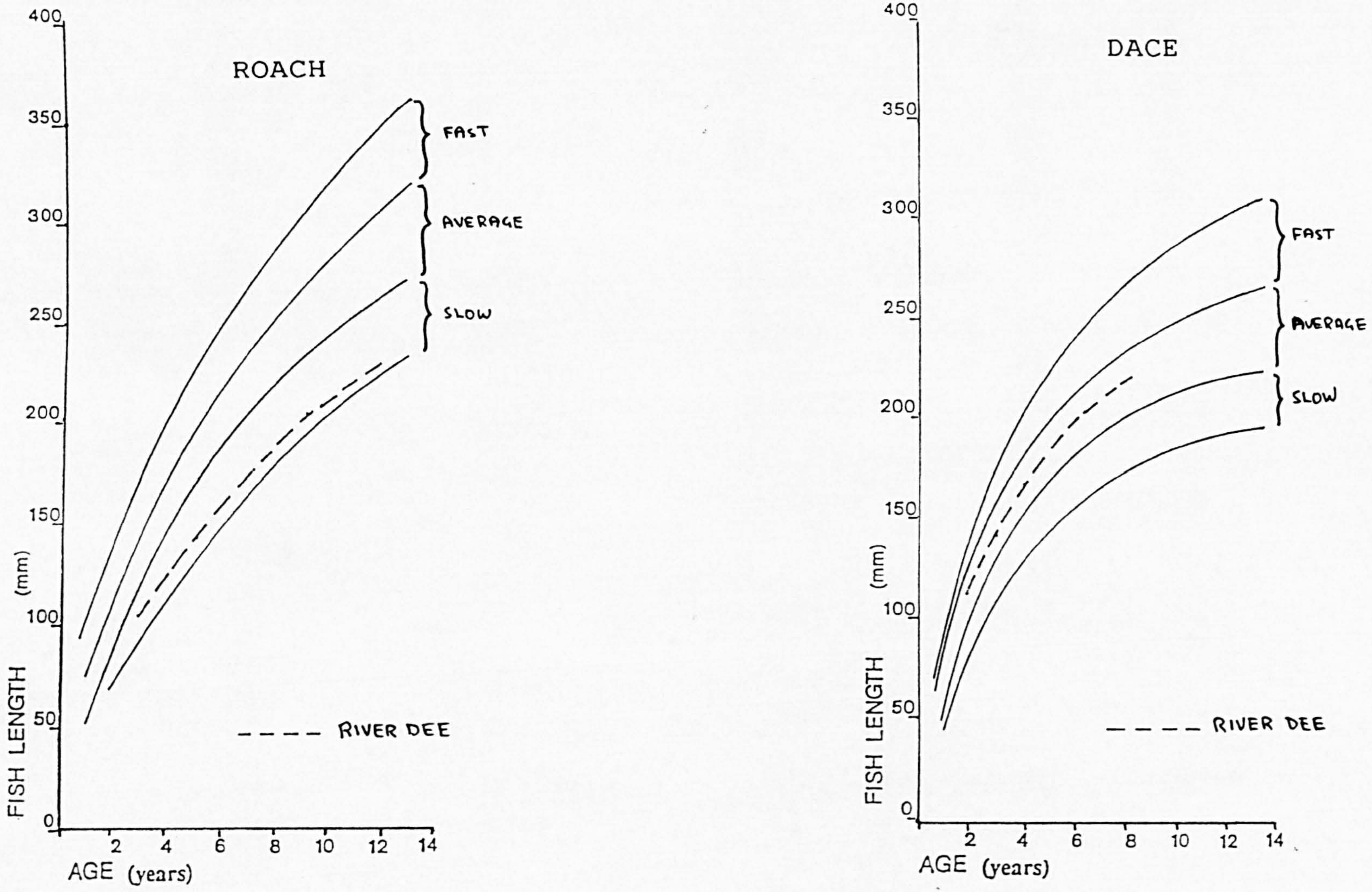
From Anglers Catches in 1988 and 1989



With 95% Confidence Limits

Variations of Fish Growth in British Waters

Fig 2.29

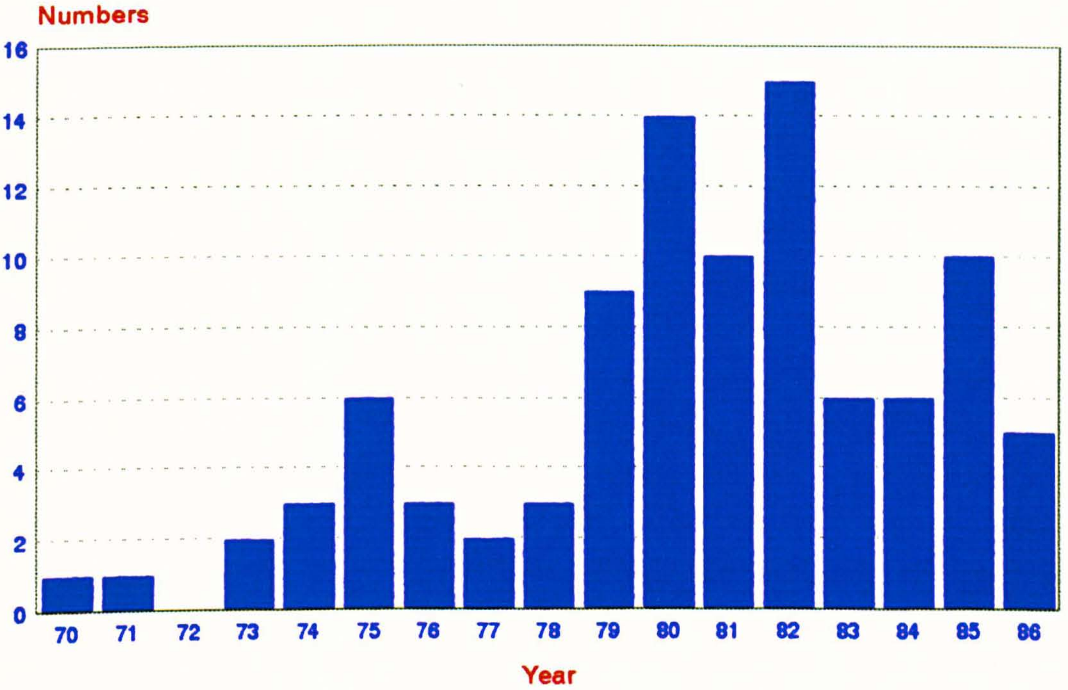


(Average Curve after Hickley and Dexter (1979) and Adapted by International Inst, Hull)

River Dee-Roach

Year Class Strength in Angler's Catches

Fig 2.30

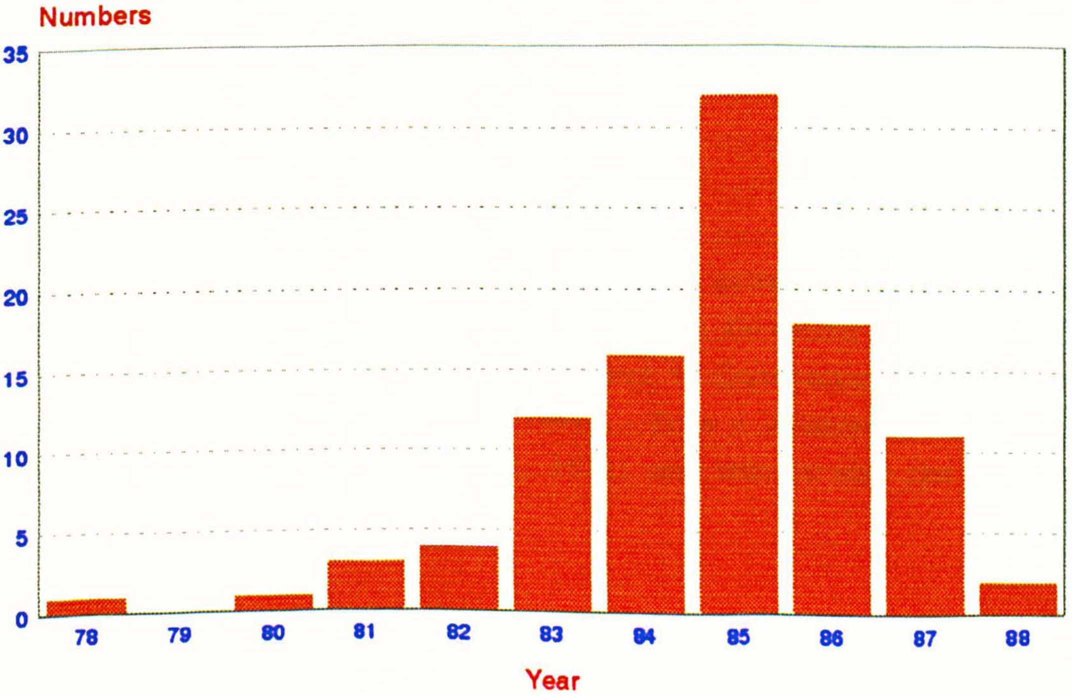


Fish caught 1988/89 & 1989/90 winters

River Dee-Dace

Year Class Strength in Angler's Catches

Fig 2.31



Fish caught 1988/89 & 1989/90 winters

situation was quite different as, the perch had almost disappeared from anglers' catches and roach too had declined. There had been an expansion in the numbers of dace throughout the lower river and this species was the predominant fish in angling returns.

Roach. (Rutilus rutilus (L.))

O'Hara (1976) reported that the dominance of roach in anglers catches ensured the Dee as a popular venue for competition events. Pearce (1983a) first recognised a decline in the late 1970's and speculated that environmental pressures reduced the ability of the species to compete, particularly with dace. It was also feared that roach too, were periodically suffering outbreaks of a myxobacterial disease causing roach ulcer disease. This may well have been true in the early 1970's, when this disease was most prevalent (Mawdesley-Thomas and Bucke, 1973) but since that time there has been no indication either from reports or direct observations that roach stockshave been affected by disease. Pearce (1983a) suggested that other pressures were possibly restricting the abundance of the species. The decline of roach and their scarcity in recent years has concerned anglers and demands for some answers and positive action for remedial measures was the principle aim of this study.

It can be seen from Fig 2.4 that roach are still to be found in rod catches close to Chester, but their presence is extremely variable and at times few or no roach are caught. The fish, in the main, are long lived specimens with the modal age in the catches being 9 years and a wide scatter in the age structure of the stock (Fig 2.30). This scarcity is very different to the mid 1960's when angling reports suggested that bag weights of up to 20kg were not unusual.

Dace. (Leuciscus leuciscus (L.))

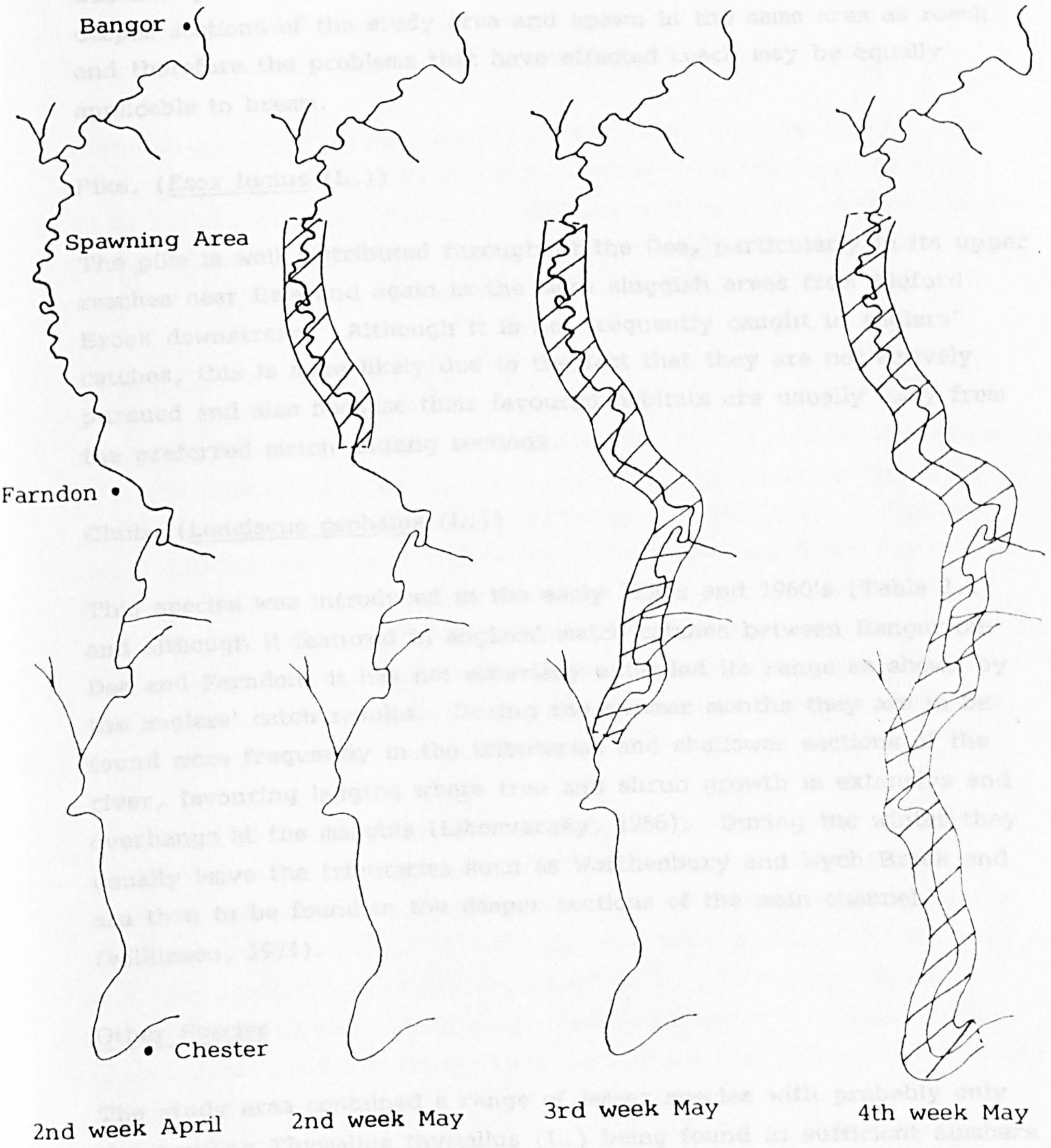
On the Dee, dace populations have increased progressively over the years to such an extent that they are now to be found upriver as far as Llangollen (Woolland, 1972) and downriver to Queensferry in the estuarial area (O'Hara, 1976 and Johnson, 1981). It is a relatively fast growing fish, but not long lived (Maitland, 1972) and this is why the population structure is made up of just a few year classes (Fig 2.31). In 1990 the predominant age grouping was between 3 and 6 years and the oldest fish achieved 13 years. It is active in all types of river conditions and water qualities for example, some of the more contaminated tributaries, like the River Clywedog, have a large population of mature dace (Fig 2.20 and 2.21), with males being proportionally larger than females (Fig 2.22). Maturity generally occurs in the fourth year (Mann 1974; Mills and Mann 1986) when the fish have reached 16cm (Phillipart, 1971,1981). The different sizes of the sexes demonstrated in Fig 2.22 can be an important life history strategy because, competition in a food deficient habitat will be less limiting as the fish develop. The species adaptability to different river zones and habitats has also assisted its wide colonisation, but perhaps more important is its ability to move long distances.

The dace spawns in shallower areas of the river (Pers observation) utilising well washed fine gravel zones in the upper section of the Cheshire Plain. They lay eggs on to the gravel in April and when the young fry emerge they soon passively disperse downstream (Fig 2.32). The dace is also adept at maximising its feeding area preferring the marginal areas where there is a degree of disturbance and as the fry mature they move into the mid-channel where they seek terrestrial insects, (Barnabus, 1971). On account of this preference they can be often seen rising actively at dusk and sometimes can become a nuisance to anglers who are specifically fly fishing for trout.

Bream. (Abramis brama (L.))

This species has never been widely distributed or abundant in the river, but where it occurs it is found in deep water sections which, periodically yield very large catches. Eccleston is the most productive area, but in the 1960's, deeper sections near Chester also yielded good weights of fish (Pearce, 1983b). The fish caught were generally large, between 1 and 2kg, and scale readings revealed that they were long-lived fish. O'Hara (1976) determined that strong year classes only occurred infrequently and were often widely spaced. Small bream are rarely seen and, despite regular hand netting and micronetting for juveniles in this study, do not appear very frequently in samples. Although the bream

Fig 2.32



River Dee - Dace Fry Migration
(Bangor-on-Dee to Chester)

was not specifically studied in this programme, they are resident in the deeper sections of the study area and spawn in the same area as roach and therefore the problems that have affected roach may be equally applicable to bream.

Pike. (Esox lucius (L.))

The pike is well distributed throughout the Dee, particularly in its upper reaches near Bala and again in the more sluggish areas from Aldford Brook downstream. Although it is not frequently caught in anglers' catches, this is more likely due to the fact that they are not actively pursued and also because their favoured habitats are usually away from the preferred match angling sections.

Chub. (Leuciscus cephalus (L.))

This species was introduced in the early 1950's and 1960's (Table 2.1) and although it featured in anglers' match catches between Bangor-on-Dee and Farndon, it has not materially extended its range as shown by the anglers' catch results. During the summer months they are to be found more frequently in the tributaries and shallower sections of the river, favouring lengths where tree and shrub growth is extensive and overhangs at the margins (Libosvarsky, 1966). During the winter they usually leave the tributaries such as Worthenbury and Wych Brook and are then to be found in the deeper sections of the main channel (Wilkinson, 1974).

Other Species

The study area contained a range of lesser species with probably only the grayling Thymallus thymallus (L.) being found in sufficient numbers to be exploited regularly by anglers. Although frequently grouped, incorrectly, with the salmonids of the river, angling match reports indicated that they were increasingly present in catches in the Overton to Bangor-on-Dee length during the summer months. Regulation has probably extended their range and indications are that this will continue, (Woolland, 1972). Further upstream, between Bala and Erbistock, the population has increased to a level that the Dee is now considered one of the finest grayling fisheries in the country and a centre for international fly fishing events (Hodgson and Scutter, 1983).

Barbel Barbus barbus (L.) are a new species to the Dee and, like the chub, have probably been introduced illegally from the River Severn. Their spread and abundance has been slow with only the occasional fish being caught by anglers. The most recent and probably the largest was a fish of 3.6kg landed at Erbistock in March 1992.

ii) Restocking of Coarse Fish

Historically there was a considerable variation in the level of restocking that took place on the Dee and the reasons for undertaking them were equally varied (Dee and Clwyd Annual Reports, 1930-91). Before the war, stocking was increased after the formation of the River Boards, on account of their extended responsibilities with regards to coarse fish under the 1923 Salmon and Freshwater Fisheries Act. The fish, which were principally roach and perch, came from a diverse source of still waters around the catchment area and questionable benefit was derived from these improvement efforts (Pearce, 1983a).

By the early 1960's increased importance of coarse fisheries, following a growth in interest in the sport (NOP,1971), initiated a phase of non-selective fish transfers which was aimed at enhancing the populations of roach, perch and bream. At this time legitimate stockings by the Dee and Clwyd River Board were supplemented by a number of illegal additions from other waters, which included non-native species which were carried out by anglers, frustrated by the declining quality of their sport on the river.

Again no sustained benefits were detected as anglers' catch returns from the period showed no sign of improvement, (Pearce, 1983b). Not only did stocked fish come from enclosed waters, but also some were from stunted fish communities in overpopulated or nutrient deficient waters, eg Alwen Reservoir. Poorly developed musculature (Broughton et.al., 1977) probably meant that the fish were washed from the Dee soon after being put in. In the studies of O'Hara (1976), unusual species were recorded from the tideway which could be directly related to stockings of this kind. It was regrettable that so much effort created no identifiable gain, but it did enable management to pursuade angling interests to adopt a different policy and to co-operate fully in the evaluation of the problem that could possibly lead to a more effective solution. The influence was such that by the beginning of the 1980's pressure to transfer random, ill-suited stock was almost removed and following this, only a very small addition of roach in 1986 materialised.

With regards to illegal stockings, only chub and barbel are likely to have entered the Dee in this way, and in both cases the likely source is the River Severn. Reports of illicit stockings of chub in c1955 and 1971 were reported by O.Hara et al (1983) but unlike the barbel they have adapted well and have expanded their range. The first barbel were introduced around 1980 and even today only occassional fish are caught.

2.4.2 Size and Structure of the Roach and Dace Populations

2.4.2 i) Anglers' Catches

A problem of the lower Dee fishery, was the anglers perceived decline in stock size and distribution, not only from year to year but also within a single season.

Many environmental factors influence variation in stock size and distribution. River depth and diversity of channel size and shape are known to be important (Stuart, 1959). Swales (1980) considered the influence of habitat structures on fish populations. Water flow, velocity, bed slope and river width were the basis on which Huet (1959,1962 and 1973) defined a zonal distribution classification for European rivers, although Backiel (1964) and Hynes (1970) stressed the need for caution in its application in new locations.

Habitat diversity is a key factor in influencing fish population in all river corridors and river management methodologies are being developed which recognise this, not only taking account of geological and geomorphological features, but also vegetative abundance. Milner et.al.(1985) has advanced a method titled 'Habscore' which codes variability in habitat. Eaton (1986), and Hodgson, Pearce and Eaton (1988) have also promoted schemes to develop habitat in order to improve fisheries populations.

In the present study, adult fish were assessed using anglers' catches. The advantages of using this method as a means of obtaining information on adult fish populations on the Dee was:

i) The length of river covered by the sampling was extensive.

ii) Fishing took place during a specified time period and involved using the consistent technique of rod and line,

iii) The dependency on favourable conditions for sampling was not nearly so crucial,

iv) The majority of fish were retained and weighed at the end of the event and therefore were available for analysis,

v) The sample size obtained was consistently high and could not have been acquired by any other means,

vi) All fish could be returned to the river alive.

The use of anglers as a means of sampling was also convenient for the dissemination of information on the research programme being performed. Using them as sampling technicians invariably lead to greater co-operation where assistance was especially needed, for example in the implementation of the tagging scheme.

The main disadvantages of using anglers' catches as it applied to the Dee were:

i) There was possible size and species selection of the fish caught by angling, whether it be with the elimination of smaller fish from the sample because they were not able to be caught or, the older, larger fish were more difficult to catch.

ii) There was a variation of location for the events according to season.

The study was pursued to establish the movement of fish seasonally, but it was found that location of events also changed, sometimes at short notice, according to the anglers predicted dispersion of fish within the lower Dee, based on experience. The majority of angling matches tended to take place in the Chester area between October and January and thereafter move to Farndon until the end of the fishing season in mid March.

iii) There was a difficulty in obtaining the total match catch and weight as clubs were more concerned with the largest catches only.

iv) The coarse fish close season was between the 14th March and the 16th June and therefore there was no angler information available during this period.

v) During the summer months, it was the holiday or pleasure angler that fished the river near Chester and the effort level varied according to the weather or river conditions prevailing at the time. Higher up the catchment, between Farndon and Bangor-on-Dee, angling matches continued to take place and therefore, in this area, summer catch statistics remained more consistent.

vi) There were differences in the ability of anglers to catch fish both within events and between events.

vii) The collection and handling of fish caught by anglers was very labour intensive.

A large number of bailiff staff from the National Rivers Authority were required to undertake the work. This was because at the completion of the event, the competition weighing of the fish started at different points of the river at the same time, to avoid unnecessary delays for competitors. Event stewards were responsible for weighing the catch of a specific number of pegs (anglers fishing locations), usually 10, but this depended on the size of the event and the number of weighing scales available to the organisers. For most matches a minimum of six water bailiffs were needed but for the larger events double this could be required. Two were necessary to undertake the tagging and logging procedures and the others had to collect the fish from different locations simultaneously and also ensure the safety and security of the fish collected, while waiting to be examined.

viii) There was a difficulty in obtaining reliable and consistent data from the anglers.

Initially it had been hoped that the angling club officials could have separately weighed the proportions of the different species caught in the matches, but this was found not to be practical because:

a) Fish were normally collectively weighed at the weigh-in and as speed was important to the anglers, individually weighing different species was unacceptable.

b) A number of individuals were weighing the fish and therefore consistency of measurement of individual fish was not assured.

c) A number of anglers could not discriminate between dace and roach, so serious inaccuracies would have developed in the data.

In the case of data acquired direct from the club secretaries, where events were not personally supervised, the requirement to record species weights and numbers was also frequently ignored. In practice the anglers were reluctant to accommodate the extra demand of weighing and recording individual species and only provided total catch weight for the top 3 or 6 anglers. On account of these difficulties, species abundance was assessed separately during the tagging programme when all fish were inspected individually.

During the period of sampling it became apparent that to obtain reliable and consistent data on coarse fish by the utilisation of catches by anglers required considerable manpower and supervision and even with the support staff available for this programme the information acquired did not satisfy all requirements. This emphasised the problems of sampling large lowland rivers like the Dee and to improve this situation, alternative sources of information were pursued.

Data from angling reports in local newspapers were used to extract catch weights from competition events on the river. The interest in fishing locally, ensured that reports were regular, comprehensive and were of sufficient detail to provide useful information. The format dictated that the angling club, location and top three catch weights were recorded for each competition. By consultation with local club secretaries, duplication of data from events were avoided and numbers of competitors could be acquired. Collectively this approach gave a consistent and composite picture of the catches being made on the river. Minotti and Malvarez (1991), have similarly used information from newspapers, which in their investigation, was used to assess the timing and spatial distribution of migratory fish on the Parana River in Argentina.

From the study an accurate representation of species ratio at the two locations of Farndon and Chester was established, which confirmed the dominance of dace and the scarcity of roach and other species at both locations. This finding was consistent with anglers comments, that catches declined at Chester seasonally, usually at the end of each year, although the timing of the movement appeared not to be consistent from year to year. For instance in 1988/89 a decline in catch at Chester did not take place until March, in 89/90 it was February and 90/91 it was January.

The results from all matches detailed in Table 2.2-2.6 confirm that there is a problem of fishing quality in the river close to Chester. Figures from the Dee do not compare favourably with other rivers where coarse fishing is important. Catch rates recorded from competitions on the River Trent were 114.7 $gm/man.hr^{-1}$ (Cowx and Broughton, 1986), the River Ouse, 58 $gm/man.hr^{-1}$ (Axford, 1979) and River Severn, 82-176 $gm/man.hr^{-1}$ (Hickley and North, 1981).

The figures are not directly comparable however, because on the Dee only the top three anglers weights were included in the analysis as opposed to the total catch weight on the other rivers. At Chester this may not affect interpretation too greatly because the catch weights recorded below the top 3 are small. At Farndon this is not the case, and therefore the comparisons are more suspect and probably underestimates against the other rivers. Comparisons between the two areas on the Dee, however, are relevant because the method is consistent.

2.4.2 ii) Movement of Roach and Dace

This part of the study was initiated to investigate the use of the system by coarse fish which would also assist in establishing the reasons for anglers stated decline in catches during periods of the year, at Chester. As dace and roach were the main species caught by the anglers in matches, it was considered that a representative sample could be acquired from different areas to enable assessment on seasonal movements to be made.

A tag return of 5.27% was achieved for dace and 4.12% for roach but at the outset a figure closer to 10% had been hoped for. Davidson (pers comm) with salmon tag returns managed to achieve 7% with a higher profile campaign of publicity and monitoring. It is believed that this figure for coarse fish could have been improved with greater effort on the bankside, as reports were received of anglers having caught fish with tags which they had not declared. Midway through the programme a prize draw of £100, directed through the local branch of the Welsh Federation of Anglers in co-operation with Chester Anglers Association, did boost returns and probably indicated that the standard £1 tag reward was inadequate. As money for incentives was limited, this figure was appropriate at the start of the project, particularly in view of the large number of fish being tagged and the potential for large number of returns being made. Despite attempts to reassure anglers of the value of the scheme, there was still some who were opposed, and therefore returns from this source were predictably limited. Details of the promotion of the tagging scheme together with an example of the returns received from anglers are revealed in Fig 2.33 and 2.34.

From the data available it was shown that roach for most of the year move in the channel between Chester and Eccleston and then some swim upstream to the Aldford area, possibly to spawn in the first tributary where spawning can take place. Diamond (1985) suggested that roach used traditional spawning ground annually. Whether this pattern of movement is consistent within the whole stock is doubtful because, even with the limited information, there is a degree of variablity as to where the roach are distributed at different times of year. Movement patterns may have become more localised than in the past because there is now no special requirement to seek out suitable spawning areas, such as that found in Aldford Brook. This is because of the wider availability of spawning media, following an increase in weed growth in the lower river (See Chapter 5).

With dace, the winter movement occurred upstream, usually around early January, into the Farndon reach where they remained until the close of the fishing season. What happens to the fish after this time was difficult to establish because of the close fishing period (March-June) but it is pertinant to note that of the four dace tags returned in the summer months, one had moved upstream 9 km to Shocklach by June, another 30 km upstream to Overton-on-Dee by September and the remaining two returned downstream, one to Eccleston and the other to the tideway at Saltney below Chester Weir, in June and July respectively.

Observation on the river during the spawning period showed spawning to be active between Farndon and Bangor-on-Dee. It is therefore believed that dace migrated in both directions from Chester and Overton and

Fig 2.33

NOTICE TO ALL ANGLERS.

RIVER DEE

COARSE FISHERIES IMPROVEMENT PROGRAMME.

TAGGING SCHEME.

As part of the above programme the National Rivers Authority is investigating the populations and movement patterns of coarse fish in the Lower Dee particularly Roach, Dace and Chub.

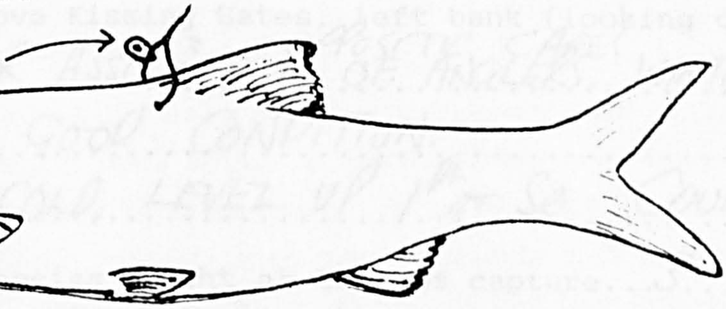
Part of the investigation involves the tagging of adult fish in the river. If sufficient of these tags are returned we shall have valuable information on the coarse fish population, general movements, growth rates and most importantly the spawning success.

This part of the programme will supplement the fry stocking programme that started in 1989.

Please help by reporting all tagged captures giving the following detail:-

1) Name, Address and Telephone Number of Captor.
2) Tag numbers (include tag).
3) Species of Fish.
4) Length (nearest mm). Weight (approximate).
5) Date and Time of Capture.
6) Place of Capture (exact location).
7) Condition of Fish.
8) Condition of River.

Location of the Tag.



R E W A R D S.

The National Rivers Authority will pay an immediate £1.00 reward on receipt of the tag and information and your name will go into the Prize Draw at the end of each year of the programme. Prizes in 1989 were £50, £30 and £20.

Address to forward tags and detail:
National Rivers Authority, Fisheries Department, Shire Hall, Mold, Clwyd, CH7 6NQ. (Telephone Number - Mold (0352) 700176 - Ext.2852.)

Or

Local Fishing Tackle shops in Chester and Wrexham.

Fig 2.34

NOTICE TO ALL ANGLERS.

RIVER DEE.

COARSE FISHERIES IMPROVEMENT PROGRAMME.

TAG RETURNS.

If you catch a coarse fish from the River Dee bearing a tag you should record the following detail and then attach it to this form, and forward it to the National Rivers Authority, Fisheries Department, Shire Hall, Mold, Clwyd, CH7 6NQ, or take it to your local Fishing Tackle Shop in Chester or Wrexham.

The National Rivers Authority will pay an immediate £1 reward on receipt of the tag and information and your name will go into the Prize Draw at the end of each year of the programme. Prizes in 1989 were £50, £30 and £20.

INFORMATION REQUIRED.

TAG

Tag No. 013

Date of Capture 5/11/89 Time 12.00 MIDDAY

Species of Fish DACE

Length 195 mm nearest mm. Weight 3½ OZ (Approx.)

Exact Place of Capture LEFT BANK, 60 YARDS UPSTREAM. SUSPENTION BRIDG. OPPOSITE CAFE.
(Example 55 yards above Kissing Gates, left bank (looking downstream))

Fishing Event CHESTER ASSOCIATION OF ANGLERS. WINTER LEAGUE.

Condition of Fish GOOD CONDITION.

Condition of River COLD, LEVEL UP 1 FT or SO COULERD

Number of Fish and Species caught at time of capture 3 DACE
ALL IN GOOD CONDITION

Name, Address and Telephone Number of Captor PHILIP GEORGE KINNEST
3, WALTHALL STREET. CREWE, CHESHIRE. CW2 7JZ

Thank you for your co-operation in providing this information.

Fisheries Department,
National Rivers Authority.

congregated to spawn in this section of river and then migrated back to their original locations. Not all dace, however, move in this way as modest catches continue to be made even into February and March in the Chester/Eccleston area but the majority are small and immature. None of the dace that moved appreciable distances were immature. Of the 15 dace that had moved over 5km the smallest was 18cm and the largest 26cm with the mean in the range 19.0-19.9cm.

Populations of dace from other areas may well be present outside the area of the tagging scheme. In total 1593 dace were tagged and when assessment was made of the number of fish taken by the anglers catching a tagged fish at Chester, 16 fish were caught for every tagged fish and at Farndon this increased to 25.3. In the total fish kill that occured on the Afon Clywedog in November 1990 not one tagged fish was found in a total stock of 1283 fish even though 73% were above the size for potentially migrating fish. It was also shown from the results of the kill, supported by the findings of Wilkinson, (1974) in studies on three tributaries of the Worthenbury brook system, that adult dace, more than juveniles, populate the tributaries of the upper Cheshire Plain. This would suggest that tagging of dace in the main river alone is insufficient to fully evaluate the movement pattern of the species or assess its population size.

It has been shown that the dace population movement and distribution in the Dee is complex but their ability to move quickly over long distance has been a large part of their success. Kennedy, (1969) stated that the dace preferred swifter currents than most cyprinids and as a lithophil spawner resembled the minnow and gudgeon, rather than roach or bream that deposit their eggs on plants. The water quality and bed substrates found in the lowland Dee tributaries (Chadwick, 1984 and Wilkinson, 1974) are less suitable for successful spawning recruitment of dace while the high quality, consistent flows and suitable bed substrates between Bangor-on-Dee and Farndon provide more appropriate habitat (Pearce, unpublished).

The way the pressures of the system impact on the dace and other species will be examined in Chapter 3 but to fully understand the intricacies of what influences their movement pattern and distribution will require further detailed research.

2.4.3) Age and Growth Structure of Roach and Dace

In both roach and dace, the annulli were clearly apparent and represented a closing together of the arranged circulli which, dependent on the species, are laid down during the winter or early spring period. Variations were observed, particularly with the presence of replacement scales where no central focus could be seen. Such scales were frequently found in younger fish. Some scales showed a certain degree of fracturing and others had false checks where the annulli appeared to be present but were not consistent all the way round. No extensive erosion was apparent on the outer edge of the scale in either species, such as can be a problem in salmonids at critical phases of the life cycle. A difficulty was experienced with the roach as they became older, because in larger fish the banding became closer together and had a tendency to merge with earlier annulli.

From Fig 2.29 it was revealed that the growth rate of the roach in the Dee was below the average for other rivers and could be considered stunted. The age structure of the population principally comprised of older stock with few small fish being found and despite the low numbers sampled there was a very wide range of year classes present in the population at Chester (Fig 2.30). No appreciable stock of roach occurred at Farndon as only the occasional fish was recorded in catches.

The anglers do not exploit roach up to 3 years old to any appreciable degree but there appeared to be an apparent scarcity of fish in the 2nd and 3rd year class as few were caught in seine netting at the margins or gill netting in the tributaries. Capture of juveniles in the margins was not a problem particularly in the very warm years of 1989 and 1990. In a river like the Dee there is a difficulty in sampling these 2nd and 3rd year classes as they move out of the margins into deeper water and become less available. It is an aspect that needs further investigation because whereas '0+'fish are subject to variation in year class strength Mills and Mann (1985), the survival of juveniles through their first and

Plate 2.2 Spawning Area for Dace

2.4.3) Age and Growth Structure of Roach and Dace

In both roach and dace, the annulli were clearly apparent and represented a closing together of the arranged circulli which, dependent on the species, are laid down during the winter or early spring period. Variations were observed, particularly with the presence of replacement scales where no central focus could be seen. Such scales were frequently found in younger fish. Some scales showed a certain degree of fracturing and others had false checks where the annulli appeared to be present but were not consistent all the way round. No extensive erosion was apparent on the outer edge of the scale in either species, such as can be a problem in salmonids at critical phases of the life cycle. A difficulty was experienced with the roach as they became older, because in larger fish the banding became closer together and had a tendency to merge with earlier annulli.

From Fig 2.29 it was revealed that the growth rate of the roach in the Dee was below the average for other rivers and could be considered second winter may be more crucial. The flows and forces present in the lower river will be examined further in Chapter 3.

The dace population was comparitively short lived, with most fish in anglers catches between 3 and 7 years (Fig 2.31). The growth rate was comparable with other rivers and no stunting in the stock was evident. The movement results indicate that it is a highly mobile stock with the younger year classes being more stable but although dace move in and out of the tributaries, ie River Clywedog, there is still doubt as to the degree of mixing of the stocks from the different areas.

Summary

It has been shown that the fish population in the study area, particularly in respect of roach, is small and may not be of sufficient size to create a recovery in future years to restore a good coarse fishery for the angler. It would also appear that the numbers of bream and perch are likewise very small and possibly similarly restricted in their development. The reasons for the problems will be investigated by assessing the pressures in the river system that may have influenced the fishery and brought about its changed status.

Chapter 3

3.0 Changes in River Regime which may have affected Cyprinids

Introduction

On any river system there is a range of natural factors that influence how the ecological systems develop and these features vary considerably within each catchment. Ward and Stanford (1989) have tried to categorize the natural interactive pathways so that cause and effect of change can be more clearly appreciated. They suggested four main components : longitudinal (from source to sea), lateral (river to floodplain), vertical (riverine to groundwater) and temporal (time scales). Even though these components are applicable whatever size of river is being considered, mans' influence is often a major factor in any individual river system.

Eaton (1989) has reviewed the way man historically has influenced changes to river habitats which emphasizes how little regard has been taken to the ecological consequences of such developments. In lowland river corridors man-made influences can impact severely on the environment and this is probably especially true of large rivers supporting commercial activities and industry. For example, on the River Vistula in Poland, the problems emanate specifically from heavy abstraction and pollution (Backiel and Penczak, 1989). On the River Ganga in India, change has resulted from more general cultural development and expansion in the catchment (Natarajan, 1989).

Whatever the causes, it is necessary, when formulating management plans aimed at improving the ecological integrity of a river, to identify the pressures that are most prevalent before advancing practical solutions.

On the River Dee four major, man affected influences on fish populations were identified and these are detailed in order to attempt to explain the mechanics of the system. These are:

i) Land drainage and flood prevention.
ii) Water quality.
iii) River flow regime.
iv) Recreational boat traffic.

3.1 Land Drainage and Flood Prevention

Anthropogenic activity on river channels, particularly land use changes, can exacerbate flooding and instability in rivers by concentrating flow between floodbanks (Hey and Winterbottom, 1990). In historical times on the River Dee the rich, glacial deposits of the flood plain provided a suitable environment for farming development and production. The periodic inundation of the land from floods also assisted with natural fertilisation of such areas until the development of inorganic fertilisers became the major way in which productivity was maintained.

As farming practices advanced, the seasonal flooding of lowland land became a positive hindrance and therefore the emphasis changed from actually utilising the benefits of flood water, to the other extreme of directing efforts to prevent flood plains acting in their natural way. This was achieved by the construction of flood embankments along the lengths that were vulnerable to overtopping, which on the Cheshire Plain extends from Overton to within a few kilometres of Chester. The construction of flood banks has been a progressive one as techniques and equipment have made the task easier. To a great extent the developments have been influenced by the trends and demands within the farming industry.

From Overton to Farndon the flood banks are designed for a one in a hundred year flood and consequently are rarely threatened with overtopping (Braine, 1959). Downstream of Farndon however, the land levels in places are within two metres of normal river levels and flood and drainage is somewhat problematical. There are three main reasons for this, all of which can play a part:

i) The discharge capacity to the estuary at Chester is limited to just 7mm/day of catchment rainfall because of the constricted channel through the sandstone outcrop on which the city is built (Lambert, 1988).

ii) Chester Weir is an obstacle that creates a 4.3metre AOD head level upstream and therefore rises in river level do not need to be great to create a flooding effect.

iii) The combination of high river flow with an extreme spring tidal sequence, pushed higher with along channel wind currents in the tideway, can quickly create flood conditions even in summer.

Sections of the upper Cheshire plain are developed as rich agricultural pasture because they are rarely inundated with flood water on account of protection from high flood banks. Lower down the study area however, there are other areas of the flood plain that frequently operate as they did historically, by flooding seasonally and remaining waterlogged and untenable for farming. Despite the limitations for farming, little consideration is directed to utilising such land for more beneficial conservation interests, although it does provide inland feeding ground for birds like curlew Numenius arquata, snipe Gallinago gallinago and lapwing Vanellus vanellus during drier periods and for waders and other waterfowl when wet (Williams, 1971).

Attempts to reduce flooding problems in the lowland area have been made eg Aldford Brook sluices, but they have been largely unsuccessful for the reasons outlined and therefore, during extreme floods, discharge from the system is closely related to natural conditions.

During the 1964 flood when 615 m^3sec^{-1} was recorded at Erbistock, which in effect is an actual 1 in 100 year event, the land covered extended to 2% of the whole catchment and 5% of the lower catchment; this represented 35.4 km^2 (c3500 hectares). The calculated maximum flood extent is around 132km^2 (c13200 hectares) or 13% of the whole catchment.

Therefore even during this extreme flood only 27% of the maximum flood plain was in actual fact inundated. The reasons for this comparatively low figure probably results from the alleviating effects of the newly constructed Llyn Celyn and the flood prevention measures along the catchment that had taken place over the years.

In recent years the effects of such extreme floods as were experienced in 1964 and studies previously undertaken by Braine (1959) and Rofe and Rafferty (1961) have influenced the management strategy on flood protection on the Dee. Financial support, from the farmers and riparian owners through the Land Drainage Levy, has given the impetus for the changes to be implemented. The aim was not to eliminate flooding but to limit the time frequency that it occurred and to minimize the time duration that the land was inundated. Flood embankments were favoured to expensive pumping schemes, apart from the Pulford Brook area (Fig 1.2), although a combination of both was necessary on the coastal section below Chester where the land surrounding the river is close to sea level.

One important feature of flood prevention schemes is the change from previously "poor" quality land, in farming terms, into high quality, high value agricultural land to benefit the dairy industry and improve crop production. The progressive loss of flood plain area to agriculture by the construction of embankments and the drainage of soils, reduces the available wetland both to fish and other forms of wildlife. With fish, this can lead to reduced recruitment area and also backwaters where both adult and juvenile fish can seek refuge, during period of high river flow. These elements of conservation importance were probably not fully appreciated at the time of change and consequently much valuable land, in the ecological sense, was lost.

3.2 Water Quality

In quality terms the River Dee water is of a very high standard which comes somewhere between a clear oligotrophic river like the Test (Harrod, 1964) and a moderately eutrophic river like the Frome (Westlake, 1966).

The comprehensive monitoring programme that is undertaken by the National Rivers Authority (Welsh Region) assists in maintaining quality standards and the high river flows ensure that few water quality problems are created for fish life in the river catchment. The level of river regulation also minimises any potential risks of fish kills in the main corridor, particularly from low dissolved oxygen as a result of increased summer flows. Therefore most parameters do not detrimentally impact on the fisheries resource. Periodically, during extreme hot weather and higher river temperatures, salmonids are affected in the estuarial reach below Chester Weir but coarse fish, being more tolerant of poorer water quality, are rarely affected (Hodgson et.al, 1980)

Water quality analyses for 1989, expressed as mean monthly figures, are shown for three locations within the study area namely: at Farndon Bridge, Ironbridge and the Suspension Bridge at Chester (Tables 3.1-3.3).

3.3 River Regime

3.3.1 Introduction

The River Dee has been shown to have a deep and uniform channel for much of the study area. Sheldon (1968) established that river depth was important in determining fish distribution and diversity and Lelek and Lusk (1965) found that on the Rokytna River in Poland the lowest biomass of fish was found in those areas where there was a uniform bed.

Flow and velocity in a river channel can also influence the biological development that occurs and Welcomme (1985) detailed the effects of such parameters on a range of different rivers. The flow regime of the Dee was therefore examined to establish its impact in the study area and how that integrated with the ecology of the system.

The temperature regime in an aquatic environment combined with flow and slope are often the primary factors that can influence the nature of the river type and dictate the plant and animal species that will colonize most successfully (de Nie, 1986). On the Dee this could be important, as

Table 3.1

Chemical Analysis

River Dee - Farndon Bridge

1989

	pH	Cond	Temp	DO	Do	BOD	Ammonia	Nitrogen	Nitrate	Sus Solids	Chloride	Phosphate	Chloro a
		mmhos/cm	%C	%	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	ug/l
January	7.1	167	4.2	93	8.6	1.3	0.12	1.3	0.03	7	22	0.2	1
February	7.5	188	6.5	85	10.4	1	0.11	1.3	0.02	11	26	0.2	1.5
March	7.3	117	6.3	79	9.7	1.6	0.14	1.2	0.02	80	15	0.1	5.4
April	7.3	115	7.3	93	8.6	2.4	0.08	1	0.03	51	16	0.1	4.9
May	7.8	413	18	86	8.1	<1.6	0.43	1.6	0.09	9	44	0.5	14.6
June	7.8	358	19.7	80	10.1	3.8	0.04	1.1	0.08	8	44	0.5	3.5
July	7.8	278	20.1	96	8.7	<1.0	0.07	1.2	0.04	7	39	0.4	1.7
August	7.8	228	16.8	79	7.6	1.4	0.03	0.6	0.01	6	31	0.3	8.6
September	7.9	506	15	111	11.2	0.8	<0.01	0.8	0.02	7	39	0.3	1.2
October	7.6	290	11.4	66	7.2	1.6	0.09	0.7	0.03	5	41	0.4	1.3
November	7.3	171	9.1	86	9.9	1.5	0.09	1.2	0.02	11	20	0.1	3.2
December	7.8	393	3.9	84	11	2.2	0.48	1.1	0.04	6	51	0.4	4.1

Table 3.2

Chemical Analysis

River Dee Ironbridge

1989

	pH	Cond	Temp	DO	DO	BOD	Ammonia	Nitrogen	Nitrate	Sus Solids	Chloride	Phosphate	Chloro a
		mmhos/cm	%C	%	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	ug/l
January	7.2	189	4	90	8.9	1.3	0.2	1.5	0.02	10	24	0.1	1
February	7.4	218	6.4	94	12	1.2	0.1	1.5	0.02	12	29	0.2	1.5
March	7.2	147	6.3	88	11.2	1.4	0.1	1.4	0.02	156	17	0.1	6
April	7.4	143	7.6	116	14	1.8	0.1	1.3	0.02	90	16	0.1	1
May	7.9	372	18.1	98	9.6	1.3	0.1	1.9	0.06	9	43	0.5	7.9
June	7.8	327	19.7	78	7.7	1.4	0.1	1.1	0.06	10	43	0.5	6.7
July	7.8	318	20.1	100	9.1	1.2	<0.01	1.3	0.03	10	42	0.4	2
August	7.9	252	17.2	70	6.7	1	0.02	0.8	0.01	7	32	0.3	3.1
September	7.7	321	15	105	10.6	2.1	0.05	0.9	0.02	6	41	0.4	2.8
October	7.6	304	11.7	72	7.8	1.2	0.02	0.7	0.02	6	42	0.4	1.9
November	7.3	185	9	88	10.2	1.5	0.08	1.3	0.02	9	20	0.1	3.5
December	7.7	391	3.7	89	11.7	2.1	0.5	1.1	0.04	19	49	0.4	<1

Chemical Analysis

Table 3.3

River Dee Suspension Bridge

1989

	pH	Cond	Temp	DO	DO	BOD	Ammonia	Nitrogen	Nitrate	Sus Solids	Chloride	Phosphate	Chloro a
		mmhos/cm	%C	%	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	ug/l
January	7.2	193	4.7	84	10.5	1.9	0.1	1.6	0.01	6	25	0.2	1
February	7.4	272	6.6	89	10.9	1.5	0.2	1.5	0.02	11	29	0.2	<1
March	7.4	171	6.6	90	10.8	1.9	0.2	1.7	0.03	158	21	0.2	8.1
April	7.3	145	7.3	121	14.5	1.7	0.1	1.3	0.03	90	16	0.1	2
May	8	366	20.7	117	10.5	2.2	0.1	1.8	0.06	20	49	0.4	16.9
June	8.7	333	20.6	134	12	2.2	<0.02	1.1	0.04	60	46	0.4	101
July	7.9	311	20.7	102	9.1	1.7	0.08	1.2	0.04	54	40	0.3	8.4
August	8.1	302	18.1	90	8.5	4.2	0.1	0.7	0.02	269	38	0.3	57.3
September	7.8	346	15	115	11.6	1.4	0.1	0.9	0.04	23	43	0.4	17.8
October	7.7	335	11.6	79	8.6	1.5	0.1	0.7	0.02	47	45	0.4	18.4
November	7.4	201	9.1	83	9.5	1.3	0.1	1.4	0.02	16	22	0.1	3.8
December	7.7	411	3.9	79	10.4	1.8	0.5	1	0.05	44	53	0.4	15.1

changes in river flow, through regulation, invariably result in altered river temperatures. For example, Crisp (1977) detected temperature fluctuations in the River Tees following the construction of the Cow Green regulating reservoir and Cowx et.al., (1981) recognised the importance of minimizing temperature differences of regulated releases from Llyn Clywedog to the River Severn.

An assessment of water temperature variations, both before and after regulation, was therefore made so that the relationship with the other pressures that existed in the river system could be evaluated.

3.3.2. Methods

i) River flow

River flow data were obtained from the National Rivers Authority (Welsh Region) hydrological archive for the periods required. These were analysed by tabulating the mean daily flow for the river at Manley Hall, near Erbistock.

ii) River temperature

To assess the temperature variations with river flow in the study area, it was necessary to establish the temperature changes that occur within the river catchment as a whole and more particularly under the regulated regime.

Daily river temperature data, for 1983, was acquired for 4 different points on the river (National Rivers Authority archive). The locations were: Bala (top of the catchment); Manley Hall (midway down the river); Ironbridge, (within the study area) and Shotton (in the tideway), 10km below Chester Weir (See Fig 1.1). 1983 was used because it was the only full daily temperature data set available for the river system, at the four points specified.

Other data collected included local daily air temperature from 1983 acquired from Ness Gardens (Liverpool University) on the Wirral, so assessment of climatic influence could be made.

To establish whether historical changes in river temperature had taken place following regulation, daily river temperatures for the Dee at Manley Hall were also obtained (National River Authority archive). From these figures the number of degree days above 12^{o}C were calculated. This level was chosen because Mills and Mann (1985) used this temperature as their baseline when they examined correlations between year class strength and temperature in some cyprinids.

Data were available from 1953, prior to the first major regulation of the Dee in 1965, through until 1991. In order to compare the effects of water temperature change following regulation, a baseline, from a waterbody which allowed for climatic variations over the years, was also required. The nearest and most extensive data set was that for the surface water temperatures of Lake Windermere (Institute of Freshwater Ecology archive). Although these figures are from a still water and not a river, the data was appropriate because it was used to establish if there was any climatic variation that could account for any water temperature differences on the Dee pre and post regulation.

The Mann-Whitney test described in Samuels (1989) was used to compare the two independant samples which represented the number of degree days above 12^{o}C for the pre and post regulation period. 12 years from 1953-1964 were available for the former period and 27 years (1965-1991) for the latter. In order to establish whether there was any wide variation in the post regulation period, two selected year bandings were tested against the pre-regulation decade. These were 1965-1974 and 1975-1991. The Mann-Whitney test statistic (U_s) has advantages because it is valid no matter what the form of the population distributions and also it does not focus on any particular parameter such as mean or median and for this reason is called a non-parametric test.

3.3.3 Results

i) River Flow

The flow in the lower Dee is typical of a lowland river, being moderate to slow flowing with mean current velocities of 0.2 $m.sec^{-1}$ during the summer months and 0.7 $m.sec^{-1}$ in the winter period but higher flows can exceed 1.6 $m.sec^{-1}$ at times of flood (Hodgson et.al. 1980).

Measurements of mean current velocities over a range of flows from long term data at Ironbridge, indicated that both across the width of the river (Table 3.4 and Fig 3.1) and down the water column (Table 3.5), velocities uniformally increased with increasing flow. Along the margins the velocities during the summer months were barely above the level of detection, while in the winter the flow close to the bottom of the shallow areas was just 0.03 $m.sec^{-1}$, less than that experienced in mid channel.

The channel shape of the lower river shown in Fig 1.5 dictates that even though there may be a 20-30 times increase in flow during a winter spate, there is only a few metres difference in the actual width of the river. This is because much of the river channel is steep sided and in most areas flood embankments are present. A wide range of flows and velocities are experienced within the channel confines each year as shown in Fig 1.7, which emphasizes the problems that both flora and fauna experience and the special adaptations that may be necessary for their survival.

ii) River Temperature

Figures 3.2-3.4 show the water temperatures and river flow in the periods January to May, May to September and September to December respectively, at three different points on the catchment in 1983.

It can be seen from Fig 3.2 that Manley Hall and Ironbridge have similar temperature gradients, while Bala is invariably colder apart from a period in early February when the upper site is approximately a degree warmer. This coincides with the time of lowest air temperatures in 1983 signified

River Dee Channel - Ironbridge

Table 3.4

Flow Velocities at surface (m/sec^{-1})

Flow Rate (m^3sec^{-1})	Staff guage m	Distance across channel 5m	8m	10m	15m	17m		Mean Velocity (m/sec^{-1})	Water Volume sq m
102	5.62	0.635	0.879	0.861	0.672	0.355		0.71	143.8
82	5.28	0.631	0.753	0.715	0.598	0.318		0.64	128.5
65	5.19	0.419	0.657	0.668	0.45	0.187		0.53	122.1
54	4.92	0.427	0.613	0.56	0.47	0.195		0.48	111.1
42	4.78	0.385	0.469	0.476	0.347	0.177		0.4	105.2
31	4.63	0.261	0.38	0.368	0.288	0.115		0.3	100
19	4.5	0.258	0.255	0.222	0.181	0.085		0.2	95.4
14	4.43	0.149	0.198	0.183	0.131	0.015		0.15	91.3
11	4.41	0.079	0.146	0.151	0.115	0.057		0.12	89.5

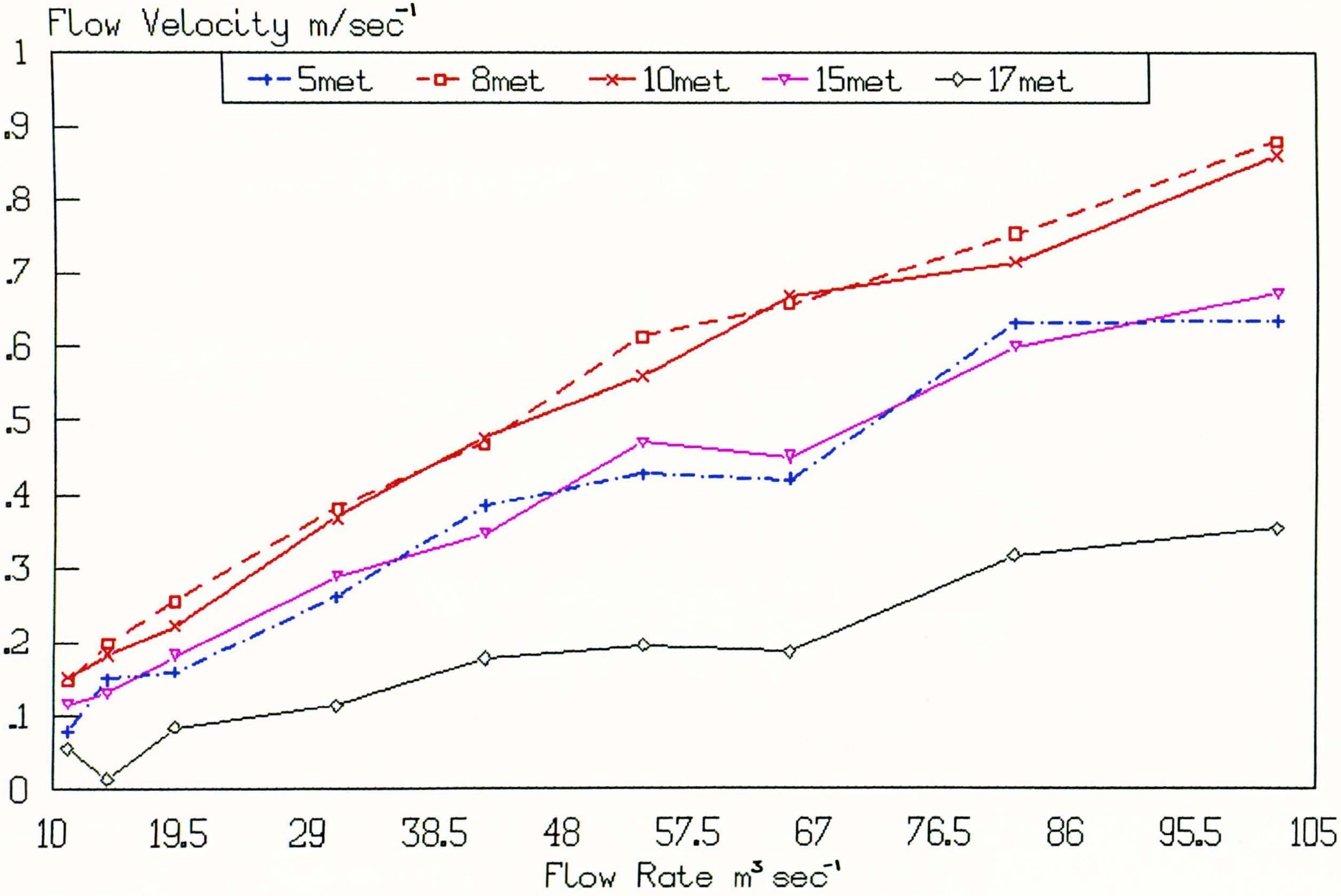
Table 3.5

Flow Velocities with depth (m/sec^{-1})

Flow Rate (m^3sec^{-1})		Centre of the Channel: Depth 0.2m	Depth 0.8m	Mean Velocity (m/sec^{-1})		At the side: Depth 0.2m	Depth 0.8m	Mean Velocity (m/sec^{-1})	
102		1.02	0.75	0.86		0.57	0.64	0.64	
82		0.88	0.56	0.72		0.62	0.52	0.63	
65		0.73	0.61	0.67		0.44	0.3	0.42	
54		0.68	0.48	0.56		0.42	0.36	0.43	
42		0.54	0.45	0.48		0.35	0.31	0.39	
31		0.4	0.33	0.37		0.25	0.2	0.26	
19		0.27	0.2	0.22		0.16	0.15	0.16	
14		0.22	0.15	0.18		0.15	0.1	0.15	
11		0.17	0.14	0.15		0.04	0.06	0.08	

Flow Velocities across the Channel
River Dee Ironbridge

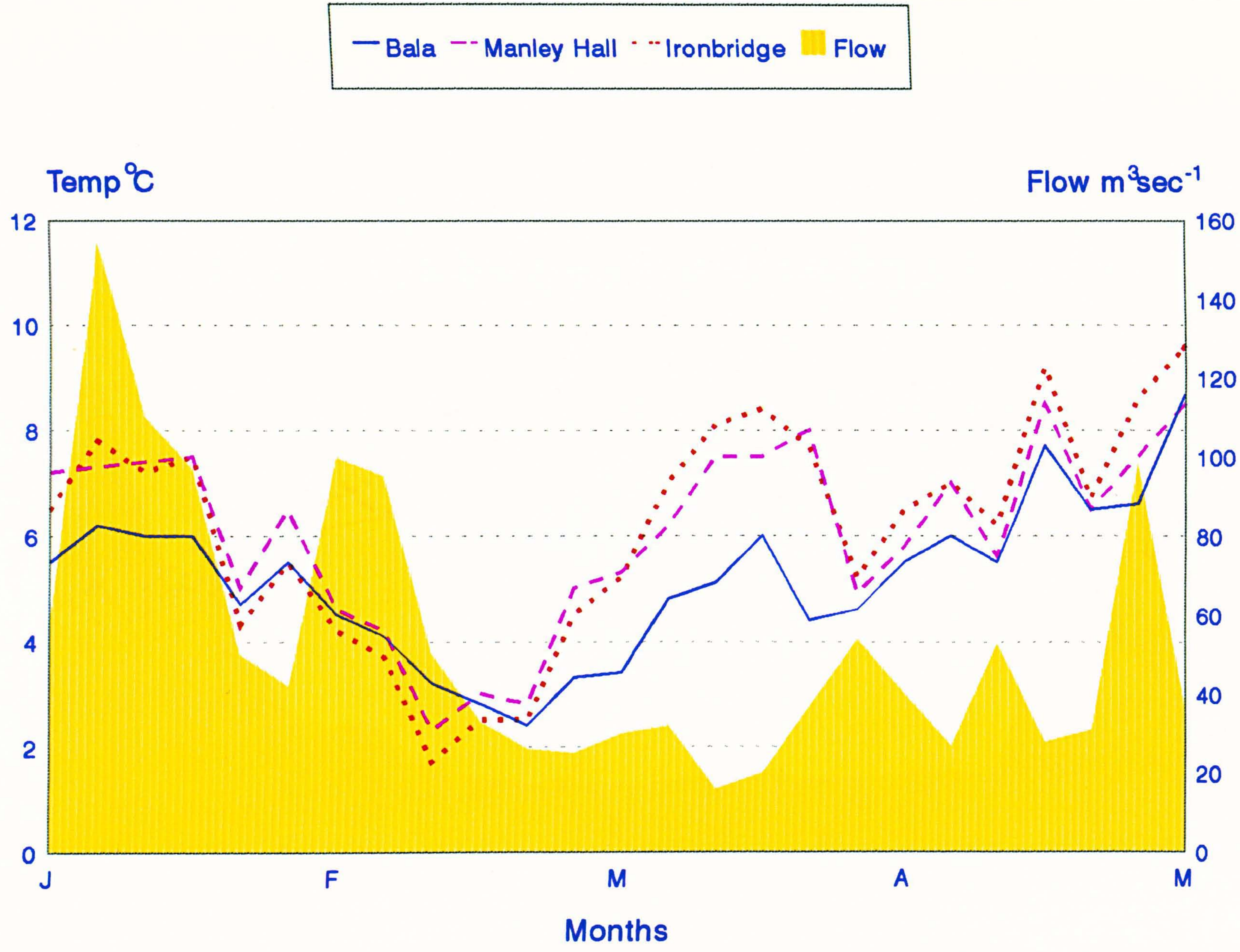
Fig 3.1



Daily Mean River Temperatures/Flow

January-April 1983

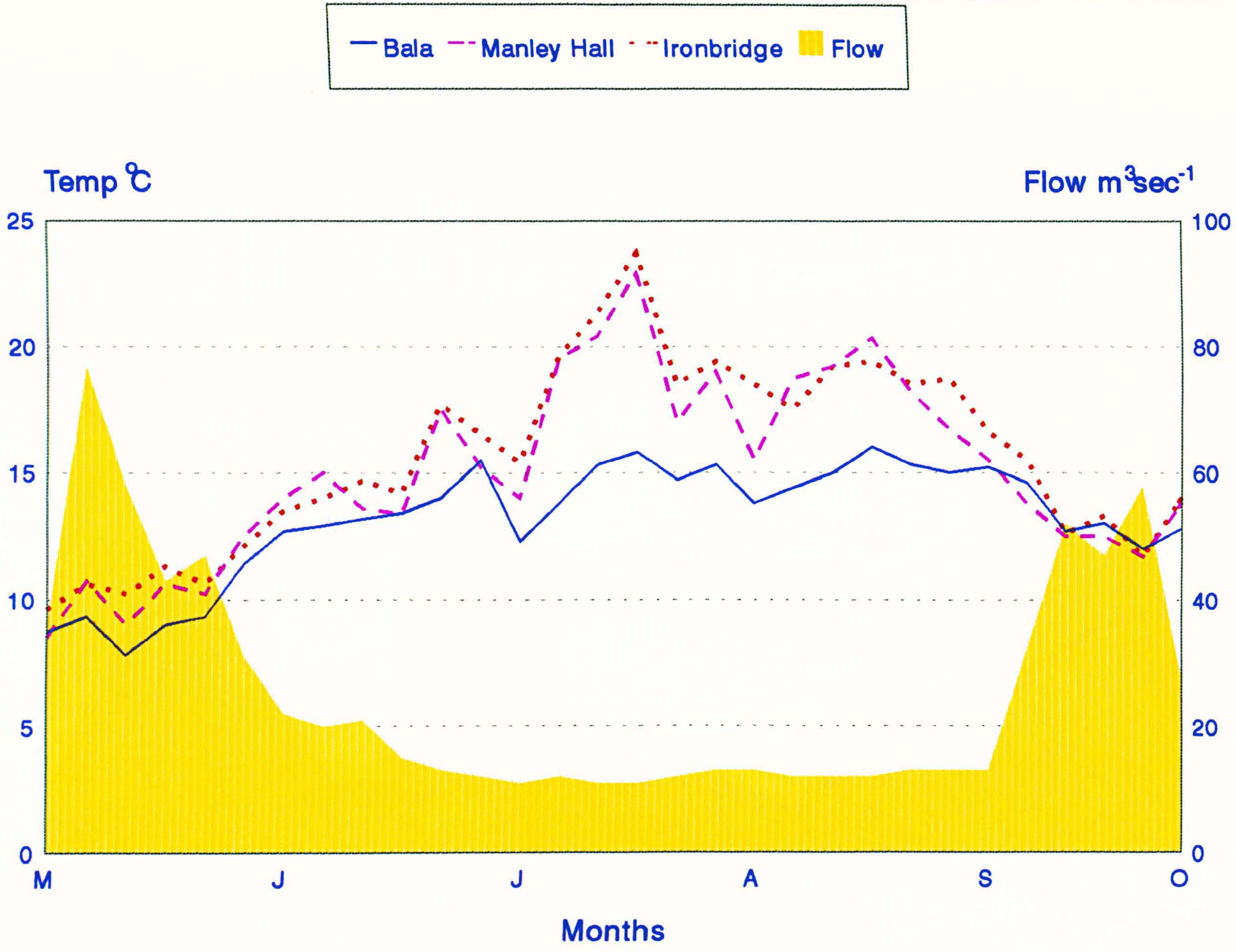
Fig 3.2



Daily Mean River Temperatures/Flow

May-September 1983

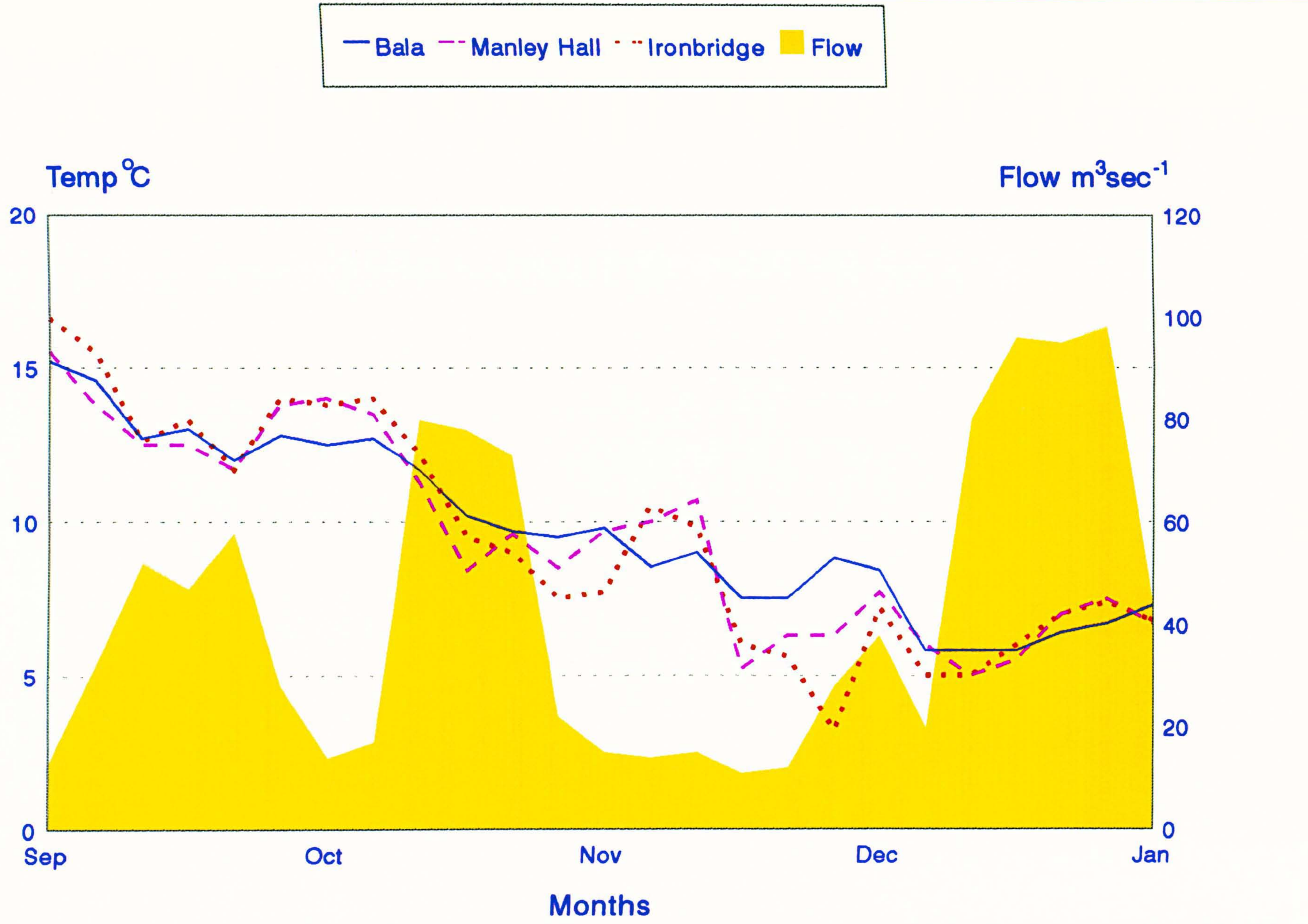
Fig 3.3



Daily Mean River Temperatures/Flow

September-December 1983

Fig 3.4



in Fig 3.5. During periods of increased flow, as in February and late March, whether it be from large or small spates, temperature differences between all three sites almost immediately become small. Conversely, at times of sustained low flow and higher air temperatures, as in March, the differential between Bala and the two sites downstream progressivly widens, and in this year a 4^{o} difference was recorded.

These results showed that it was in the area of steeper gradient between Bala and Manley Hall where the major temperature fluctuations took place and this was influenced by the air temperature, whether it be extreme cold or somewhat higher temperatures. From Manley Hall to Ironbridge there was little difference except at times of high air temperature when the differential climbed to a maximum of 1^{o} in mid March and late April. It was also shown that a small rise in river flow quickly eliminated any appreciable temperature differences down the river.

It is shown from Fig 3.3 that, again during the summer months, the major temperature differential occurred between Bala and the sites downstream rather than between Manley Hall and Ironbridge. This suggested that even during the summer when air temperatures were high (Fig 3.5) and flows were stable (Fig 1.6), there was little temperature difference within the study area. Although summer spates were infrequent in 1983, higher flows in early June and again in September reacted similarly to the early part of the year by quickly suppressing temperature differences down the catchment. Comparable results are to be found for the end of the year.

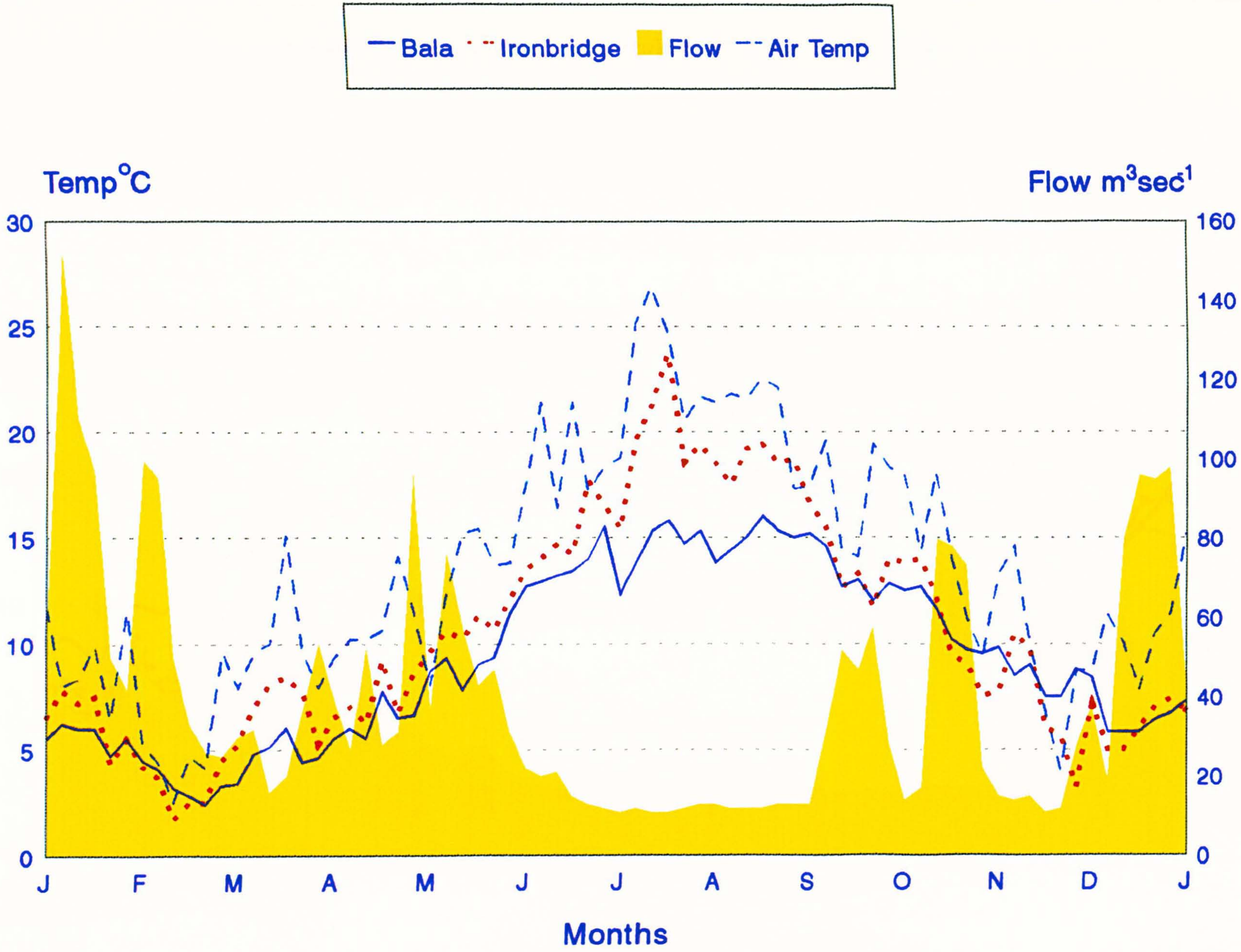
In the summer months there was a considerable warming of the water between Bala and Manley Hall, for example in mid July there was approximately a 7^{o} difference between the two points but, downstream of Manley Hall no appreciable gain was achieved.

From a comparison of water temperatures at Ironbridge and Shotton (Fig 3.6), it can be seen that up to a $4^{o}C$ difference can occur between the two points. This is likely to be as a consequence of solar radiation and higher air temperatures having greater effect in the very shallow, sandy and exposed section of the estuarial channel below Chester, where

Fig 3.5

Daily Mean River and Air Temperatures/Flow

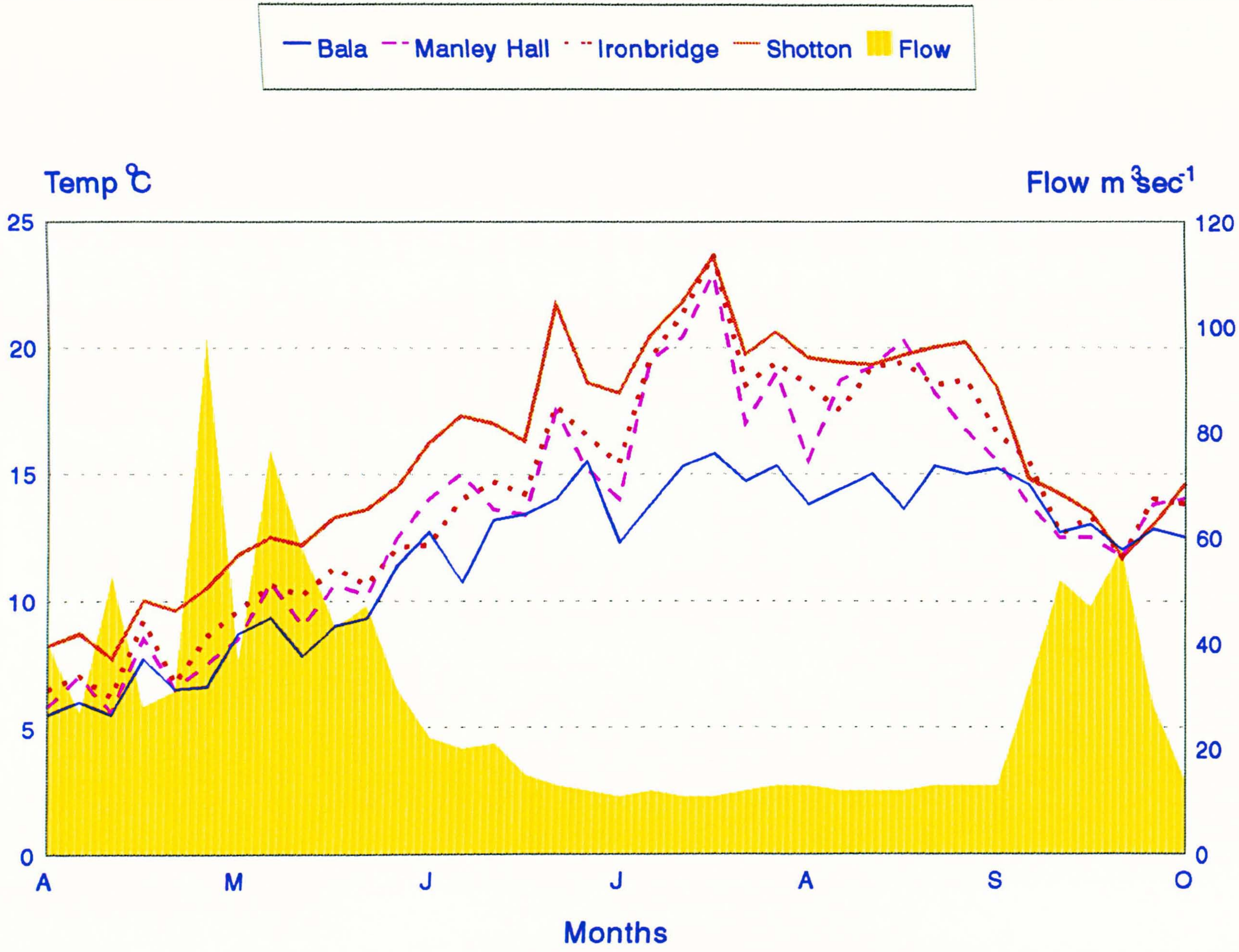
January-December 1983



Daily Mean River Temperatures/Flow

April-September 1983

Fig 3.6



considerable warming can occur (Hodgson et.al., 1980). Again any subsequent rise in river flow quickly suppresses any temperature difference which may develop. This is particularly demonstrated from September onwards in Fig 3.6.

In Table 3.6 the number of degree days above 12°C for water temperature at Manley Hall on the River Dee are presented. Fig 3.7 graphically compares these annual figures with those for the surface water temperature of Lake Windermere. After 1965, when significant regulation started, there was an increased divergence between the two temperature plots. When the 10 year periods, both pre and post regulation, were compared for the two locations (Table 3.7 and Fig 3.8), on the Dee there was an average 86 degree days/year reduction in the period after 1964, which represented 17% of the original mean total. 21% of this loss occurred in June when roach fry are newly hatched. In comparison the water temperature of Windermere had a net gain of 5 degree days/year during the same period.

The Mann-Whitney analysis produced a test statistic (U_S) of 85.5 with the sample number 'n_1' and 'n_2' being 10 in each case. The analysis confirmed that, with the directional hypothesis, the two 10 year periods tested were significantly different at $0.005 > P > 0.001$. This suggested that the Dee water temperature became lower at Manley Hall following regulation.

When the 10 year period prior to regulation was compared with the 17 years from 1975-1991, a test statistic (U_S) of 137 was calculated with sample numbers 'n_1' and 'n_2' representing 10 and 17 years respectively. Again this showed the two periods were significantly different at $0.001 > P > 0.005$, indicating consistent lower temperatures following regulation in 1965 which has continued until 1991 and probably up to the present day.

It has been shown that the Dee has become colder at the point of the river (Manley Hall) which is in the section where the largest temperature increases are achieved. The cooling element of the increased flow is likely to compound this effect further downstream when it reaches the Cheshire plain because the river then becomes deeper and more heavily

Table 3.6

River Dee - Manley Hall,Erbistock

Water Temperature - Degree Days >12° C

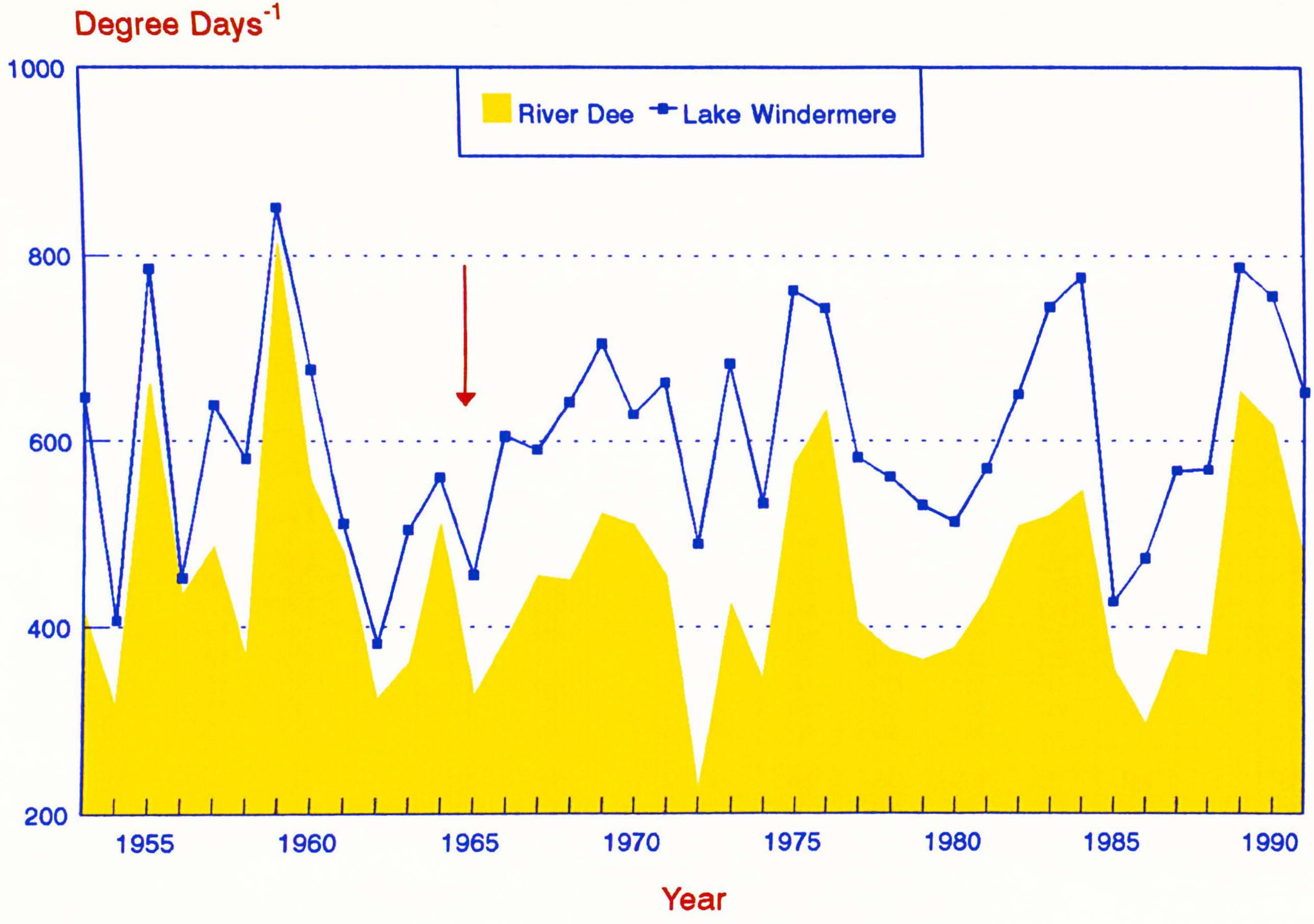
1953-1991

	April	May	June	July	August	Sept	Oct	Total
1953		38	82.2	138.3	129.8	26.8	1.2	416
1954		19.7	56.3	64.7	83.6	58.2	31.7	314
1955	9.8	9.7	69.6	234.1	228	95.1	15.1	662
1956		70	123	134.5	60.5	45.3	1	435
1957	2.8	47.5	169.6	146.2	94.8	25.5		488
1958	4.4	16	55.2	112.3	106.5	70.9	0.2	365
1959		74.6	169.6	219.3	202.8	116.4	29.3	812
1960		62.8	192.4	146	108.9	42.7		553
1961	0.2	22.4	125.3	131.1	108.4	81.7	9.8	478
1962		7.9	92.3	118.8	81.4	26.3	0.7	327
1963		14.7	120.9	100.4	94.3	32.1	0.7	363
1964		62.4	95	149.8	137.7	64.8	0.4	510
1965		20.9	98.9	91.8	108.4	3.9	1.5	326
1966	0.5	16.5	107	119.5	81	59.5	2	388
1967		3	109.5	167	142.5	29	3	455
1968	0.5	6	109	166	137	27.5	8.6	454
1969		2.3	102.3	173.4	147.1	73.2	28.2	525
1970		46.4	158.8	118.3	122.2	64.7	2.4	512
1971		50.5	50.5	176.4	92.2	75.1	15.6	461
1972		0.5	13.5	113.5	81.8	15	0.8	227
1973		29.3	109.8	119.3	109	61.4	5.3	433
1974	4.9	62.6	102.1	92.6	91.2	2		356
1975	1.3	15	141.3	179.1	186.3	52.9	0.6	576
1976		67.9	182.5	193.2	159.8	27.7	1.5	633
1977		55	52.1	146.8	99	45.4	8.6	407
1978		56.3	61.4	119.3	84.9	48.1	5	375
1979		6.5	86.9	142.5	98	45.8	18.9	399
1980	2.2	42.2	62.7	96.8	118.1	61.6		384
1981	2.3	16.4	52	127.3	158.8	68.5	3.4	429
1982	2.7	54.6	113.2	149.2	124	64	0.2	508
1983		2.7	76.6	222.8	167.1	38	11.8	519
1984		17.7	118.6	185.5	168	48.3	7.7	546
1985		33.9	53.4	174.6	79.4	71	17	429
1986		2.1	87.2	125	58.8	6.3	9	295
1987	14	30	41.3	121.7	122	46.3	0.1	375
1988	5.7	32.3	126.3	106.5	72.3	25.5		369
1989		97.5	137.5	210	133	67	7.2	652
1990	8.8	89.8	88.8	183.1	190.7	44	11.7	617
1991		41.9	41.8	180.9	133.9	75	1.9	475

Water Temperature in the River Dee and Lake Windermere

Number of Degree Days above 12°C Annually (1953-1991)

Fig 3.7



↑ = Regulation from Llyn Celyn

Table 3.7

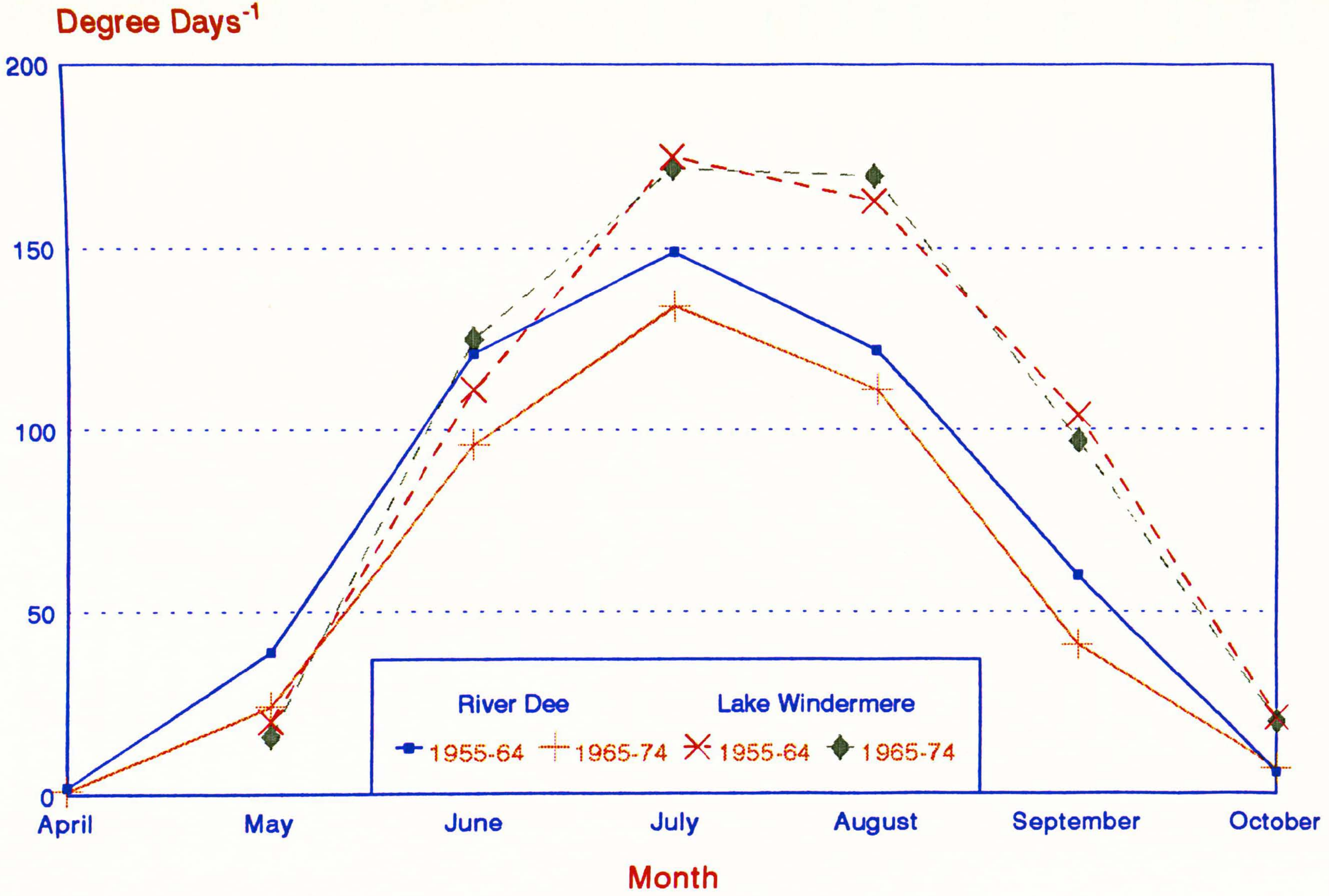
Water Temperature - Degree Days >12° C
Pre and Post Regulation Period on the River Dee

River Dee									Lake Windermere							
	April	May	June	July	August	Sept	Oct	Total	May	June	July	August	Sept	Oct	Nov	Total
1955	9.8	9.7	69.6	234.1	228	95.1	15.1	662	10	84	264	259	141	27		785
1956		70	123	134.5	60.5	45.3	1	435	17	81	156	108	81	9		452
1957	2.8	47.5	169.6	146.2	94.8	25.5		488	18	164	219	173	55	10		639
1958	4.4	16	55.2	112.3	106.5	70.9	0.2	365	67	90	168	162	147	14		581
1959		74.6	169.6	219.3	202.8	116.4	29.3	812	67	148	204	207	153	72		851
1960		62.8	192.4	146	108.9	42.7		553	37	175	163	170	115	17		677
1961	0.2	22.4	125.3	131.1	108.4	81.7	9.8	478	25	85	144	122	110	25		511
1962		7.9	92.3	118.8	81.4	26.3	0.7	327	1	78	126	101	63	13		382
1963		14.7	120.9	100.4	94.3	32.1	0.7	363	7	120	146	154	70	8		505
1964		62.4	95	149.8	137.7	64.8	0.4	510	21	83	163	176	103	15		561
Total	17	389	1213	1492	1224	601	57	4993	203	1108	1753	1632	1038	210		5944
Mean	1.7	38.9	121.3	149.2	122.4	60.1	5.7	500	20.3	110.8	175.3	163.2	103.8	21		595
1965		20.9	98.9	91.8	108.4	3.9	1.5	326	11	95	139	134	61	16		456
1966	0.5	16.5	107	119.5	81	59.5	2	388	8	144	187	139	97	31		606
1967		3	109.5	167	142.5	29	3	455	1	141	180	165	93	11		591
1968	0.5	6	109	166	137	27.5	8.6	454	11	167	159	175	108	22		642
1969		2.3	102.3	173.4	147.1	73.2	28.2	525	11	143	179	212	124	35	1	705
1970		46.4	158.8	118.3	122.2	64.7	2.4	512	38	185	141	174	78	13		629
1971		50.5	50.5	176.4	92.2	75.1	15.6	461	32	78	215	175	128	35		663
1972		0.5	13.5	113.5	81.8	15	0.8	227	3	24	170	176	97	19		489
1973		29.3	109.8	119.3	109	61.4	5.3	433	17	144	194	192	120	16		683
1974	4.9	62.6	102.1	92.6	91.2	2		356	29	126	158	155	65			533
Total	7	239	963	1338	1112	412	66	4137	161	1247	1722	1697	971	198	1	5997
	0.7	23.9	96.3	133.8	111.2	41.2	6.6	414	16.1	124.7	172.2	169.7	97.1	19.8	0.1	600
Level of Change Pre and Post Regulation																
Total	-10	-150	-250	-154	-112	-189	7	-856	-42	139	-31	65	-67	-12	1	53
Mean	-1	-15	-25	-15.4	-11.2	-18.9	0.7	-86	-4.2	13.9	-3.1	6.5	-6.7	-1.2	0.1	5

Mean Monthly Water Temperatures in Degree Days >12 °C

River Dee and Lake Windermere - Pre and Post Regulation Period

Fig 3.8



10 year period before and after 1965

shaded by trees. Trees probably reduce the level of solar radiation on to the water surface in this area and thereby limit the warming capability. Any expansion of the tree line along the river corridor could exacerbate this effect and therefore the extent of change in bankside trees and plants will be examined in Chapter 5.

3.4 Wave Action

3.4.1 Introduction

Murphy and Eaton (1983) established that boat wash from recreational traffic could have serious destructive effects upon plant communities in a closed water system of a canal. The wave energy impacted on the sides of the canal by destabilising the bed sediment layers, which displaced the weed and made recolonisation much more difficult.

The River Dee has considerable water based recreational activity near Chester and therefore the effects of boat wave action on bankside habitat also needed to be examined, to assess whether similar problems were being encountered.

3.4.2 Methods

i) In order to demonstrate the impact of wave action on the bankside margins, a short trial, to measure the degree of wash from a boat operating at different speeds, was undertaken. The section of bank used was situated at Caldy close to Chester (Fig 1.2). This had a shallow gradient of 10:1 (Horizontal:Vertical). The boat used was 4m long with shallow draught and was powered by a 40hp jet engine. Trials were from different distances offshore, ranging from 5 to 40m at speeds of 5mph and 10mph. Measurements were taken by metric rule, one fixed vertically to record the wave height and one parallel to the slope to measure the degree of swash (scour up the bank by the advancing wave) and the extent of the backwash (scour down the bank by the receding wave). Three successive trials, for each speed and distance, were undertaken during a period of low summer flow velocities. Measurements of impact of individual recreational boats were also taken at the same time for comparison.

ii) Separate trials to assess temperature fluctuations at the margins were also undertaken, but in this case the normal movement of boat traffic on two days (22nd June and 4th July 1989) was used. Measurement of temperature, by a portable meter, was taken at regular time intervals at 5 points from the edge of the channel out to 8m in deep water.

3.4.3 Results

i) Mean measurements of wave heights and wash impact at the bank by successive boat trials on the Dee are given in Table 3.8. It can be seen from the results that on a shallow slope, where aquatic weeds have the greatest chance of colonising, the extent of boat wash wave can extend to over 1m at the margin at 5mph, which is just below the permitted byelaw speed limit of 6mph imposed by Chester City Council. Wave effects are shown to extend the impact considerably at higher speeds which are not unusual by pleasure craft on the river. Specific observations on boats passing the trial site measured over 3.5m in respect of large passenger craft and 33cm with smaller boats.

It can be seen that there is not only a wave transmitted up the bank but the receding wave also erodes down the bank. On exposed and unprotected bank side margins, the wave surge and then regression causes destabilising of the soft substrates, which could prevent macrophytic colonisation where most severe (See Chapter 5). As a consequence of boat traffic the growth of vegetation out into the channel is limited. This can be seen in Plate 5.1, at a site close to Chester, where the shallow margin extends a further 2 metres from the bank, beyond the weed fringe. Disturbance of the margins by boats also decreases the clarity of the water by increasing suspended solid loadings. The changes that occur in water clarity, on a typical mid-summer day, are shown in Fig 3.9, both before boat activity starts at 7.00hrs and again at peak activity at 14.00hrs.

In Fig 3.10 the number of licenced craft registered to use the river by Chester City Council has shown a considerable variation in the past 20

Table 3.8

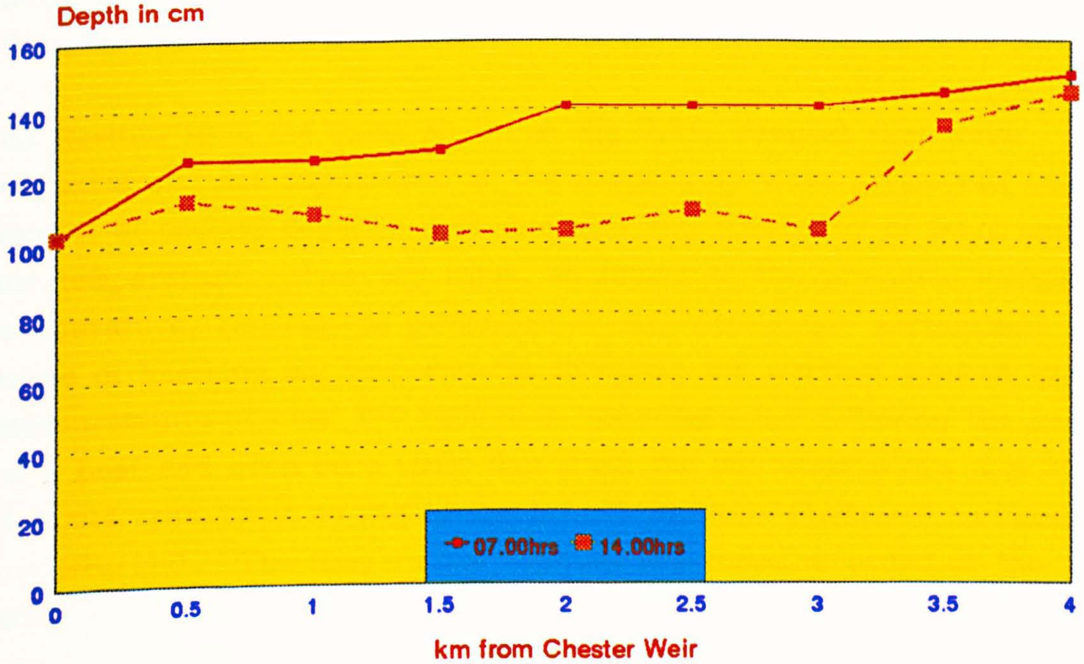
Boat Wash Trials at the Margins

River Dee, Caldy

Mean Wave Height (cm)							
		Distance from bank					
		5m	10m	20m	30m	40m	
Speed of Boat							
5mph		6.9	4.3	4.1	3.3	2.3	
10mph			19	9.3	7.4	4.2	
Mean Extent of Swash (cm)							
5mph		60	42	59	33	26	
10mph		148	80	58	50	45	
Mean Extent of Backwash (cm)							
5mph		48	28	23	20	11	
10mph		120	60	50	40	35	
Total Margin Affected (cm)							
5mph		108	70	100	53	37	
10mph		268	140	108	90	80	
Actual Boat Traffic Impact (cm)							
			Estimated Speed (mph)	Wave Height (cm)	Swash (cm)	Backwash (cm)	Total Bank Affected (cm)
Small Boat (<3m)			4	6	22	11	33
Large Boat (>20m)			10	25	150	220	370
Speed Boat (4.5m)			15	15	90	70	160

Variations of Water Clarity during a Day in Mid Summer
River Dee,Chester

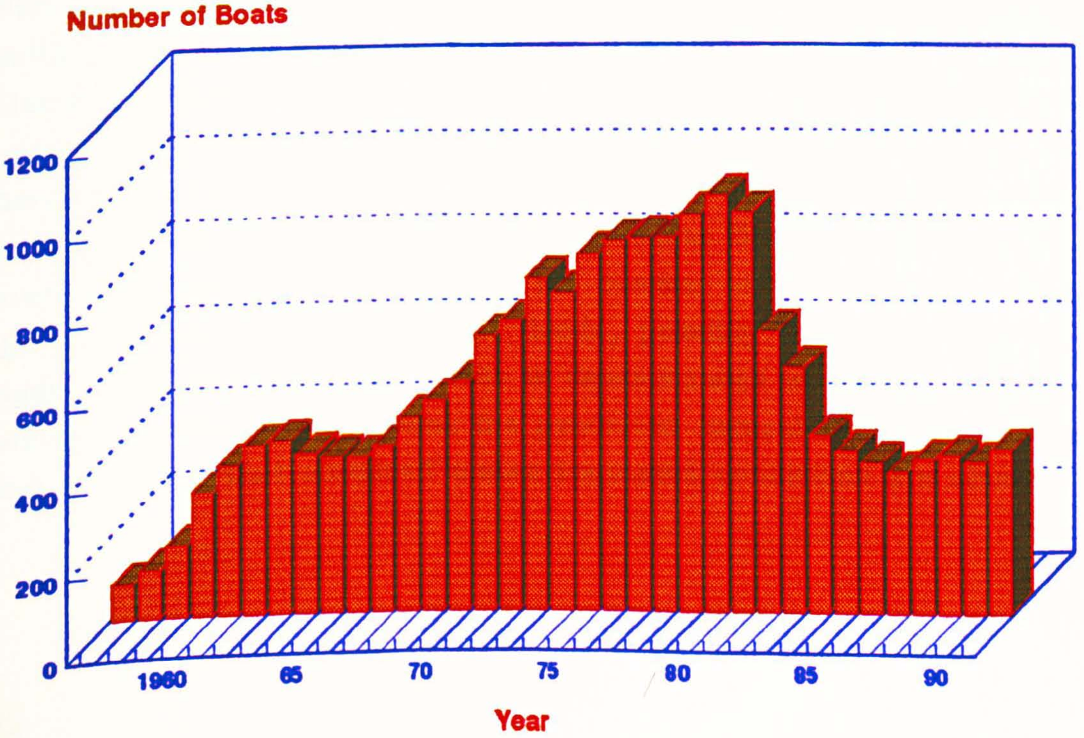
Fig 3.9



17th July 1987
Using Secchi Disc

Registered Boat Licences
River Dee,Chester 1957-1991

Fig 3.10



years and Pearce (unpublished) deduced that the lack of vegetation distribution, in the lower river in the early eighties, was as a direct consequence of the build up of boat traffic. The reduction in the numbers of boats, following increased river fees in 1981 imposed by the City Council, resulted in a reverse of this trend, with Elodea nuttallii in particular expanding its range and density in the lower river (See Chapter 5).

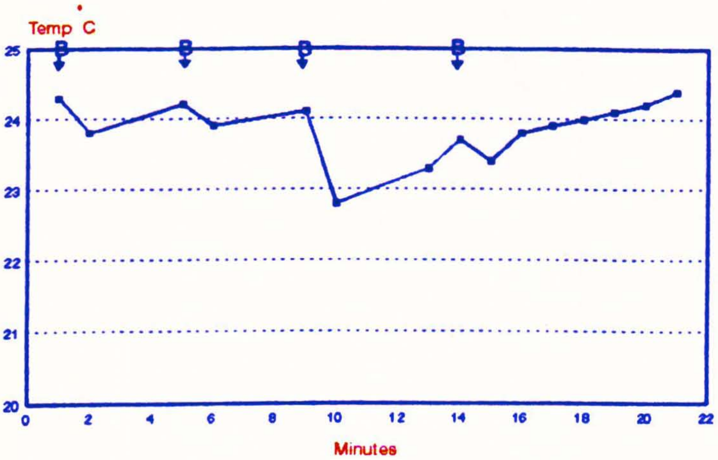
ii) Results from the trials shown in Fig 3.11, suggest that water temperatures are suppressed at the margins by wave action but the extent of cooling depends upon the size and frequency of wave and the air temperature. Recovery rates, to return to the pre-wave margin temperature, can also be prolonged or may not occur, particularly at times of lowering air temperatures following the warmest part of the day. Measurements of over 1°C reduction were recorded following the passing of a boat and even on a warm day when the air temperature was 25.2°C, it could take 10min to regain the loss if the area continued to remain undisturbed. The temperature changes are those recorded in the shallowest area of the margin (15cm). It can be seen from Fig 3.12 that the differential temperatures between mid-channel and the margin become progressively smaller moving into the channel. Any temperature gains are therefore quickly lost by minimal disturbance because movement of water takes place from the deep, cold mid-channel.

3.4 Discussion

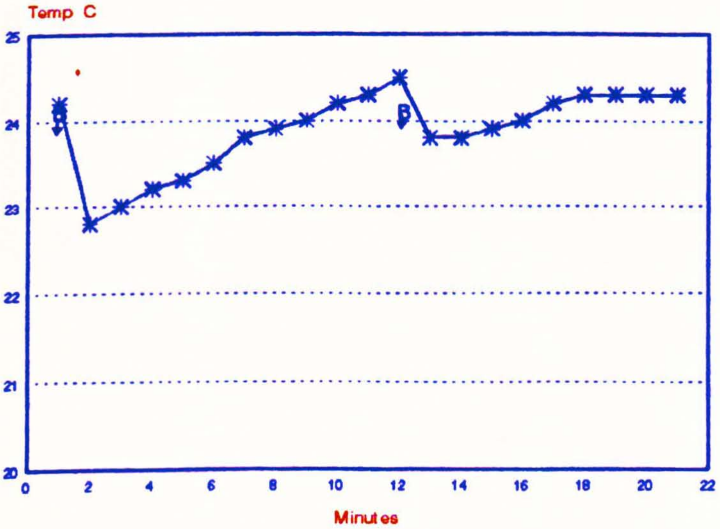
The River Dee has been regulated since the early 1950's but initially the enhanced flows were only small being used to supply water to the Llangollen Canal (branch of the Shropshire Union Canal). It was not until 1965, when Llyn Celyn discharged for the first time, that the Dee flow regime changed markedly. The average summer flow was enhanced approximately three times but, by controlling flow in the headwaters, the presence of severe flood flows in the summer were almost eliminated. In the winter the extreme peaks of floods, possibly the most erosive component, were reduced. This is demonstrated in Fig 3.13 and 3.14 where the difference between the predicted natural river flow for 1989/90 and the flows that occurred under regulated conditions are shown. When

Impact of Boat Wash on Margin Water Temperature Fig 3.11

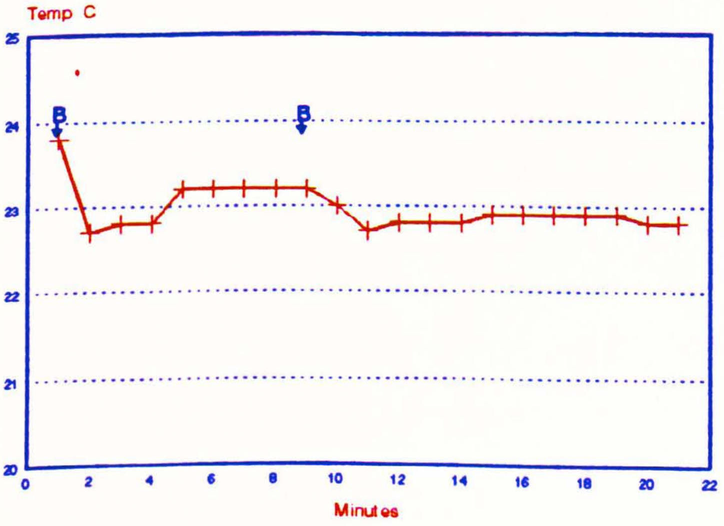
River Dee, Chester -24th July 1989



Time 14.00-14.30
Air Temp 25.3 °C(start), 25.2°C(end)
B = Boat Passing



Time 15.00-15.30
Air Temp 25.0 °C(start), 24.8°C (end)
B = Boat Passing

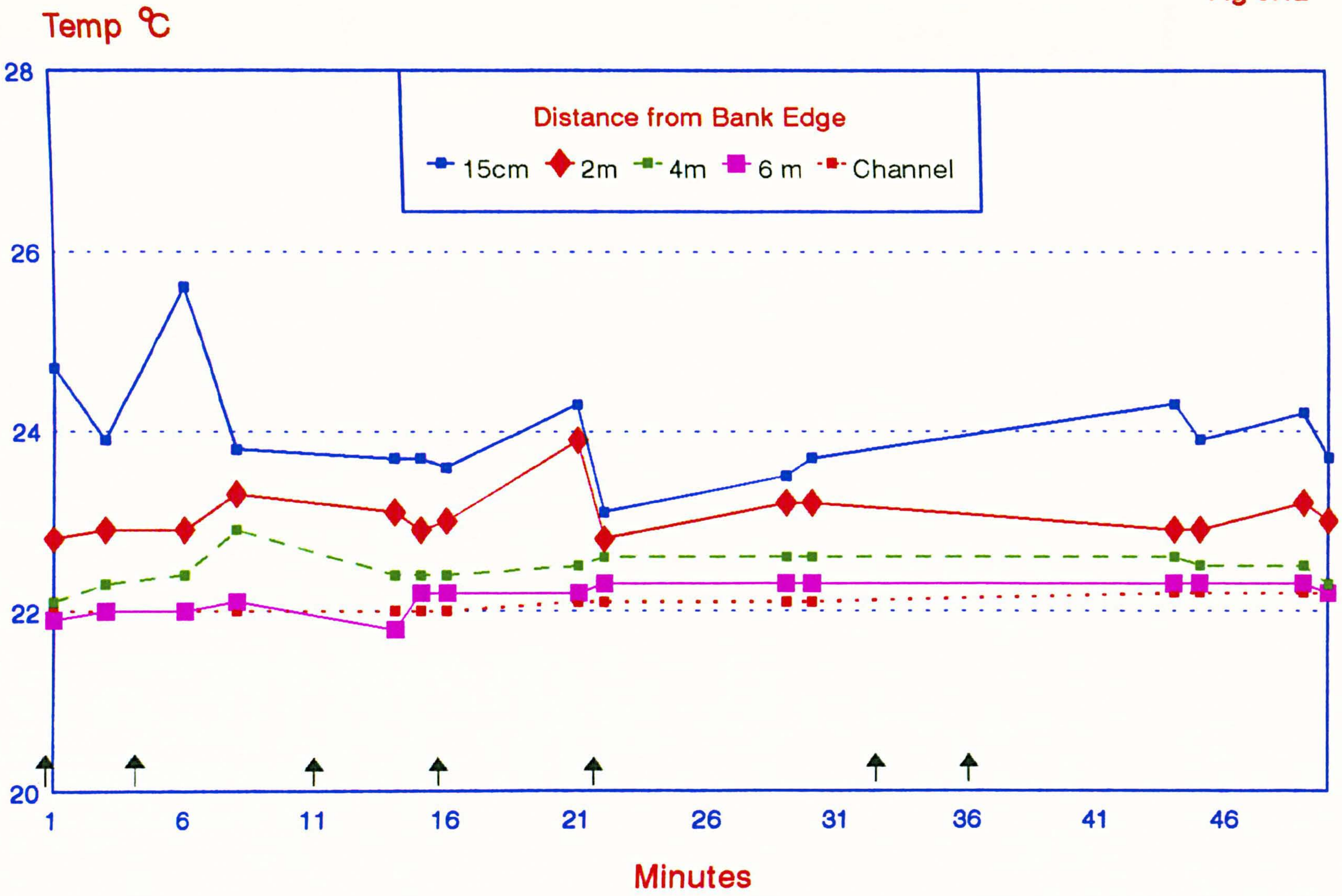


Time 16.00-16.30
Air Temp 23.8 °C(start), 23.0°C (end)
B = Boat Passing

Water Temperature changes at the Margins caused by Boat Wash

River Dee, Chester - 22nd June 1989

Fig 3.12

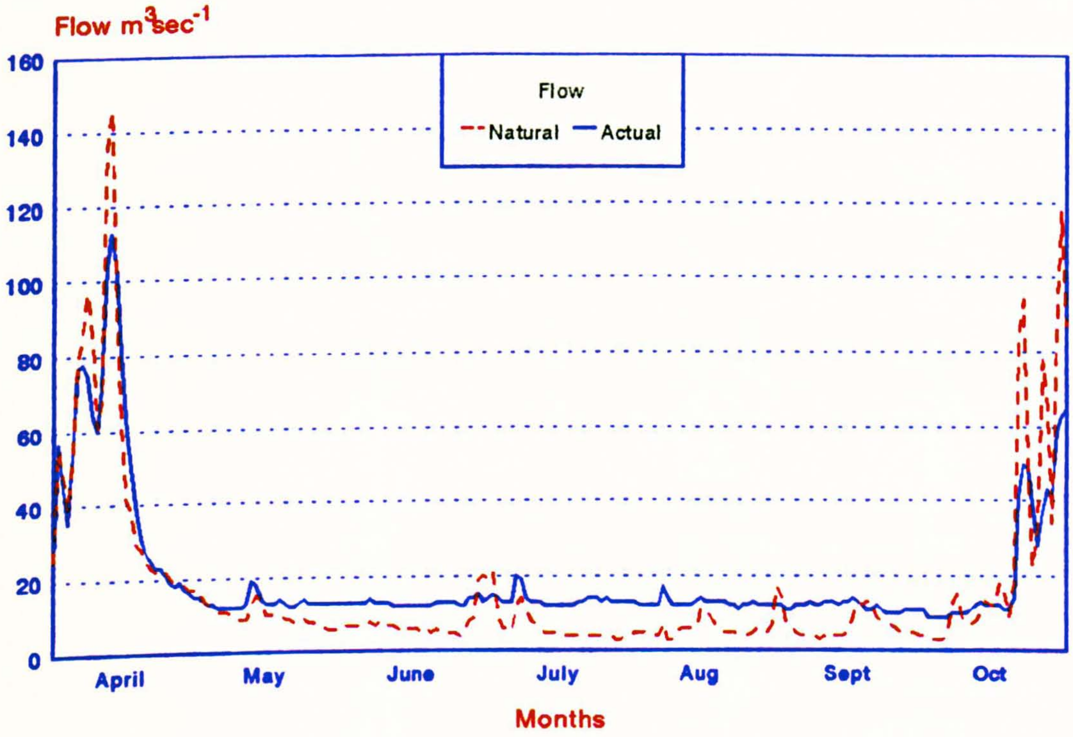


Time 13.40-14.30

Arrows = Boat Passing

River Dee Flow Regime
Impact of Regulation-Summer 1989

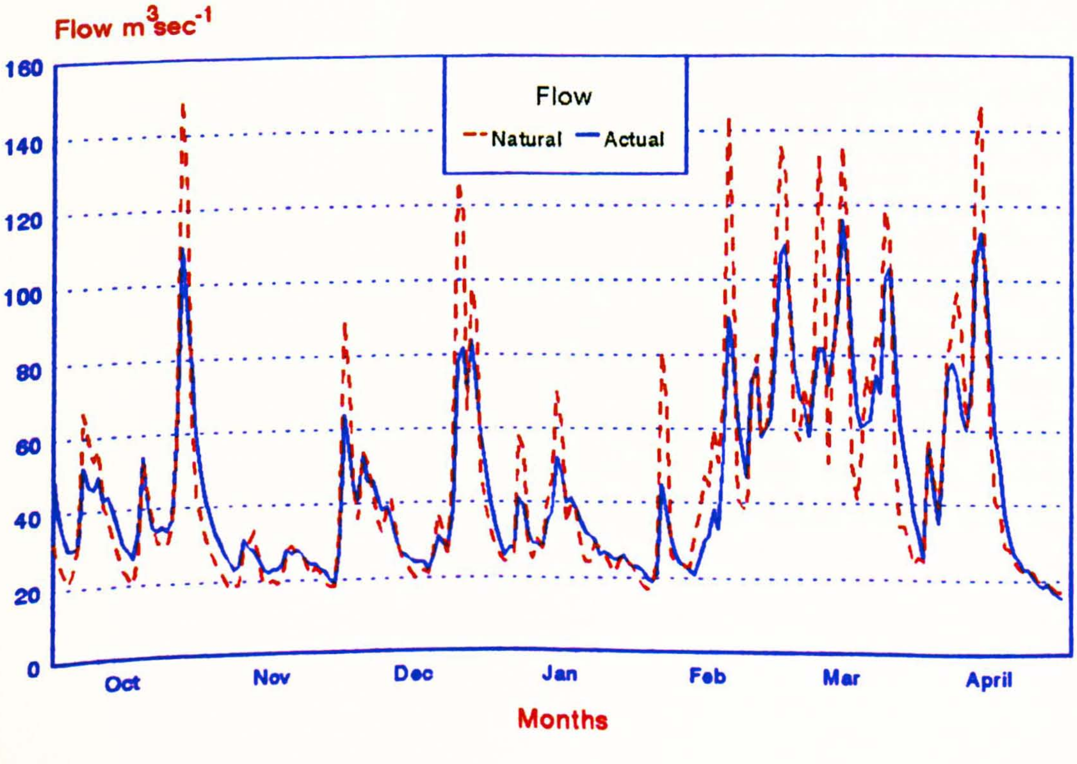
Fig 3.13



Eccleston Ferry

River Dee Flow Regime
Impact of Regulation-Winter 1989/90

Fig 3.14



Eccleston Ferry

the flood embankments are overtopped with the largest floods, the erosive energies may not be any greater than smaller floods because at these times flow energy is dissipated across the flood plain. As floods of this kind are now very infrequent, as a consequence of management control, the majority of flood water energy is likely to remain consistently within the river channel.

The reservoirs in the headwaters only control approximately 17% of the Dee catchment but the effectiveness of reducing floods down the valley depends upon where the rain is falling and also the amount of available storage in the reservoirs at any one time (Lambert, 1988). Fig 1.7 shows the rule curves for Llyn Celyn by which the system is presently controlled, although weather conditions influence the variations of flow from year to year.

The enhanced flows have affected the way fish populations are influenced in the catchment. For instance, salmonids now move upstream much quicker from the Erbistock area to the upper reaches near Corwen (Dee and Clwyd Fisheries Report 1980). Although clear changes to non-salmonid fish distribution outside of the study area are difficult to evaluate and constitute a need for extra study, there is an indication that grayling have moved progressively down the catchment following increased regulation (Woolland, 1972).

The study area is typical of a large lowland river with low flow velocities in the summer months ($<0.5 m.sec^{-1}$) but subject to more rigorous flow conditions in the winter months when the velocities can exceed 1.6 $m.sec^{-1}$. Kreitmann, (1932) tabulated the maximum sustained swimming speeds of certain freshwater fish. These included : Chub $2.7m.sec^{-1}$; Dace $1.8m.sec^{-1}$; Bream $0.6m.sec^{-1}$ and Pike $0.45m.sec^{-1}$. These swimming speeds closely relate to the river slope/zonation of fish relationship, that Huet (1949) advanced and as roach favour more closely his defined 'bream zone', a sustained swimming speed lower than dace would be expected. With flow velocities in the lower river periodically occurring in excess of this and also because there are few tributaries or sanctuary areas where fish can shelter, it is likely that high flows will impose considerable pressure on the survival of adult roach and other less mobile species. Juveniles, with less developed musculature, will possibly be more exposed to the dangers of being washed from the system at times of high catchment run-off (See Chapter 4).

High flows can also generate erosive forces within a river system which can also influence variations in water chemistry, particularly in respect of suspended solid loadings. Erosion is therefore not only a factor that can cause local impact in the form of damage to banks etc, it can also influence aquatic conditions downstream. Keown et al (1977) reviewed the types of erosion that could impact upon a riverine system and all had an effect on the ecology.

Current velocity creates a progressive impact on river banks and it is a primary element that influences sediment loading. The directly measured flow does not truly reflect the potential forces of erosion that take place in a river system. This is probably best described as the tractive force (or sheer stress), which is the force exerted by the sediment/water mixture on both the bed of the river and the bank. Simon et.al. (1979) suggested that the equation : To = Yds could equate to the average sheer stress (To = Tractive Force; Y = Specific weight of the sediment/water mixture; d = Average depth of flow and s = Channel slope). Lane et.al. (1955) calculated that the sheer stress had its greatest impact at about two thirds of the depth below the air water interface. This sheer stress was maximised on bends of rivers where the forces became screwlike or helicoidal in nature. These transverse currents which could represent 15% of the mean current velocity are often cited as the principal components of scouring and deposition at bends in rivers.

On the River Dee the channel is deep (ie more than 3 metres) almost throughout the length of the study area and also the banks are often vertical. From Bangor-on-Dee to Farndon the banks are largely unprotected by trees and therefore the stress forces are likely to be severe creating the problem of serious erosion which is found throughout this length. From Farndon to Chester, where the tree line is more extensive, root systems are likely to penetrate deep within and down the outside of the banks and limit the impact of sheer stress. The extent to which erosion takes place depends largely on the variation of the flow. Fig 3.15 shows that flood events, in the summer since regulation, are smoothed out and not now problematical. The major impact of channel scour occurs in the winter, when the headwater reservoirs are unable to totally control the precipitation that falls within the catchment. For much of the study area, the impact of erosive forces from river flow largely occur as a result of the higher winter run-off constrained within the river channel, rather than being allowed to dissipate across the flood plain. Flood embankments exacerbate this situation and because of human settlement within the plain, for example Bangor-on-Dee, any major changes to existing flood protection measures are unlikely in the future.

More stable flows in the summer months should however be more favourable for macrophytic colonisation and therefore beneficial for the creation of aquatic habitat. As the river channel is predominantly deep (Fig 1.4), there is in fact little area where this can take place. Shallow margins are predominantly found closer to Chester where silt deposits accummulate but it is in this area that other elements start to impact during the summer.

The disturbance to margins also increases suspended solids levels in the water column and decreases clarity and thereby light penetration to the lower layers (Fig 3.9). Keown et.al. (1977) described erosion by wave action as a contributory cause of increased sediment loading within a system. Wind generated wave action is of lesser importance on river system because of the limited surface where waves can be created. Large tracts of the river, from Bangor-on-Dee to Farndon, have high flood banks and therefore limited areas for interference from wind, apart from the occasional long straight section. In this shallower and sheltered regime a marginally warmer environment should be created on the water surface, which may account for the increased macrophyte growth to be found in this area (See Chapter 5). From Farndon to Chester the extensive tree line prevents appreciable wind action.

On the Dee the greatest impact of wave action on the ecology comes from the forces created by recreational boating, particularly motorised craft used by tourists close to Chester. Wave action from boats has been shown to impact in the marginal substrates in this area of river and the extent of influence is dependant upon the speed of craft and the height of the wave generated. Not only is it the extent of the advancing wave that causes disturbance but also the receding wave creates turbulence down the shore below the waterline. The area of impact was found to be around 1m for small craft at low speeds on banks with shallow gradient but larger passenger craft at similar speeds increased the area of disturbance to over 3.5m. The scouring action of the wave in the margin limits vegetation encroachment into the channel and probably limits natural colonisation by plants even where shallow areas exist.

According to Bhowmik (1975) the maximum wave height generated by a moving boat is a function of draft, speed and length of boat and the distance between the boat and the wave gage. In principal a wave generated from a boat is made up of two independent waves:

1) Diverging waves created by the bow.

2) Transverse waves generated by displaced water behind the boat.

The maximum height of the wave takes place where these two waves converge on each other and the angle of the convergence increases with decreasing water depth (Johnson, 1957). The erosive properties of the wave therefore not only have a surface and lateral penetration but also a downward and rolling dimension which is at its most damaging when progressing into shallow water.

Erosion properties of wave action can be even more serious than one would predict from wave height observed because as Wright, (1982) found, depending upon the distance of the boat to the bank, the waves generated can actually be amplified and create a greater wave height at the bank. The speed of craft also influences how wave energy is developed because generally wave heights decrease faster from high speed boats than from low speed craft (Byrne et.al., 1980).

The boat size is a further factor that must be considered when assessing wave action. It was noted on the Dee, that smaller vessels with rounded hulls produced waves similar in height to those produced by larger vessels with flatter hulls. The shape of the hull of craft and its impact on wave generation is detailed in Inland Waterways Advisory Council (1983) and therefore to minimize impact from this direction on the Dee, future consideration of the design of craft allowed on the river should be made.

As the Dee rises at around 1000m above sea level, in the hills beyond Llyn Tegid, the shallow, high altitude headwater streams naturally have a large annual and diurnal range of temperatures (Deutschmann, 1987). Normally rivers originate in upland areas and flow, with varying velocities, down to the sea with temperatures being lowest in the headwaters but progressively becoming higher downstream. On the River Dee the circumstances are different because the slope of the river does not have a typical gradual gradient from source to sea (Fig 1.3). The steepest section on the main corridor is to be found mid way down and not at the upper end. At the upper end the river temperatures are likely to remain cool in the deeper, meandering section from Bala to Corwen. The main temperature gains and losses to the system have been demonstrated to occur in the steeper section between Llangollen and Manley Hall, where it is shallower and faster flowing and therefore more influenced by air temperature fluctuations. The lowland section within the study has been shown to be short in length compared to rivers like the Wye, Trent and Thames (Fig 1.6), deep and heavily shaded by trees (Chapter 5) where temperature rises along its length are small. Even prior to regulation it is likely that in cool years the Dee was subject to low summer water temperatures which were unfavourable for roach and other lowland species. The higher flows and lower water temperatures resulting from regulated releases have probably compounded this effect and increased the number of years when unfavourable conditions prevail.

The temperature regime, in the study area, during periods of consistent flow, is somewhat buffered from short term fluctuations in air temperature. With the construction of the two reservoirs, Llyn Celyn and Brenig, water is now retained in deep, cold, upland reservoirs (Hunt, 1970). The greater volume of water passing down the system, now transfers colder water from these reservoirs and from natural spates more quickly down the catchment than occurred previously. Thus temperatures in the lower reaches rarely rise above 20°C in summer which is cool for productive, river coarse fisheries (Mann, 1985).

Regulation was considered by the Dee and Clwyd River Authority, at the time of its proposed implementation, to be more beneficial to cyprinid fish because of water quality improvements, but possibly detrimental to salmonids (Blezard et.al. 1970). As salmonids are stenothermal, cool water fish which spawn in gravel in the upper parts of catchments, any detrimental effects to their well-being of small water temperature changes, brought about by regulation, are likely to be minimal. Both as juveniles and as adults the areas they frequent are already prone to wide fluctuations in temperature (Edwards, et.al. 1979). This is however not true for roach and other lowland river cyprinids such as bream and perch, which can be affected either directly or indirectly by small changes in river temperature (Coutant, 1987).

Growth development of juveniles can be affected by small variations in temperature (Kamler, 1992). Spawning success is also influenced by temperature fluctuations in coarse fish, by influencing maturation (Easton and Dolben, 1980 and Jordan, Pers comm). Mills and Mann (1985) showed that river temperature, in early summer, can be crucial for the production of strong year classes, therefore, if juvenile development on the Dee is more dependant on the main river channel for fry production, subtle temperature changes within the river corridor could be important to the success or failure of a particular spawning season and year class.

As roach are phytophilous, they are more dependant than other coarse fish for the availability of macrophytes in order to successfully spawn. The type of flow regime throughout the study area and the anthroprogenic water based activites that take place near Chester, have been shown to be damaging to the river channel and likely detrimental to weed development. Pearce (unpublished) recorded that, on the Dee at Chester, roach utilised the willow roots as spawning medium in 1980, at a time when macrophytes were very sparce. This activity emphasised the difficulty that roach were experiencing in finding suitable spawning medium. Juveniles of roach and bream also benefit from a food supply that is to some extent dictated by vegetation development (Mann, 1973). Further Wilkinson (1974), confirmed by results of the fish kill on the River Clywedog in 1990, indicated that some of the tributaries were more populated by adult dace populations rather than juvenile fish or adult roach. Collectively there is a high dependancy on favourable conditions and habitat being available in the main river particularly in respect of roach. Therefore contrary to Blezard et.al. (1970), the potential impact of regulation is likely to have been more detrimental to roach and other eurythermic species of the lower Dee rather than salmonids as had been originally perceived.

3.5 Summary

Evidence suggests that the increased flows from regulation have suppressed water temperatures in the lower catchment and possibly reduced the level of successful breeding in species such as roach, bream and perch. Slower growth rate in roach fry in the period soon after hatching could also jeopardise survival of the young fish over their first winter, leading to greater pressure on year classes in seasons when river and weather conditions are unfavourable.

Investigations of the river regime of the Dee and factors influencing it, have also indicated that the changes could have impacted on the juvenile stages of roach indirectly, by affecting the environment in which they feed and develop. As the shallow marginal areas of the main river channel were often frequented by juvenile fish, this area was investigated to establish if it was favourable for fry development.

Chapter 4 Juvenile Fish of the River Dee

4.1 Introduction

Factors affecting the development of juvenile stocks in the Dee were considered of importance because it was believed that problems of adult recruitment, particularly with roach, may be the consequence of environmental pressure on the early stages.

Growth is the main quantifiable element that is used for the assessment of the well-being or otherwise in fish. The energy used to achieve growth in fish is, however, just one element of the total energy budget defined by Weatherley and Gill (1987), the other two being energy used for the metabolic processes of the body and energy directed for the purpose of swimming. The allocation between the three has important implications for the development of fish, but research has not as yet fully evaluated the allocation and how changing circumstances in the environment influence apportionment. It is obvious, however, that the availability and nutrient value of food consumed influences the extent to which growth can take place, (Hofer et al, 1985). Therefore the feeding regime and factors that influence food availability and capture are necessary elements to evaluate, when considering growth development in juvenile fish.

The amount of available food that exists in any particular habitat is very much dependant upon environmental conditions and biological features operating within it (Witcomb, 1965). Mann (1965) has examined the energy sources that exist in aquatic systems and assessed how they interplay with different organisms.

As fish grow in size, the requirement for different foods to meet nutritional demands frequently necessitates a change of habitat, but this can be achieved so long as each respective habitat provides the required energy budget for the fish to develop. The important exogenous parameters that play a part in the development of fish include food, temperature, dissolved oxygen, water quality and competition (Wootton,1990). Food and temperature are the principal exogenous factors that influence growth in fish, with food providing the source for the energy budget and temperature influencing the rate at which the total energy budget is distributed (Hochachka and Somero, 1984).

Growth rates in fish also depend upon factors other than food. Endogenous factors, notably the genetic makeup of the fish, can override external environmental conditions appertaining at any one time. Matty (1985) has indicated that the factors influencing growth in fishes are far from being fully understood and warrant further research.

In the River Dee, fry populations frequented the marginal areas just after hatching and during their first full summer of development. Roach and dace fry growth, their feeding regime and the conditions within the margins were therefore examined in more detail to establish their importance to juvenile fish.

4.2 Methods

4.2.1 Benthos

To assess the distribution of food resources in the bankside margins, a site at Caldy, some 2km upstream of Chester Weir, was chosen (Fig 1.2). Two sampling areas were used to establish whether there was any difference in species abundance between a protected and a non-protected environment. The first represented a 200m length of shoreline protected from river wave action by a line of wooden pallets and from cattle by fencing on the landward side. The second adjoined the first but was unprotected in both respects.

In a lowland river like the Dee the bed deposits at the edge of the channel are invariably soft and, depending on location, can be quite deep (Ryder and Pensendorfer, 1989). In such a medium, accurate quantitative samples can be taken using either a grab or a core sampler, but in the present study the former method was chosen because some sampling work was necessary in mid channel where the substrate was harder and only a grab would be effective. A spring-loaded Ekman Grab

Sampler was used throughout and was found to be reasonably adaptable to the range of substrates found and gave repeatable samples.

Five grab samples were taken, at random, from the two areas at monthly intervals from April to December. Samples were also taken across the width of the channel and down the length of the study area, to establish chironomid distribution.

The efficiency of collecting samples by the use of an Ekman grab is affected by the following factors:

i) The ability to penetrate the substrate to a sufficient depth.

As the substrates in the sampling area were predominantly soft silts, problems of this kind were avoided. When sampling in mid channel from a boat, flow drift and the harder substrate at such locations made the task of achieving consistent samples more difficult.

ii) The closure angle of the grab.

The design of the Ekman grab dictates that as the jaws close progressively there is an ever deepening bite into the substrate, so the sample fraction from the lower depths, and therefore the collection of deeper organisms, will be proportionately less.

In highly accurate quantitative assessments this error can be significant, but in this study where mainly comparative assessments were being made, the bias was less important.

iii) The degree of jaw closure.

The jaws of a grab can close incompletely and lead to spillage of the sample once lifted away from the bed. The influencing factor is generally the presence of debris or stones jamming in the jaws, which in practice occurs more in weedy areas.

As most samples were from the soft substrate in shallow water, problems of this nature were largely avoided. Some difficulty was experienced with taking samples from mid-channel where the substrate was appreciably harder, but when this occurred samples were repeated.

4.2.2 Plankton

Plankton samples were taken at monthly intervals from May to October, within 5m of the edge of the channel and in 60cm depth of water at Caldy (Fig 1.2).

In the case of phytoplankton samples, single one litre bottles were filled. For zooplankton, five samples, each made up of three, 2m sweeps, were taken with a 250 mm framed hand net with 250 um mesh, to which was attached a small 50ml plastic bottle. All samples were preserved in 5% formalin. A Unilux-II, binocular microscope with a x4 lens and x10 eyepiece was then used to indentify the plankton found.

4.2.3 Fry

Roach were collected throughout the summer months at approximately 4 weekly intervals in each of the years 1986, 1989 and 1991. In respect of dace, samples were collected in 1989 and 1991 but in 1986 insufficient were taken therefore diet composition is not included for dace in this year. After hatching, samples were collected randomly within shoals of fish at the margins by means of a long-handled micromesh (2mm) handnet, but as the fry became larger and more active (> 20mm), a micromesh seine net (2.5mm) was found to be more efficient for obtaining the required number. In respect of the diet studies, to avoid any diurnal variations in consumption rates by the dace and roach fry, as indicated by Weatherley (1985), fry were collected as close to midday as was possible. Twenty fish of each species were collected at each sampling station and preserved in 5% formalin.

The size of sample indicated as a requirement by previous authors (eg Cassie, 1971, Abel, 1973 and Weatherley, 1985) has varied according to the experimental site and the objectives of the research. In this study it was necessary to develop a wide profile to include several environmental factors that had a role to play in influencing population variation. Therefore the sample size needed to be kept to a manageable level yet, be capable of yielding statistically reliable information on growth and diet change in the two species within seasons and between seasons. For this reason 10 fish were selected at random from the main sample by choosing those that had bisected a vertical line on the underside of a petri dish in which they had been spread. These fish were then used for both diet and growth assessment.

4.2.4.1 Assessment of Diet

i) Choice of procedure

There were two basic aspects that needed to be addressed when the gut contents of fry were examined. There was firstly, the range of organisms or food items on which the fish were feeding and secondly, the volume of food that was being ingested.

To view and then remove the gut to examine the stomach contents, it was necessary to make an incision in the wall of the anterior body cavity. Two methods were attempted initially to assess which was most suitable for all size ranges of fry that were to be examined.

The first involved a ventral cut from the gill cover to the anus. The second started with a cut around the gill cover, following the lateral line, until reaching an imaginary vertical line from the anus and then cutting back to the ventral surface.

The advantage of the latter method was the avoidance of accidently penetrating the gut and therefore causing loss of food constituents before gut removal. This was particularly appropriate with newly hatched fry, which were very fragile and difficult to cut along the ventral surface. It was decided that the latter method would be universally adopted and that the gut could be easily removed by folding back the gut wall and cutting the gut at either end to effect removal.

In young cyprinid fry, like roach and dace, there are marked developmental changes in the way the gut grows. At the newly hatched stage, the gut is a very simple tube which does not develop any bends until the fish are about 6 weeks old. After this time it progressively forms two 180° loops which run parallel and are loosely attached by fatty tissue. When studying the young stages it is, therefore, difficult to select comparable sections of the gut at the different sizes of the fry, although as the fish become larger some relationship with the turns of the gut can be made.

Roach and dace do not have a distinct stomach. Instead they have a wider chamber at the anterior end, which progressively becomes a narrow and fairly uniform tube throughout the rest of its length. For the purpose of the study, it was decided that in young fry the whole length of the gut would be used for the assessment of food organisms, but when the gut became looped then only the section between the oesophagus and the first loop would be examined and food quantified.

ii) Examination of Gut Contents

In the diet survey the frequencies and respective volumes of the constituent food items, consumed by roach and dace from the river, was determined. To extract the food consumed, the gut was removed from the body cavity and the appropriate length carefully sectioned. The gut was then cut longitudinally and the contents transfered to a microscope slide.

To calculate the volume of food a volumetric slide was made, using the technique described by Hellawell and Abel (1971). This consisted of a microscope slide (26mm x 76mm) to which were affixed two cover slips (22mm x 22mm) at opposite ends of the slide by using Canada Balsam and Xylene. Initially a small piece of graph paper with a 1mm grid was affixed to the base of the slide, so an area of coverage could be calculated when the food mass was placed upon it. It was soon found preferable to use an eyepiece grid which could also be calibrated to assess area. The eyepiece grid was a one centimetre square graduated into 100 identical squares, each one square millimetre. The volume of food was calculated by compressing the food mass between the cover slips by the means of a second slide and then counting the number of squares that were covered. To establish actual volume, the area which had been calculated from the number of squares, was multiplied by the known thickness of the coverslips on the test slide ie 0.68mm and then recorded as mm^3.

Food volume alone does not take into account the size of the respective fish because larger fish would be expected to be more capable of taking in greater volumes of food. To overcome this problem, food volume intakes were expressed in relation to the weight of the fish. The food volume expressed in this way did not take account of stomach fullness, so a separate visual percentage assessment of this volume was made. A calculation of the potential intake of the fish could then be made and was useful in examining fluctuations in diet ratios.

In diet studies, it may not be necessary to calculate specific food constituents where it is satisfactory just to establish comparative food volumes consumed. In this study, detail on the diet of fry was required and therefore a method was adopted that had a consistency of application to fish of all sizes sampled, as well as providing data on both volumes and diet constituents.

The advantages of the techniques were, that it was applicable to a wide size range of fish fry and also the analysis could be quick because the gut was dissected and the food removed, sorted, volume assessed, identified and counted, all on the one slide within a matter of minutes, which avoided unnecessary dehydration of the contents.

The expansion of the method as recommended by Hellawell and Abel (1971), to draw and then weigh various paper tracing or outlines of food to assess food volumes, was considered inappropriate because the variability of outline tracings and difficulty in cutting the outlines would not only have been a potential source of error but would also have been slower, creating problems when examining such small fish and associated quantities of food.

Once the food volume was established, it was then necessary to identify the food items and their relative abundances in the sample. The latter aspect was more difficult to achieve because many stomachs contained food which was mixed or partly digested. Cyprinids, like roach and dace, macerate their food considerably, (Kamler, 1992) and as stomach contents included mixtures of detritus, algae, other plant material and mucus, it was almost impossible to sort the dietary components and measure them accurately.

Various schemes for fish gut analysis and the presentation of the data have been put forward by a number of authors for example Swynnerton and Worthington (1940), Frost (1943) and Hynes (1950), who all used different points systems to assay stomach fullness. In order to effect a calculation for the level of food items in this study a proportional assessment scheme, following the principles of Hynes (1950), was adopted.

The amounts of each food type were calculated in each fish and then expressed as a percentage of the food items over the whole group of fish. To achieve this, a scoring index of between 1 and 100 was used in gradations of 5 units to assess the proportion of each food item in each gut. The quantification of food items were made by the use of Kyowa Unilux-11 microscope with a x4 lens and x10 eyepiece, although for ease of identification of smaller food types a x10 lens was used initially. For consistency, all calculations on proportion were made under the lower magnification. The mean values for each food type were then calculated as the percentage of the food items in the respective group.

4.2.4.2 Measurement of growth

The growth attained in juvenile fish is a reflection of the feeding regime that exists in a particular microhabitat and also the environmental factors that may influence it. It is therefore the best indicator of how favourable or otherwise the collective conditions are for a particular individual or species.

All selected fish were first washed in distilled water, to remove formalin, and then damp dried, before being measured and weighed. They were then transferred to a glass slide and a measurement of fork length was taken to the nearest 0.1 mm using a calibrated scale with a binocular microscope. In the case of newly hatched fry, fin shape had not developed so the length of each specimen was taken from the nose to the tip of the fin. Speed of analysis was important with very small fish on account of rapid dehydration and resulting adhesion of the tail to the slide, leading to potential damage. Wet weights to 1mg were recorded using a Sauter single pan balance. No adjustments were made for shrinkage in the measurements of fry as a result of the effects of formalin. This is because all samples were preserved in the same way and no fry growth comparisons were made with other river systems.

The 'Coefficient of Condition' is a useful indicator of favourable growth development and, as fry are undergoing considerable body changes in their first year, an evaluation of well-being was required. The formula selected was that used by Broughton and Jones (1978) :

$$K = \frac{100\,K}{L^{3}}$$

(where 'K'= Coefficient of Condition; 'W' = weight in grammes; 'L' = fork length).

In addition, it was important that a measure be made of the percentage daily growth rate so as to assess the progressive change in growth at different times of the season. This was calculated using the formula proposed by Grigorash <u>et.al</u>. (1973), which is expressed in the formula :

$$\%\ \text{M.D.W.I.} \cdot \frac{2(WT \ \cdot Wt\ )}{(T \cdot t)(WT \ \cdot Wt\ )} \text{x100}$$

(% M.D.W.I.= % Mean Daily Weight Increase; WT = Fish weight in gms after T days and Wt = Weight in gms after t days; T>t).

4.3 Results

4.3.1 Benthos

In Table 4.1 the numbers of the three main taxa recorded, chironomid larvae, oligochaetes and the mollusc Sphaerium sp, are plotted.

While oligochaetes were in the greatest number and Sphaerium the least, there was no clear seasonal variation with either, nor did there appear to be any fluctuations that could be related to periods of times when feeding pressures from juvenile fish would be likely to be at their highest. There was, however, a decline in abundance of chironomids in the summer months, despite this being the time when climatic and riverine conditions were most favourable for their development. The summer decrease occurred in both the compounded and uncompounded areas.

Table 4.2 shows the cross-channel distribution of chironomids and it is noteworthy that numbers are greater in the more scoured area of mid-channel. The longitudinal distribution of chironomids in the river from Farndon to Chester (Table 4.3) again showed an increase in abundance in the middle of the channel although their was a progressive decline towards Chester. As this was sampled during the summer months, when flows are more stable, it is possible that other patterns of distribution occurred during the winter when flows are higher. The other organisms that were recorded included oligochaete worms and Sphaerium sp, which populate soft substrates and therefore were more abundant at the margins. Caddis larvae, which prefer predominantly sandy deposits, were absent from the margins but more abundant in mid channel. It is likely that caddis larvae and Sphaerium sp are both too large to be consumed by first year fry but, Lammens and Hoogenboezem (1991) established that they featured in the diet of adult roach.

Table 4.1

Organisms in Marginal Benthic Substrates

River Dee - Caldy, Chester (1986)

Margin behind Temporary Barrier

	Chironomids (Nos m^{-2})			Oligochaetes (Nos m^{-2})			Sphaerium sp (Nos m^{-2})		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
April	37	88	66	570	716	614	0	7	4
May	10	41	30	392	810	591	3	17	8
June	6	25	11	416	913	720	3	17	11
July	1	9	5	33	528	287	1	18	9
August	2	18	6	464	902	745	7	9	8
September	1	30	10	76	216	137	1	7	3
October	10	50	23	210	442	326	0	6	2
November	19	106	53	76	734	388	8	39	19
December	66	102	78	8	39	19	8	16	11

Margin in Open

Nos/m^{-2}

April	110	263	196	186	549	365	8	22	14
May	31	146	72	35	123	62	0	3	2
June	5	88	34	212	588	381	8	22	16
July	1	39	12	26	403	253	19	90	43
August	3	6	4	288	1550	658	8	29	17
September	60	124	92	224	454	312	7	19	13
October	16	48	30	64	156	108	15	32	24
November	67	134	103	196	398	285	4	34	19
December	0	103	24	0	75	33	0	4	2

Table 4.2

Sediment Organisms across the Channel (Mean Nos/m^2)

River Dee - Caldy

Aug-86

Organisms	Rht Margin	20m	40m	60m	Lft Margin
Chironomid sp	15	41	65	34	43
Oligochaete sp	108	19	12	115	134
Sphaerium sp	8	0	0	0	34
Caddis larvae	0	31	36	19	0

Table 4.3

Chironomid Distribution in River Bed Substrate (Nos/m^2)

River Dee from Farndon to Chester Weir

Aug-86

Distance from Chester Weir km	Side			Middle		
	Min	Max	Mean	Min	Max	Mean
22	14	457	194	28	571	345
20	0	86	52	14	1428	440
18	14	28	20	171	728	331
16	14	257	97	157	428	277
14	14	171	97	71	214	154
12	71	171	120	28	286	123
10	0	142	37	43	171	100
8	0	86	28	14	114	46
6	0	142	40	0	428	120
4	14	86	34	0	28	6
2	0	0	0	0	0	0
0	0	43	17	0	14	9

4.3.2 Plankton

The phytoplankton species recorded in the two areas of the margins are given in Table 4.4.
It can be seen that the species of phytoplankton found at the margins are mainly made up of still water species that are drifting downstream, which are defined as river plankton. This pattern was established throughout the study period when flow velocities were constant and slow ($<0.5 m.s^{-1}$), but it is likely that at other times, when flows are higher, their presence may be reduced further. A feature that related to the warm, stable period of the summer was the abundance of filamentous algae within beds of Nuphar lutea that developed in the protected area.

On account of the weed growth in the protected area, sampling for zooplankton was impractical and not undertaken. The availability of zooplankton in the open area, which was subject to more disturbance from river flow, was found to be very sparse and therefore details were not recorded.

4.3.3 Fry

4.3.3.1 Diet of Fry

i) Diet of Dace

The diet of fish changes with increase in growth and the choice of food can depend upon seasonal fluctuations in the availability of organisms Wootton (1990). These patterns in adult dace have been shown by Sillah (1981) and Cowx (1989) and in juvenile fish by Weatherley (1985).

In each of the summer periods of 1989 and 1991, the dominant food item in dace was emergent insects (recorded as terrestrials), suggesting that the fry were active in the surface layers of the water column, where this food supply would be most abundant. Detritus was recorded in most months and, at times, contributed as much as 46% of the diet constituents, indicating that the fry were also grazing in the margins. Weatherley, (1985) suggested that the presence of detritus in late

Table 4.4

Phytoplankton Composition
River Dee, Caldy
1987

Species	Protected Area						Unprotected Area					
	May	June	July	Aug	Sept	Oct	May	June	July	Aug	Sept	Oct
Anabaena												
Gomphosphaeria		x	x									
Microcystis	x	X	x	x	x			x	x			x
Closterium				x	x	x				x	x	x
Chlorella								x				x
Gleocystis	x	x	x	x						x	x	
Sphaerocystis				x								
Pediastrum			x									
Scenedesmus	x	x	x	x	x	x	x	x	x	x	x	x
Staurastrum			x	x								
Filament Algae	x	x		x	x							
Ankistrodesmus	x		x	x	x	x	x	x	x	x	x	x
Chlamydomonas								x				
Cryptomonas						x						x
Pandorina		x						x				
Euglena type					x		x				x	
Sml Flagellates	x	x	x	x		x		x	x	x		
Mallomonas					x						x	
Diatoma						x				x		
Tabellaria				x	x							x
Fragillaria		x		x	x	x				x	x	x
Synedra	x	x		x	x	x		x	x	x	x	x
Astrionella					X	X						x
Cyclotella			x	X	x	x				x	x	x
Navicula	x	x	X	X	X	X	x	x	x	X	X	X
Nitzschia		x	x									
Surirella				x	x							x
Cocconeis			x	x	x	x				x	x	
Meridion					x					x	x	
Rhoicosphenia				x							x	
Cymbella	x	x	x	x	x		x	x	x	x	x	x
Gomphonema					x							
Pinnularia			x		x					x		
Melosira	x	x	x	x	x	x			x	x	x	x
Meriamopedia												
Phacus												
Actinastrum												
Amphora												
Melompedia												

x = Present X = Abundant

summer was related to the foraging for algae in the margins, but it was found in this study that algae did not feature greatly in the diet of dace, even in the very warm year of 1989, when this food item was most abundant. This would suggest that they were foraging for other seasonally available organisms which included crustaceans and chironomids. From the benthic studies a decline in chironomids was detected in the summer months (Table 4.1), when they featured in the diet of dace (Table 4.5,Fig 4.1 and 4.2). Crustaceans, being found in the water column and randomly distributed were not quantitatively monitored, so any similar relationship could not be identified. Although both are present in the gut contents, the percentage abundance was never recorded to be in excess of 25% (August,1989) for chironomids, or 17% (June,1991) for crustaceans. Although the density of the fry population was not assessed, visual observations suggested that the large number of dace fry grazing could be limiting the availability of this food source. Despite the high presence of oligochaetes in the marginal benthos (Table 4.1), there was no indication that the dace were grazing on them, as they were not found in the gut contents. Kennedy (1969) however, indicated that the detection of tubificid worms was difficult in the macerated gut contents of dace fry, as they were rapidly absorbed and only present in the gut for a short period. In the same way nematode worms could also be missed in the diet components of fry. As there was little variation in abundance of nematodes in the benthos from month to month, which was comparable to the chironomid changes, it is suggested that they do not feature greatly in the diet of dace.

The diet constituents of detritus, aeriel insects and seasonal levels of chironomids and crustaceans are broadly consistent with those found in other studies of juvenile dace, for example Starkie (1976) on the River Tweed and the Craig Goch team (1980) on the River Severn. The preferred choice of emergent insects by the dace is, however, different to that of roach (See below).

ii) Diet of Roach

Roach fry were found to be actively foraging in the margins because algae and detritus were consistently found in their diet in the first

Table 4.5

Diet of Dace Fry (%)
River Dee - Chester

* = Plotted in pie chart

1989

Food Items	*		*		*		*	*
	8th June	21st June	4th July	20th July	10th Aug	25th Aug	9th Sept	2nd Oct
Algae (Round)		3.3						
Algae (Filamentous)		5	11.5	20	10	5	12	10
Chironomids		20		1.3	25.5	11	6	14.3
Cladocerans	8	3.3						
Copepods	3							
Detritus	44		49.3	11.2	23	24	26	15
Diatoms						3	1	
Plant Material	11	1.1	2.1	5			7	44.5
Rotifers								
Terrestrials	34	67.3	37.1	62.5	41.5	57	48	16.2
Other								

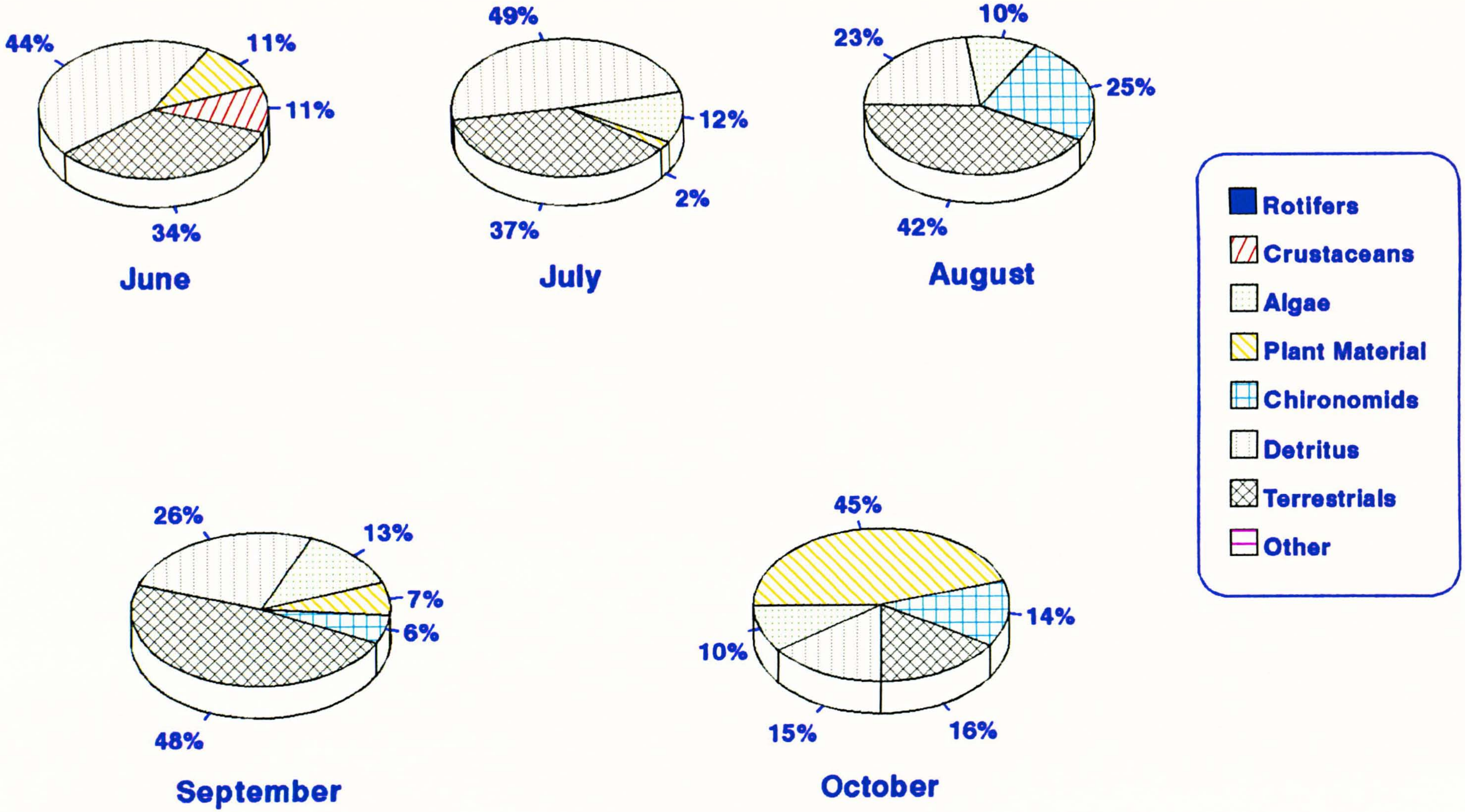
1991

	*	*	*	*	*
	10th June	10th July	2nd Aug	2nd Sept	8th Oct
Algae (Round)	8				
Algae (Filamentous)	2	17			15
Chironomids		5	6	8.3	7
Cladocerans	17	12			1
Copepods				8.3	
Detritus	46	23	6	16.7	25
Diatoms			2		0.5
Plant Material		9			10.5
Rotifers					
Terrestrials	22	34	86	66.7	41
Other	5				

Diet of Dace Fry

River Dee - Summer 1989

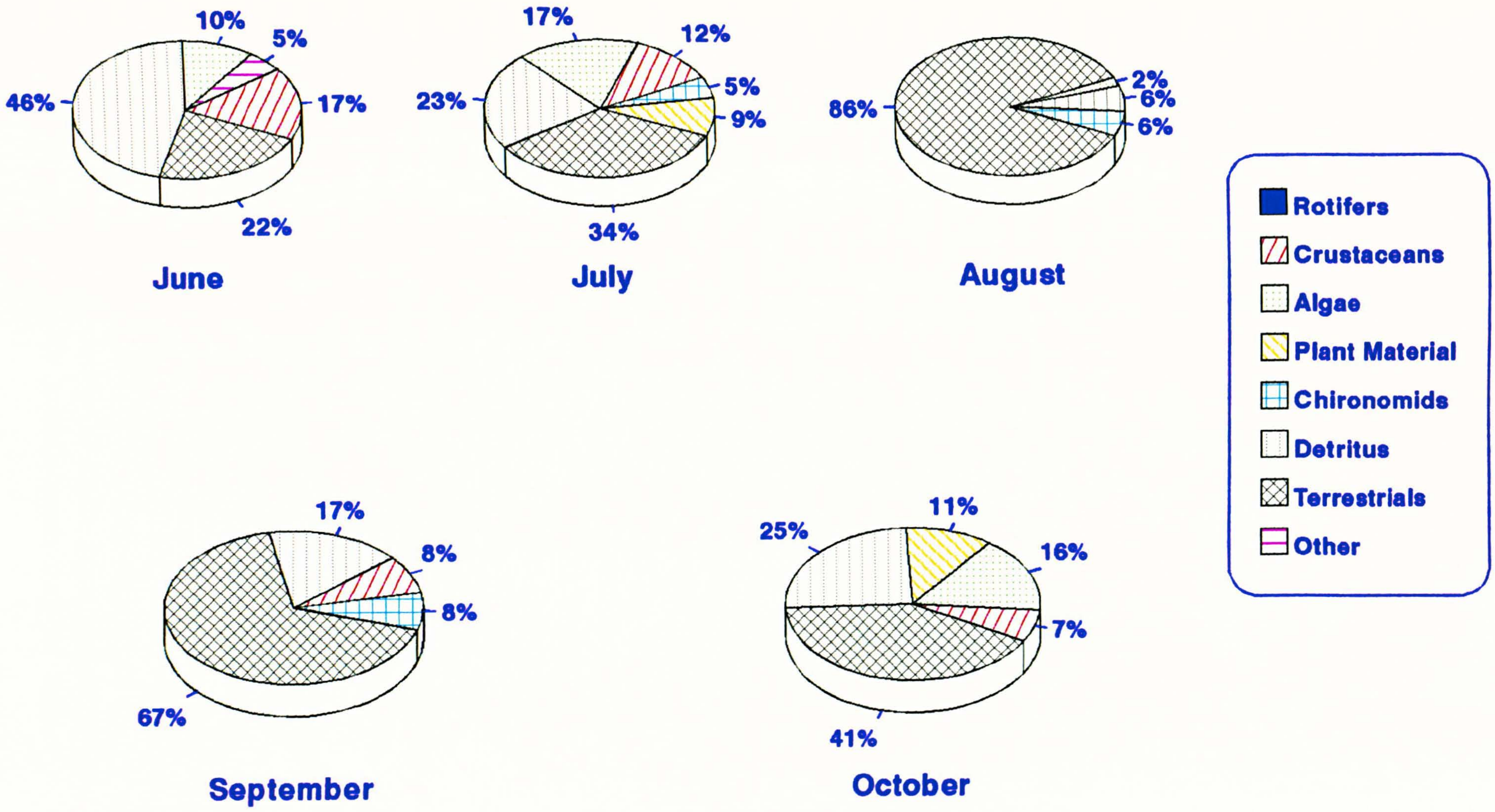
Fig 4.1



Diet of Dace Fry

River Dee - Summer 1991

Fig 4.2



summer. Easton and Dolben (1980) determined that roach invariably have a preference for rotifers after first hatching. On the Dee this was not apparent, as rotifers were only occasionally recorded and then at only very low levels of <3%. It is not known whether the limited presence of rotifers in the diet is due to preferred choice for other food items, or, whether there was a limited supply.

During the early stages there was a consistency of diet choice between algae, copepod nauplii (recorded as crustaceans) and detritus, which were almost equally represented. Crustaceans were consistently found in roach diet throughout the summer of 1986 (11-24%) (Table 4.6 and Fig 4.3) and in early summer in 1989 and 1991 (Table 4.6,Fig 4.4 and 4.5). The dominant presence of algae in diet in both these latter years, suggested that the presence of filamentous algae in the water column, either restricted the capacity to capture small crustaceans, or, that algae were the preferred choice.

It would be expected that filamentous algal development in the marginal habitat in cool summers, like 1986, would not be as extensive as in warm summers, like 1989. As plant growth is dependent on sunlight and warmth to develop (de Nie, 1986), not only would there be reduced growth of both macrophytes and algae in cool years, but also the reduced presence of macrophytes would further limit the available sheltered microhabitats in which filamentous algae could establish. The higher prominence of crustaceans in roach diet in 1986 indicated that crustaceans could become an alternative food source in cool summers, when filamentous algae are in shorter supply. It can be seen from Fig 4.6 that the ratio in the diet of roach, of riverine or planktonic algae, (classed as round) was very low compared to that of filamentous. Filamentous algae were found in protected habitats, particularly in weedy areas at the margins (Table 4.4). As roach were largely found and captured from these areas in summer, it is suggested that filamentous algae was a preferred item in diet choice. As this food was consumed in each month of the first summer it further indicated that roach were more passive feeders than dace, which sought moving food items such as emergent insects. Therefore the presence of stable microhabitats at the margins may well be more essential for juvenile roach than for dace.

Diet of Roach Fry (%)
River Dee - Chester

* = In Pie Chart

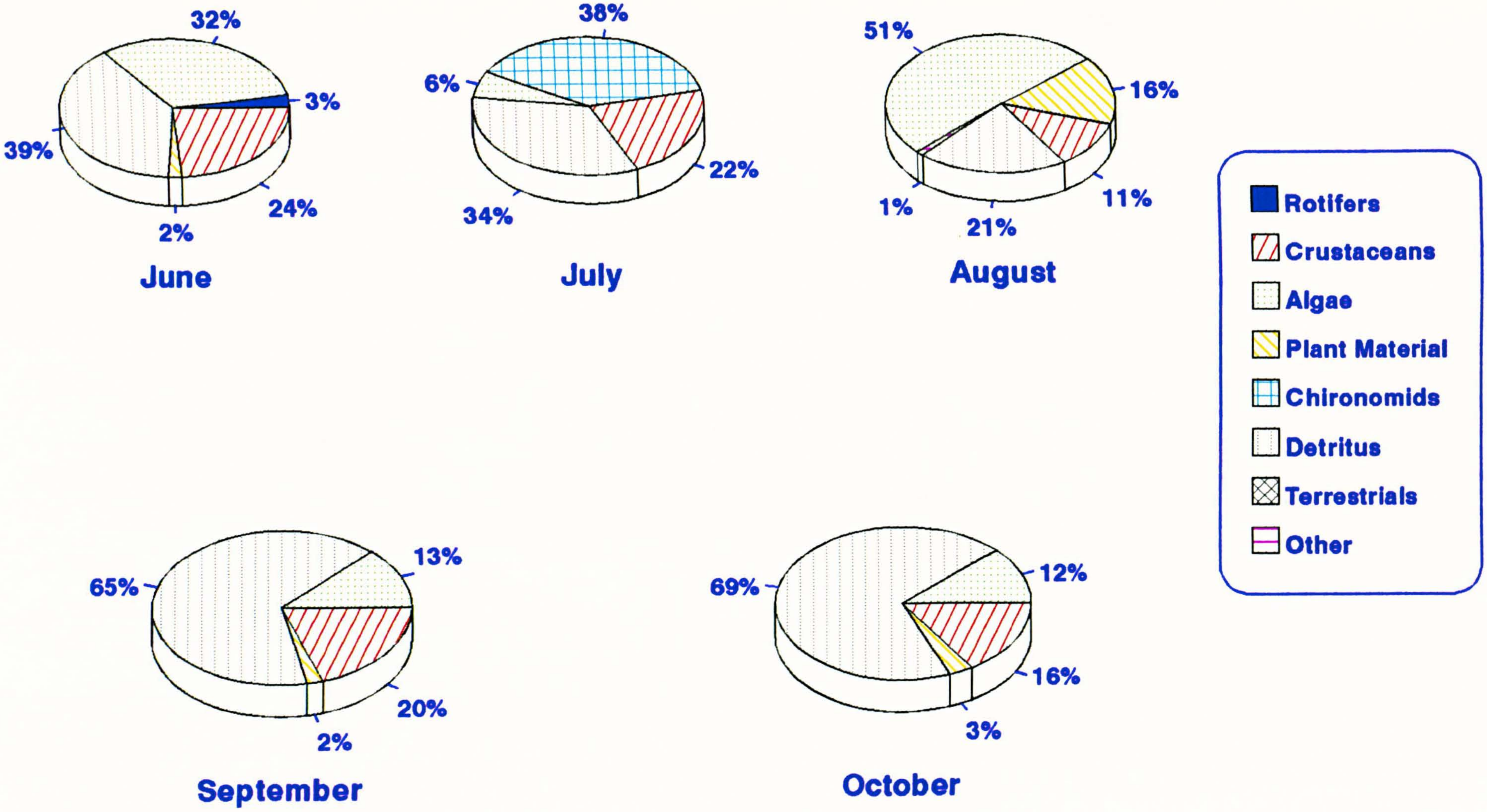
Table 4.6

Food Items									
				1986					
	*		*		*		*	*	
	12th June		10th July	24th July	7th Aug	21st Aug	4th Sept	3rd Oct	
Algae (Round)	32.2		4						
Algae (Filamentous)				32	43		9	12.3	
Chironomids			38	23					
Cladocerans	6.5		22	9.5	10.5	62.5	20	14.5	
Copepods	17.5				0.5	7.5		1.5	
Detritus	39		34	25	21	30	65.5	68.5	
Diatoms			2		8		3.5		
Plant Material	1.8			10.5	15.5		2	3.2	
Rotifers	3								
Terrestrials					1				
Other					0.5				
				1989					
	*		*		*		*	*	
	8th June	21st June	4th July		10th Aug	25th Aug	9th Sept	2nd Oct	
Algae (Round)	28.7	0.5	8.1						
Algae (Filamentous)		9.5	38.8		31.2	63	49	45	
Chironomids		20			14.4	9	7		
Cladocerans	17.5	26.5	0.6				1	1	
Copepods	21.3	1							
Detritus	25	21.5	41.3		50	24	35	52.5	
Diatoms	7.5	13.5			2.2	1	2		
Plant Material		1	8.1		2.2	1	3	1.5	
Rotifers			0.6						
Terrestrials		6	2.5			2	3		
Other		0.5							
				1991					
	*		*	*			*		*
	10th June		11th July	2nd Aug			2nd Sept		8th Oct
Algae (Round)	25			1.5					
Algae (Filamentous)			0.5	18.5			78.5		55
Chironomids			42.5	8.5					
Cladocerans	11.3		19	2.5					
Copepods	23.7								
Detritus	33.7		20	57.5			11.5		27
Diatoms	6.3		13.5	9					3
Plant Material				1					12
Rotifers									
Terrestrials			4				10		3
Other			0.5	1.5					

Fig 4.3

Diet of Roach Fry

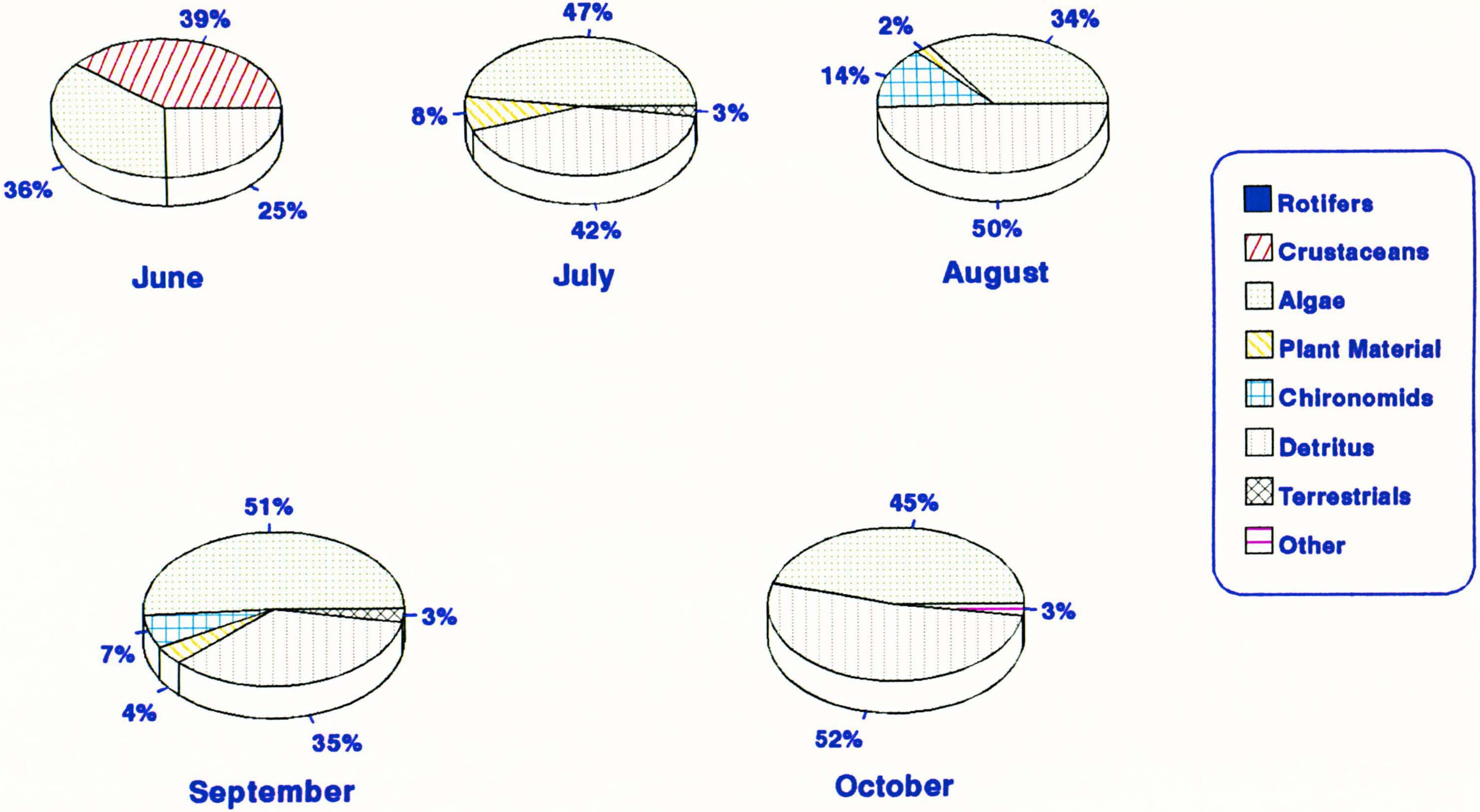
River Dee - Summer 1986



Diet of Roach Fry

River Dee - Summer 1989

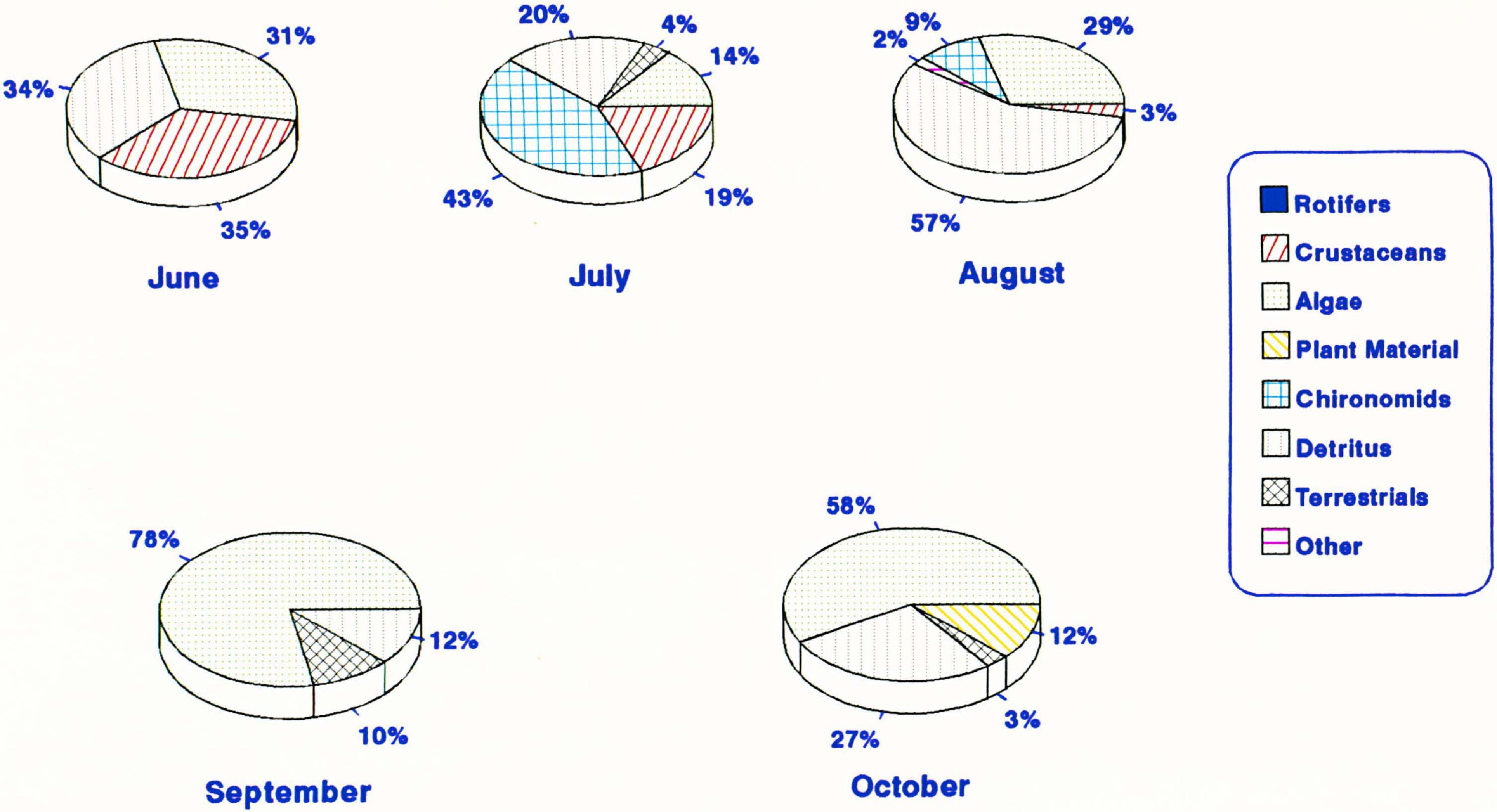
Fig 4.4



Diet of Roach Fry

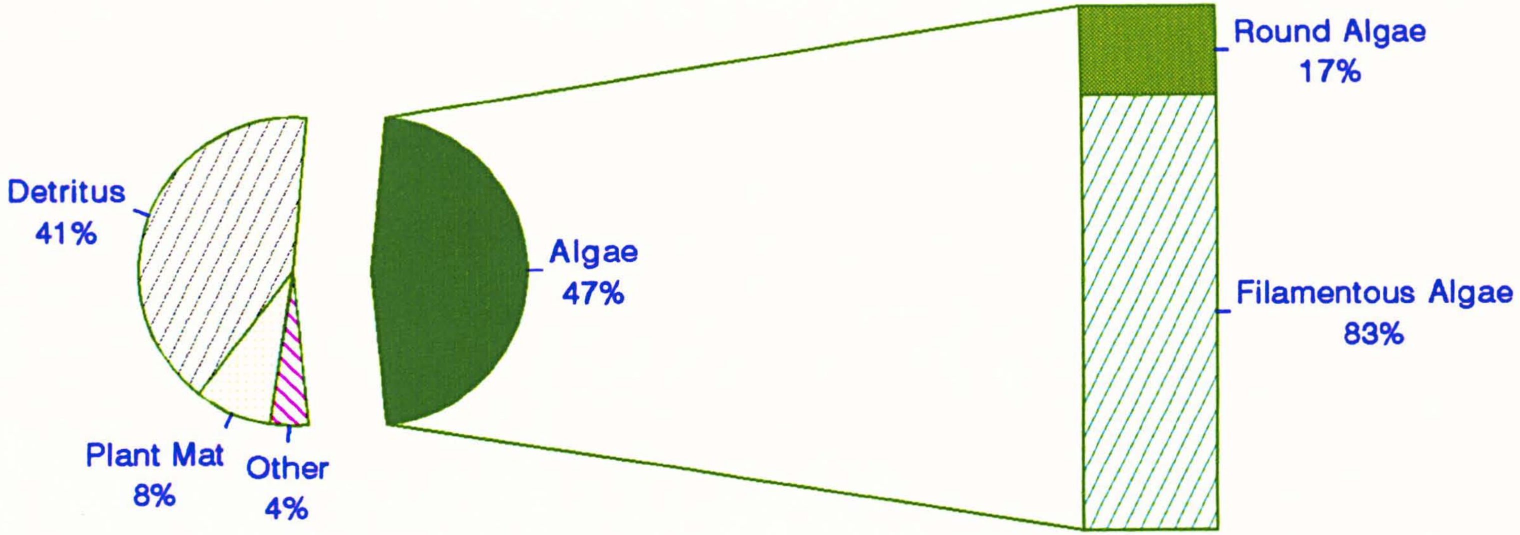
River Dee - Summer 1991

Fig 4.5



Algal Ratio in Diet of River Dee Roach
July 1989

Fig 4.6



In respect of chironomids, comparable diet selectivity to dace was found, because by July, when the fry were in excess of 16mm, up to 38% of the roach diet was made up of chironomids. It is likely that the movement of fry in and out of the margins, established from the studies on boat wave action effects (Chapter 3), was in response to released chironomids and organisms which had been disturbed from the benthos. The high level of chironomid presence in diet was probably important for increased growth rate in July and August but it was found that consumption was short-lived, indicating that similar limitation of the food source was occurring to that found in dace. By the end of the summer months there was still a consistency of diet, with algae and detritus being the main components. Unlike dace, terrestrial insects or their life stages rarely featured in the diet of roach and probably were not actively pursued in their first summer.

4.3.3.2 Growth of Fry

i) Growth of Dace

From Table 4.7 and Fig 4.7 it can be seen that, in the warm year of 1989, fry at the hatching stage were appreciably longer by 5mm, compared to fry in 1991. The growth increased progressively in each of the years sampled and in 1989 the faster growth initially achieved was maintained throughout the summer. The differential, compared to 1991, was however lost by the 18th week following accelerated growth in late summer of 1991. Entering the winter, fry from both years were similar in length at around 45mm. For 1986, early summer growth was similar to 1991 but comparable data at the end of the summer were not available.

Growth in weight was much more variable in 1989, with greater increases in June, July and August than in the same months in 1991, suggesting an abundant food source as a consequence of warmer temperatures in 1989 (Table 4.7 and Fig 4.8). In both 1989 and 1991, rapid weight gain was apparent from the beginning of September, at a point when diet was predominantly terrestrial insects. By the start of the winter the weight achieved was around 1.2gms.

River Dee
Dace Fry Development

Table 4.7

1986

Date of Sample	6th July	24th July	21st Aug	4th Sept
Fish Length mm (mean)	23.9	24.96	28.41	32.13
Fish Weight gm (mean)	0.0801	0.1357	0.186	0.311
Condition Coefficient	0.59	0.87	0.81	0.94
Mean Daily Weight Increase %		2.86	1.12	3.59
Stomach Fullness (%)	55	30	26	20
Food Volume (cu mm^{-1})	1.96	1.258	2.108	1.943
Food Volume/gm of Fish	25.04	10.34	9.96	4.38

1989

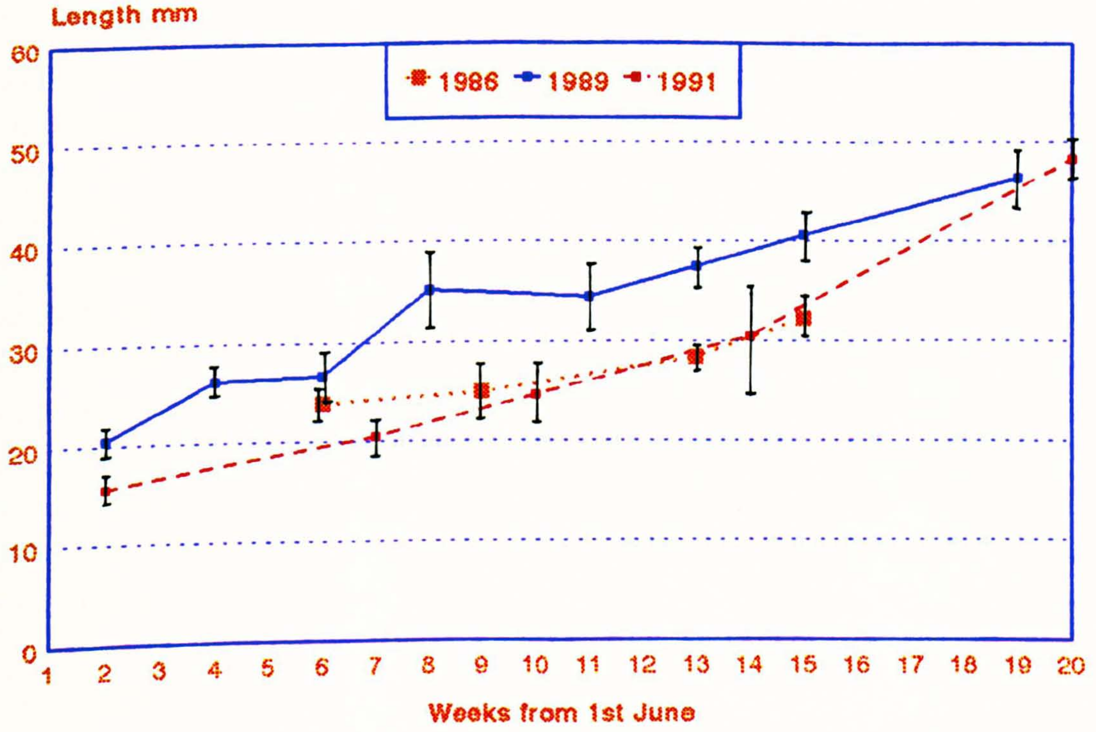
Date of Sample	8th June	21st June	4th July	20th July	10th Aug	25th Aug	9th Sept	2nd Oct
Fish Length mm (mean)	20.54	26.27	26.69	35.11	34.37	37.35	40.59	46.31
Fish Weight gm (mean)	0.0454	0.2082	0.22	0.466	0.4573	0.52	0.693	1.138
Condition Coefficient	0.52	1.15	1.16	1.08	1.13	1	1.04	1.15
Mean Daily Weight Increase %		9.88	0.42	4.48	-0.08	0.86	1.9	3.04
Stomach Fullness (%)	51	63	23	70	62	44	44	42
Food Volume (cu mm^{-1})	3.842	4.72	4.84	9.35	5.168	3.51	4.692	6.5
Food Volume/gm of Fish	80.5	25.03	31.2	20.47	12.24	7.22	6.56	6.4

1991

Date of Sample	10th June	10th July	2nd Aug	2nd Sept	8th Oct
Fish Length mm (mean)	15.62	20.54	24.64	30.48	48.27
Fish Weight gm (mean)	0.0367	0.0896	0.166	0.363	1.184
Condition Coefficient	0.96	2.12	1.11	1.28	1.05
Mean Daily Weight Increase %		2.8	2.58	2.4	2.94
Stomach Fullness (%)	50	62	44	39	64
Food Volume (cu mm^{-1})	3.06	2.04	2.38	3.351	12.47
Food Volume/gm of Fish	90.13	25.32	15.49	6.61	10.52

Growth in Length of Dace Fry
River Dee - Chester

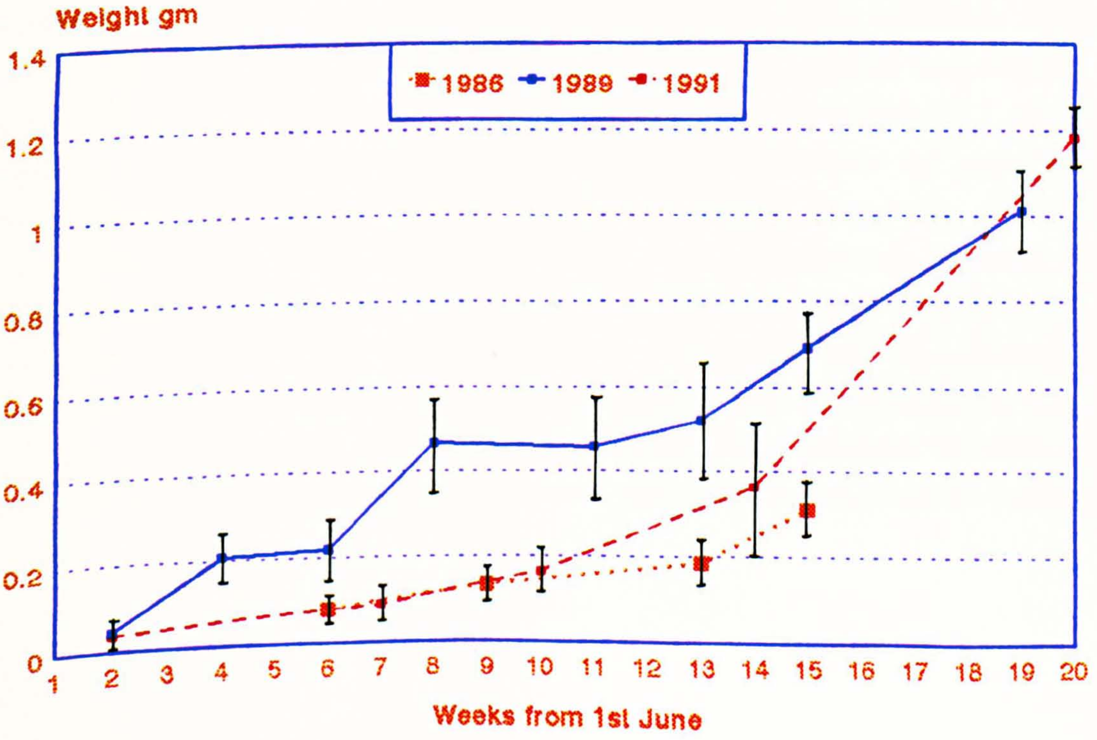
Fig 4.7



With 95% Confidence Limits

Growth in Weight of Dace Fry
River Dee - Chester

Fig 4.8

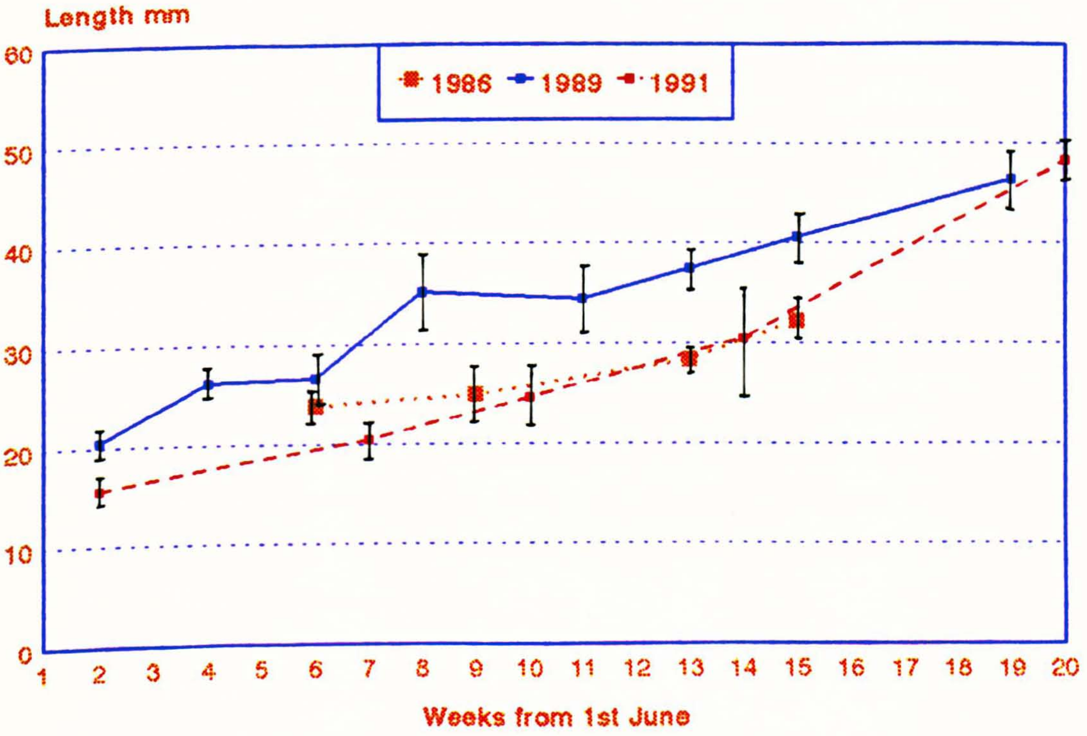


With 95% Confidence Limits

Growth in Length of Dace Fry

River Dee - Chester

Fig 4.7

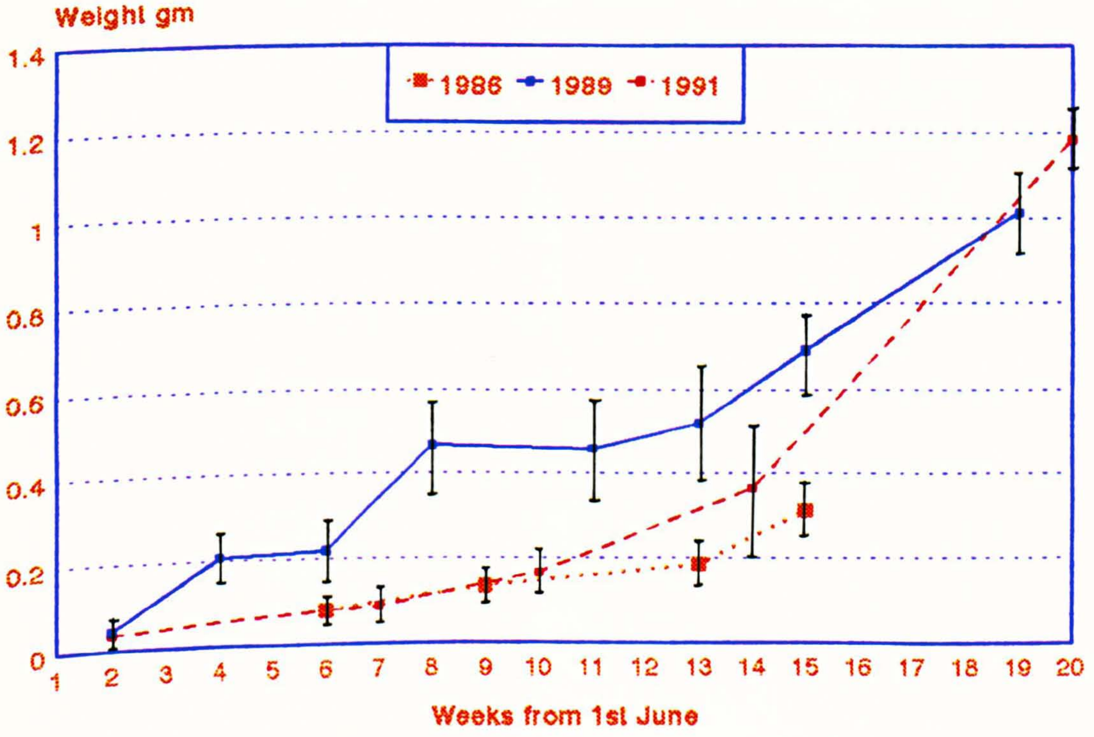


With 95% Confidence Limits

Growth in Weight of Dace Fry

River Dee - Chester

Fig 4.8



With 95% Confidence Limits

Condition coefficients, after the first hatch stage, were consistently above one in both 1989 and 1991, which suggested good growth development in both years. In the cooler year of 1986, the coefficient remained below one for the times sampled and therefore a less favourable feeding regime was the probable cause.

The mean daily weight gain (MDWI) in 1986 and 1991 was around 2% in the summer period. In 1989 however, there was considerable variability, from a maximum gain of 9.9% down to a mean loss of 0.1%. This variation could be associated with a number of factors, which would be more prevalent in a year when the potential food source was large. These include fluctuations in diet choice and consumption rates, wide variations in sizes of fish and interference in feeding, through increased competition from a larger population of fry resulting from a successful year class. More detailed study would be required to establish the actual cause, but it was shown from the level of stomach fullness in both 1989 and 1991 that it remained close to 50% and therefore food shortage was not a likely reason.

ii) Growth of Roach

With roach, there were marked differences between the growth rates achieved in the three years sampled, with 1989 having the greatest increase and 1986 the smallest (Table 4.8, Fig 4.9 and 4.10). The difference between the two extremes in growth achieved by the beginning of October was approximately 14mm in length and almost 1gm in weight. Apart from much larger fry being produced soon after hatching in June 1989, the most rapid gain was that achieved from August onwards in the same year, when the average weight increased from 0.2gm to 1.1gm in 6 weeks. This coincided with the change in diet, notably by inclusion of chironomids, but as this also occurred in 1991 the change in diet choice could not be the whole reason. In 1989 and 1991 stomach fullness was consistently high and at around 70% was notably higher than that recorded for dace. The food volume per gm of fish was also similar, indicating much the same consumption rates. The conversion of this food source to body weight increase was possibly more efficient in 1989, which may reflect the benefits of the warmer and more favourable environmental

River Dee

Roach Fry Development

Table 4.8

1986

Date of Sample	12th June	10thJuly	24th July	7th Aug	21st Aug	4th Sept	3rd Oct
Fish Length mm (mean)	6.34	12.4	16.8	18.49	23.46	27.85	31.12
Fish Weight gm (mean)	0.0015	0.018	0.0328	0.0511	0.099	0.1873	0.2211
Condition Coefficient	0.6		1.69	0.81	0.77	0.87	
Mean Daily Weight Increase %			4.38	3.11	4.56	4.41	
Stomach Fullness (%)		30	36	61	42	43	40
Food Volume (cu mm^{-1})		0.575	1.156	0.982	3.485	2.312	1.842
Food Volume/gm of Fish		29.82	36.02	19.61	35.05	11.97	8.124

1989

Date of Sample	8th June	21st June	4th July	10th Aug	25th Aug	9th Sept	2nd Oct
Fish Length mm (mean)	10.99	17.24	24.46	26.46	30.48	35.76	43.99
Fish Weight gm (mean)	0.0072	0.0437	0.1683	0.1969	0.4455	0.8239	1.1407
Condition Coefficient	0.54	0.86	1.15	1.06	1.57	1.8	1.34
Mean Daily Weight Increase %		11.01	9.04	0.42	5.16	3.98	2.02
Stomach Fullness (%)		37	38	66	78	71	71
Food Volume (cu mm^{-1})		1.36	4.352	4.004	12.24	14.01	18.224
Food Volume/gm of Fish		31.91	36.35	21.66	27.52	17.68	15.54

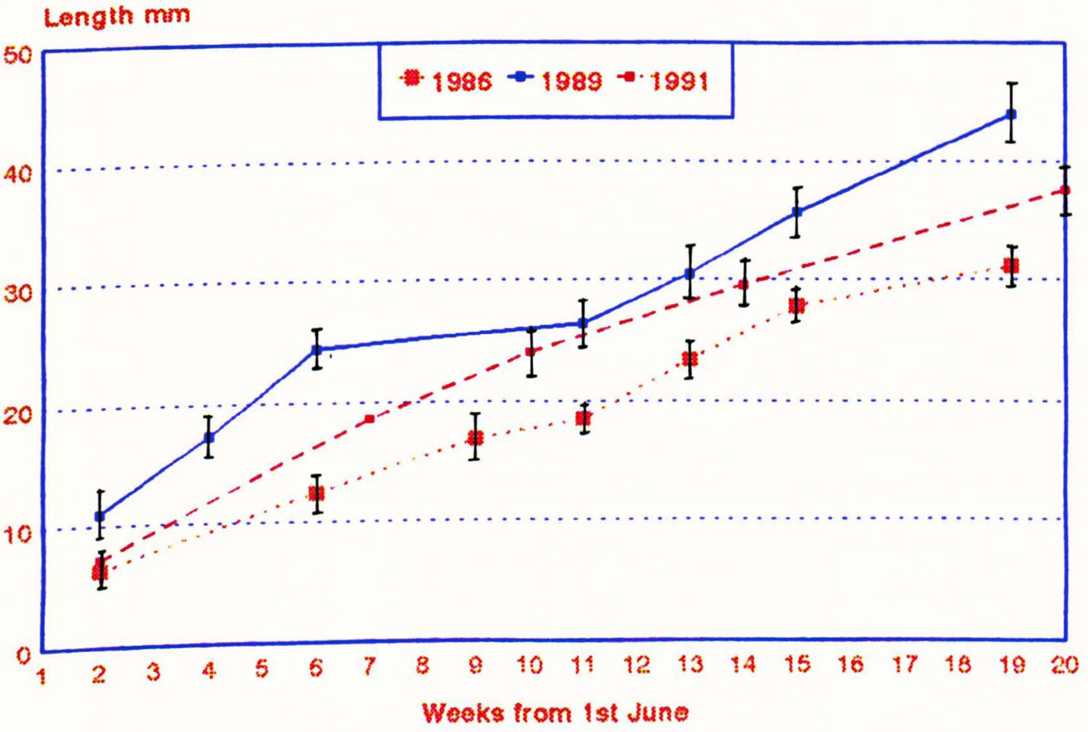
1991

Date of Sample	10th June	11th July	2nd Aug	2nd Sept	8th Oct
Fish Length mm (mean)	7.24	18.56	24.08	29.57	37.61
Fish Weight gm (mean)	0.0028	0.0699	0.195	0.3417	0.616
Condition Coefficient	0.74	1.09	1.4	1.32	1.16
Mean Daily Weight Increase %		5.95	4.29	1.76	1.59
Stomach Fullness (%)	16.25	76	50	87	74
Food Volume (cu mm^{-1})		1.813	4.344	6.271	11.71
Food Volume/gm of Fish		24.88	22.2	20.2	18.69

Growth in Length of Roach Fry

River Dee - Chester

Fig 4.9

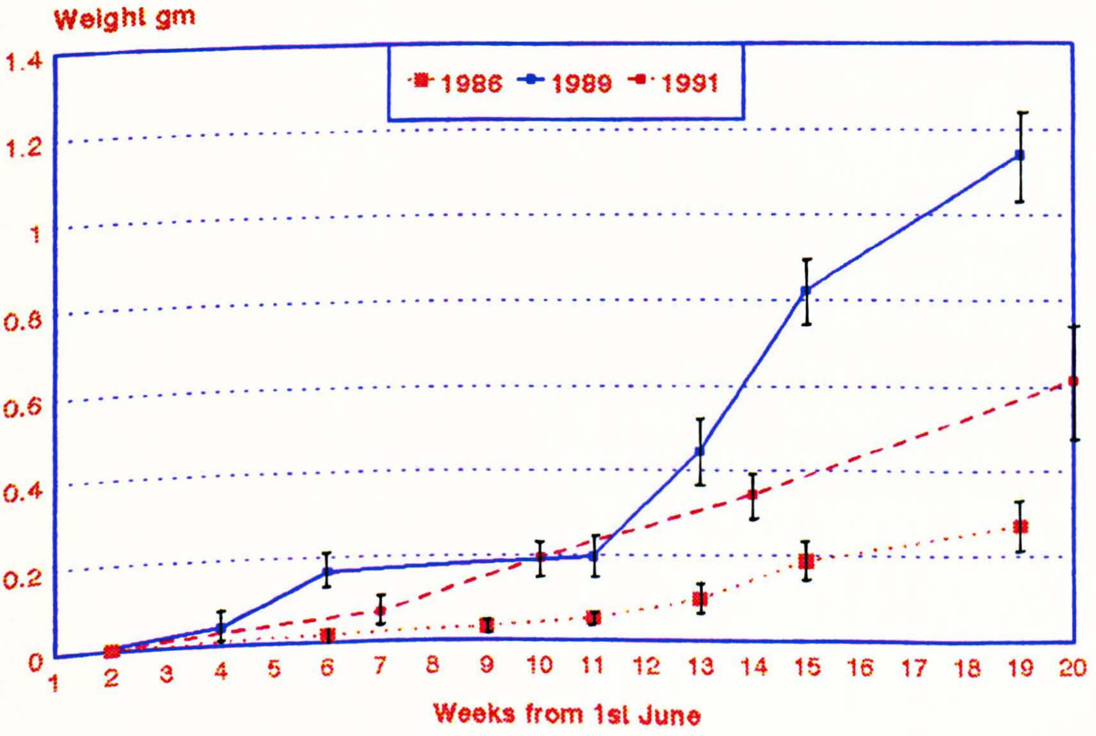


With 95% Confidence Limits

Growth in Weight of Roach Fry

River Dee - Chester

Fig 4.10



With 95% Confidence Limits

conditions in this year, or, it could be a reflection of the greater and consistent availability of food. The variation does however indicate that small differences in the feeding regime, or the environmental factors influencing them, can affect the growth potential of fry quite markedly in any one year.

4.4 Discussion

The study of diet in juvenile fish is well documented with respect to macrohabitats on river basin studies eg (Welcomme, 1985) and (Mann, 1973). However, comparatively little research has been undertaken on young roach, exceptions to this being Lightfoot (1976) and Broughton, Jones and Lightfoot (1977).

A river offers a diversity of microhabitats which are utilised by many different plant and animal communities. Jenkins et al (1984), studying invertebrate communities in the River Teifi, listed nine distinct microhabitats namely: riffle, fast run, slow run, pool, slack water, back water, tree roots, grass roots and aquatic macrophytes.

In the lower Dee at least seven of these microhabitats could be located, so evaluating the feeding regime of juvenile fish in them all would be a difficult task. Weatherley (1985) limited his studies to one small section of the River Dee at Heronbridge near Chester, but comprehensively examined food availability and extent of drift at that location. Pearce (unpublished) also studied invertebrate distribution in the lower river, but his perspective was more to establish the general biology of the river and how it related to recreational issues, rather than focussing on microhabitats and how they integrated with fish populations.

In this study, the distribution of roach juvenile stocks in the river corridor were of particular interest and as the margins were frequently populated by first year fish, consideration of their feeding habits in this location was pursued. The importance of marginal microhabitats to juvenile fish in river systems was established by Copp (1990) on the River Rhone in France. He found that roach fry did not migrate to deeper water in the flood plain channel, but remained within the relative security of the shallow lentic area, both when vegetation was abundant and also after it had died away at the end of the summer. Balon (1956) determined that roach adhere to vegetation branches or roots immediately after hatching, as young larvae have little swimming capability. Older larvae showed strong associations with microhabitat that offered cover and nutritional advantage which included shallow depths and vegetation. (Haberlehner, 1988; Rozas and Odum, 1988).

Dace fry also frequented the margins of the main river, down as far as Chester by the beginning of May, following spawning between Bangor-on-Dee and Farndon in April (Fig 2.32). It was important that their diet was compared with roach, to establish whether there were differences in feeding habits to account for the success of dace in the lower Dee in recent years.

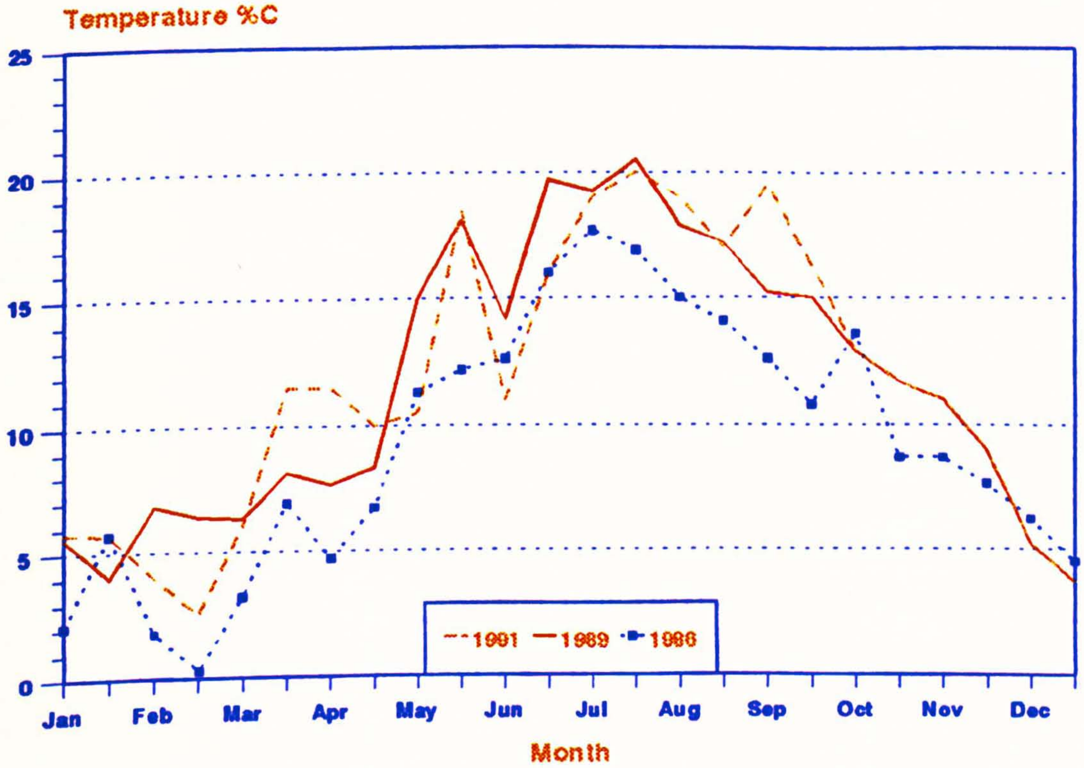
It has been shown that the marginal substrates that are available on the River Dee are narrow in dimension and limited in availability. Despite this, the invertebrate life that exists within them, although limited in species diversity, has organisms that are grazed by juvenile fish and therefore available to provide an important food source.

The results revealed that dace preferred emergent insects whereas roach fry grazed predominantly on filamentous algae found at the margins, availability of which was dependant upon higher water temperatures (Fig 4.11) and higher sunshine levels (4.12). The nematode worms that are present in the benthos appear not to be important in this respect even though they are plentiful throughout the summer months. Both species fed on chironomids from mid-summer onwards but, as chironomids are to be found earlier than this, timing of exploitation probably depends upon the fry being of sufficient size. Both species consume large volumes of detritus and lesser numbers of crustaceans, which include the small copepod nauplii in the first month after the dace and roach hatch. Chironomids are, however, actively consumed by both species and have been shown to decrease in abundance seasonally, probably as a result of predation by fry. The presence of high levels of detritus in the diet of both species suggests a high level of grazing in the margins. The disturbance of the soft marginal substrates by boat wash or flow

Monthly Water Temperatures

River Dee - Ironbridge

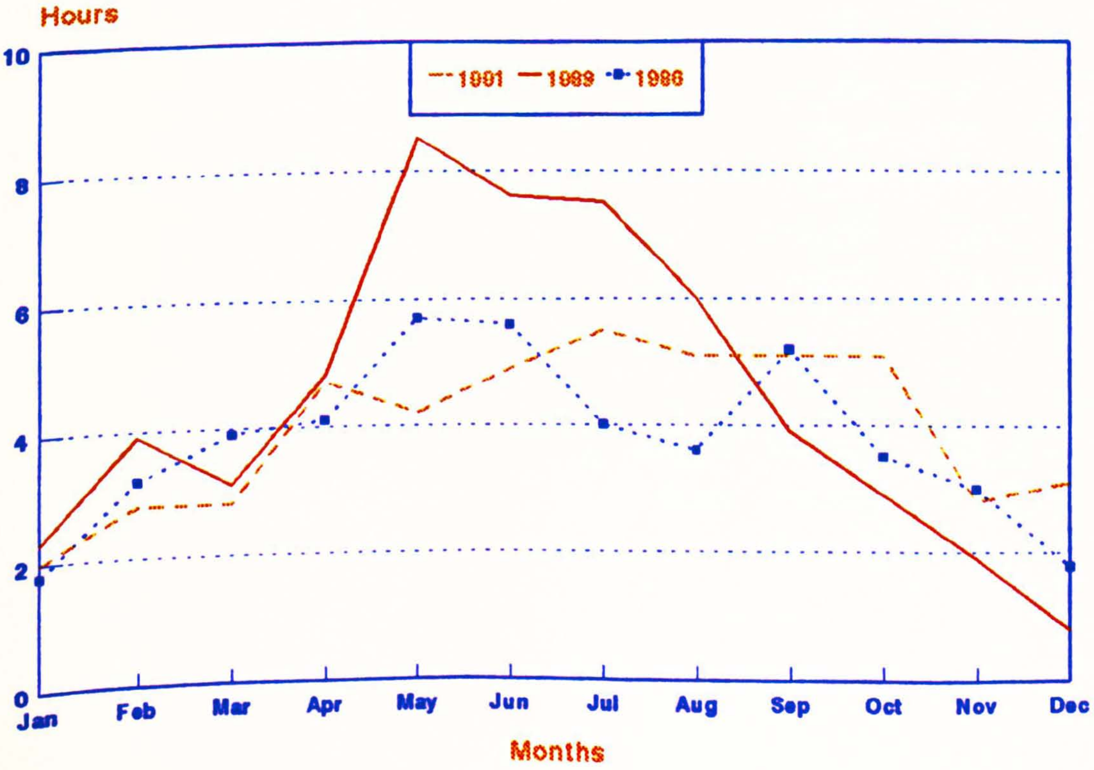
Fig 4.11



Mean Monthly Hours of Sunshine/Day

Ness Gardens, Wirral

Fig 4.12



variations is likely to expose benthic invertebrates which will assist feeding fry. Whether the detritus is consumed as a by-product along with chironomid or algae, or, because there is a shortfall in other diet components, is difficult to establish. Other studies which include Britton (1968) and Berrie (1972) from the River Thames and Cowx (1988) from the River Exe found detritus to be a regular component of the diet of both species.

It has been shown in Chapter 3 that the lower Dee is a harsh environment for stable plant and animal communities and the creation of plankton populations is no exception. The presence or absence of plankton in the margins is likely to be dependent on the flow regime at any particular time and location but the extent to which the microhabitat is disturbed by anthroprogenic activities is also an important feature, particularly close to Chester where water-based recreational pursuits are greatest. Zooplankton measurements were initially attempted but the difficulties in assessing their abundance and distribution during the season lead to their removal from the study. In respect of phytoplankton it was established that it was made up of a heterogeneous collection of still water species, which survive in the flowing regime for some time. For example Scenedesmus sp, Navicula sp, Nitzschia acicularis, Asterionella formosa and Synedra ulna were all found regularly. Marginal soft sediments and silts often contain epipelic communities that contribute to the phytoplankton drift and this is invariably made up of diatoms, coccoid Chlorophyceae (Chlorococcales and desmids), blue-green algae and euglenoids (Reynolds, 1984).

The lack of quantitive data on river algae reflects the difficulties and variabilities of sampling techniques. Butcher (1947) studied algal accumulation and growth on glass slides, but results from such methods may be atypical of natural algal behaviour. Apart from the drift or riverine phytoplankton, Reynolds (1984) details the vertical migration of algae that occurs from stream sediments towards the surface, with maximum populations at the surface towards midday. This could explain the greater observed activity of young fry in the shallows towards midday when temperatures were higher.

Results from the marginal studies on phytoplankton indicated that filamentous algae developed abundantly in sheltered areas and the diet analysis suggests that this food source is a large component of the diet of juvenile roach and may have accounted for good growth rate in the warm summer of 1989, when algae were very abundant. Hofer et.al. (1985), however, has suggested that the poor quality of plant proteins leads to a metabolic deficiency, therefore the availability of other food items may also be necessary to achieve favourable growth rate. The restricted area in the river channel where filamentous algae can develop and the variation in river and climatic conditions which can affect its growth, are likely to be major factors which can adversely impact on juvenile roach in a large lowland river like the Dee.

The feeding rate and therefore the growth rate of juvenile fish is temperature dependent and likely to be higher in warm years (Winfield and Nelson, 1991). In Chapter 3 it was demonstrated that the lower Dee has become colder as a consequence of regulation and Herzig and Winkler (1986) have indicated that roach fry have an optimum range of 12-22^{0}C for embryonic development. From Fig 4.11 it can be seen that the mean water temperature at Ironbridge is at the lower end of this range at the first hatching phase, indicated by O'Hara (1976) as the beginning of June. In cool years like 1986, summer water temperatures also rarely rise above 17^{0}C or the mid point of this range and Wieser (1991) concluded that at lower temperature ranges (ie <16^{0}C) energy turnover, and therefore metabolic processes, show a much greater dependance on temperature than in the upper temperature range. Growth rate has been shown to be affected, but other functions such as swimming capability may also be diminished, which could have consequences for survival within the flow regime of the channel, particularly in the first winter month or during periods of sudden spate.

Food abundance will also be greater in warmer years, consequently in 1989 the fastest growth was recorded for both species. Conversely the coolest year (1986) produced the slowest growth. Even in the best year of 1989, when first year dace fry reached 5cm in length and 1.2gm in weight by the beginning of October, growth in the River Dee was slower than in most other temperate rivers, for example Cragg-Hine and Jones

(1969) on Willow Brook, Mann (1974) on the River Frome and Stour, Cowx (1980) on the River Exe. In respect of roach, the best year of 1989, when 4.4cm length and 1.1gm weight was achieved by the end of the summer, compared favourably with some rivers eg River Hull (Broughton et.al., 1977) and the River Stour (Mann, 1974), but in the cooler years, when lengths of 3.0-3.7cm and weights of 0.3-0.7gm were achieved, growth rates were much less than in most other British studies (Weatherley, 1985). This suggests the diet source of the Dee may be a limiting factor on growth in the first year of developing roach and dace fry.

It has been found, however, that dace are at least 10mm longer and 0.5gm heavier than roach by the end of the first summer. Weatherley (1985) indicated that roach hatch a month later and stop growing a month earlier than dace and therefore the growing season for roach in the first summer is approximately 2 months shorter than that for dace. This, together with the variation between seasons and the periodicity within a single season of the available food supply, probably reflects the poor size of roach achieved in the first summer in the Dee. The level of survival achieved by fry overwintering will ultimately influence the strength of the respective year class. Slow growth rate of roach during the first summer is likely to adversely impact on survival during the first winter when conditions have been shown to be more severe within the river channel and the summer protection of available macrophytes have died away.

4.5 Summary

The availability of margins for feeding area for juvenile fish has been shown to be important and has influenced the diet and thereby the growth rate of both dace and roach. For roach to achieve a better growth rate, a more consistent and regular food supply in the early stages would be beneficial. Margins abundant with filamentous algae have been seen to offer the greatest chance of this being achieved and these conditions have been found to develop within the limited weedy areas that are available.

The next stage in this study was therefore to examine the macrophyte distribution along the river, to establish the degree to which weedy areas were available for fry to utilise. A method for increasing suitable on-stream marginal vegetation was also examined, to assess whether extra area could be created in the event of there being a deficiency.

Chapter 5 Need and Scope of Macrophytic Vegetation

5.1 Impact of Changing Plant Communities on Fish Populations

There is an extensive literature on the principles of ecology of aquatic macrophytes both in British rivers and other rivers around the world. Butcher (1933) drew together a table showing the dominant plants in the British Isles and similar data are available from studies in Germany (Roll (1938); Schmitz (1961)). Studies undertaken by Haslam (1978,1982), Haslam and Wolseley (1981) and Holmes (1980 and 1983) on watercourses in the British Isles include detailed surveys of the flora. The association between plants and the ecology of a river has been pursued by Hynes (1970), and Eaton (1986) has detailed the importance of waterplant ecology in landscape design. Few workers have, however, actually extended their work to establish the degree of relationship between the macrophytic population and aquatic communities that live and develop in and around them.

Aquatic vegetation is an important element in providing habitat and microhabitats that can be utilised by other plant and animal communities and studies of certain animal ecosystems have shown distinct association between the two (Dvorak and Best, 1982; Cyr and Downing, 1988). The relationship of productive coarse fisheries with abundant weed growth has been determined by Reynolds and Eaton (1983) in canal fisheries and Welcomme (1985) has reviewed its' importance in rivers. To establish the value of vegetation to riverine fisheries, it is advantageous to categorize plants into specific groups and then consider their respective requirements and likely impacts on the ecology of the river. In most river corridors the vegetation that is present can be separated into the following main headings:

i) Trees and shrubs.
ii) Marsh plants.
iii) Aquatic emergents.
iv) Submerged and floating-leaved rooted plants.
v) Free floating plants and algae.

i) Trees and shrubs

The species that are to be found along river banks are those that are tolerant of waterlogging of their root systems and have the ability to remain stable under intense action of river erosion, eg willow *Salix sp* and alder *Alnus glutinosa*. Apart from the beneficial aspect of bankside strengthening and providing landscape interest, trees also have the effect of reducing light and wind action on the water surface which, depending on circumstances, can be detrimental or beneficial to other components of the ecosystem.

ii) Marsh plants

These plants represent the greatest number of the 150 water plants in the British flora, as defined by Haslem *et al* (1975). The grouping mainly comprises marshland species that prefer permanently wet areas, but tolerate both drier conditions and water submersion for limited periods. Collectively they hold marginal substrates together with their fibrous root systems and like trees, protect banks from erosion. In the environmental perspective they provide ground cover habitat for other animals and plants and thereby enhance the ecological value of the area. When inundated with water they also offer microhabitats that can be a major source of food refuge for juvenile fish.

iii) Aquatic emergents

These plants have a buried root system below water. The lower parts of their shoots are submerged but their foliage mostly projects above the water surface. Like the marginal terrestrial plants, they offer shelter and stimulate the creation of microhabitat that other aquatic organisms can populate. With fish species such as roach, bream and perch the submerged parts of plants also offer spawning medium as well as providing habitat in which the progeny created can feed and develop (Hodgson *et. al.*, 1988).

iv) Submerged and floating leaved rooted plants

These plants are to be found both at the margins and within the main body of the river channel and include species that have short stems and grow in the immediate vicinity of the bed and others that have long trailing stems and project from the bed up to the surface. In deeper water their success depends on adequate light penetration through the water, which can be influenced by variable turbidity levels (Garrad and Hey, 1988). In eutrophic rivers like the River Clywedog, near Wrexham, they can be a very rich source of aquatic life (Hodgson, 1993) and in other localities they add to the availability of spawning medium (Witcomb, 1965) and habitat for feeding fish, eg water lilies (Nuphar lutea) (Hodgson et.al. 1988).

v) Free floating plants and algae

In rivers the presence of free floating species is limited because they are constantly washed out of the system (Williams, 1954). Their abundance is dependant upon the flow regime and whether there are bankside protected areas available which they can colonise. Where algae exist it has been established in Chapter 4 that they can be a valuable source of food for juvenile fish, particularly roach in the Dee.

In summary, in fluvial systems where trees and shrubs become established, they remain so because they are able to tolerate often extreme changes in environmental conditions without displacement. Littoral marsh and river plant colonisation varies according to the physical factors appertaining, chemical status of the bed substrate and surrounding water chemistry (Haslam, 1978). Competition between species is also a key element in defining the eventual vegetative distribution. Some species such as Ranunculus penicillatus are adaptable to a range of different habitats, but success depends upon whether they are the most tolerant in the particular environment under consideration. Haslam (1971) indicated that if the prefered locations of river weeds was known, then the effects of habitat alteration could be predicted and then usefully applied in river management planning.

Before modifications to improve or restore plant communities for fisheries can be considered, it is necessary to inventory the existing vegetation and assess how it has changed and the factors which have been influential in bringing about these changes.

5.2 Changes in Macrophyte Ecology of the River Dee

5.2.1 Introduction

In respect of the Dee catchment, the early history of Cheshire flora is well documented in De Tabley (1899), which lists in detail the many observations to 1885. Newton (1970) undertook a comparison of the gains and losses since the earlier study and deduced that the areas that showed least change were those that had suffered least interference by man. Notably absent were river habitats, suggesting that, historically they had suffered substantial change by man.

5.2.2 Method

5.2.2.1 Plant Species Distribution

Plant species were recorded for the Cheshire Dee and lower parts of the main tributaries, between the Worthenbury Brook confluence and Chester Weir, during detailed identification surveys both in mid-channel and along the bank. Surveys were undertaken in 1987 and 1991 and the detail was separated into three defined areas from Worthenbury Brook to Farndon; Farndon to Ironbridge and Ironbridge to Chester Weir. This enabled more detailed evaluation of the changes that were taking place at different points of the study area. These findings were compared with data for 1981, recorded by Pearce and detailed in Eaton, Hodgson and Pearce (1988).

5.2.2.2 Habitat Utilisation by Plants

Measurements were made of the available area of river corridor that could be colonised by plants and how that had been utilised over the the same 10 year period. These measurements included:

i) **Assessment along the bank:** length of open bank; length affected by cattle disturbance; length with trees; length with terrestrial aquatic vegetation and length with boat moorings.

ii) **Assessment within the water space:** area of margin < 2m in depth, which is an average limit of light penetration in water courses (Berrie, 1972); area of aquatic weed coverage in the margin; area of tree cover over the margin and in mid-channel; area of aquatic weed in the whole river channel.

Depth measurements were taken by means of a metric pole and all lengths and areas were estimated proportions within 100m sections, taking each bank in turn. Results were then amalgamated and presented for the three defined sections.

5.2.3 Results

5.2.3.1 Plant Species Distribution

Details of the flora survey along the study area from Worthenbury Brook to Chester Weir are presented in (Table 5.1).

i) Trees and Shrubs

The tree line that dominated the river channel was made up of two main species, namely alder Alnus glutinosa and willow Salix sp, which was typical of an environment where root systems for the most part remained wet, yet resilient to pressures brought about by seasonal floodwater. Other species that were present, but less frequent, included lombardy poplar (Populus nigra), oak (Quercus sp), sycamore (Acer pseudoplatanus), birch (Betula sp) and hawthorn (Crataegus sp). Most

The Vascular Waterplant Flora of the Cheshire Dee

Fig 5.1

No	Species	1991	1987	1970
	PTERIDOPHYTA			
1	Equisetum fluiatile	-	+	-
	ANGIOSPERMAE-DICOTYLEDONES			
2	Alnus glutinosa	+	+	+
3	Apium graveolens	-	-	+
4	Aster tripolium	+	-	-
5	Apium nodiflorum	+	+	-
6	Berula erecta	+	+	-
7	Bidens cernua	+	+	-
8	Bidens tripartita	+	+	-
9	Callitriche hamulata	-	+	-
10	Callitriche obtusangula	-	-	+
11	Callitriche platycarpa	-	+	-
12	Callitriche stagnalis	+	+	-
13	Ceratophyllum demersum	+	+	+
14	Chamaeneon angustifolium	+	-	-
15	Epilobium hirsutum	+	+	+
16	Filipendula ulmaria	+	+	-
17	Galium palustra	+	-	-
18	Gnaphalium uliginosum	+	-	-
19	Hottonia palustris	-	-	+
20	Impatiens glandulifera	+	+	+
21	Lycopus europaeus	+	+	-
22	Lysimachia nummularia	+	-	-
23	Lythrum salicaria	+	+	-
24	Mentha aquatica	+	+	-
25	Menyanthes trifoliata	-	+	-
26	Mimulus guttatus	+	+	+
27	Myosotis palustris	+	-	-
28	Myosotis scorpioides	+	+	+
29	Myosoton aquaticum	-	+	+
30	Myriophyllum spicatum	+	+	+
31	Nuphar lutea	+	+	+
32	Nymphaea alba	-	+	-
33	Oenanthe crocata	+	+	+
34	Plantago major	+	+	+
35	Polygonum amphibium	+	+	+
36	Polgonium hydropiper	+	+	-
37	Polygonum persicaria	+	+	-
38	Ranunculus aquatilis	+	+	-
39	Ranunculus baudotii	-	-	+
40	Ranunculus flammula	+	+	+
41	Ranunculus fluitans	+	+	+
42	Ranunculus penicillatus v calcareus	+	+	+
43	Ranunculus sceleratus	+	+	+
44	Ranunculus trichophyllus	-	+	+

Fig 5.1 (Cont)

		1991	1987	1970
	ANGIOSPERMAE-MONOCOTYLEDONES			
45	Rorippa amphibia	-	+	+
46	Rorippa nasturtium-aquaticum	+	+	-
47	Rorippa palustris	+	-	-
48	Rorippa sylvestris	+	+	-
49	Rumex crispus	+	+	-
50	Rumex hydrolapathum	+	+	-
51	Rumex obtusifolius	+	+	-
52	Rumex palustris	-	+	-
53	Salix alba	+	+	+
54	Salix caprea	+	+	+
55	Salix fragilis	+	+	+
56	Salix viminalis	+	+	+
57	Scrophularia aquatica	-	-	+
58	Scutellaria galericulata	-	-	+
59	Senecio aquaticus	-	+	-
60	Senecio fluviatilis	-	+	+
61	Senecio paludosus	-	-	+
62	Solanum dulcamara	+	+	+
63	Stachys palustris	-	+	+
64	Tanacetum vulgare	+	+	-
65	Thalictrum flavum	-	-	+
66	Veronica anagallis-aquatica	+	+	+
67	Veronica beccabunga	+	+	+
68	Acorus calamus	+	+	+
69	Agrostis stonifera	+	+	+
70	Alisma plantago-aquatica	+	+	-
71	Baldellia ranunculoides	-	+	+
72	Carex acuta	+	-	+
73	Carex acutiformis	-	+	-
74	Carex distichia	-	-	+
75	Carex hirta	-	-	+
76	Carex otrubae x remota	-	-	+
77	Carex pallescens	-	-	+
78	Carex pendula	-	-	+
79	Carex paniculata	+	-	-
80	Carex pseudocyperus	-	-	+
81	Carex remota	+	+	+
82	Carex riparia	+	+	+
83	Elodea canadensis	+	+	+
84	Elodea nuttallii	+	+	-
85	Glyceria maxima	+	+	+
86	Glyceria plicata	-	-	+
87	Hydrocharis morsus-ranae	-	+	+
88	Iris pseudacorus	+	+	+
89	Juncus articulatus	+	+	-
90	Juncus conglomeratus	+	-	-
91	Juncus bufonius	+	+	-
92	Juncus effusus	+	+	+
93	Juncus inflexus	+	+	+
94	Juncus geradi	-	-	+
95	Lemna gibba	+	-	-
96	Lemna minor	+	+	+
97	Lemna trisulca	+	+	+

Fig 5.1 (Cont)

	<u>Monocotyledons</u> (Cont)	<u>1991</u>	<u>1987</u>	<u>1970</u>
98	Phalaris arundinacea	+	+	+
99	Phragmites australis	+	+	–
100	Potamogeton berchtoldi	+	+	–
101	Potamogeton crispus	–	+	+
102	Potamogeton crispus x perfoliatus	–	–	+
103	Potamogeton natans	–	–	+
104	Potamogeton pectinatus	+	+	+
105	Potamogeton perfoliatus	+	+	+
106	Potamogeton pusillus	–	+	–
107	Sagittaria sagittifolia	+	+	+
108	Scirpus lacustris	–	+	+
109	Scirpus maritimus	+	–	–
110	Sparganium angustifolium	+	–	–
111	Sparganium emersum	+	+	–
112	Sparganium erectum	+	+	+
113	Typha angustifolium	+	–	–
114	Typha latifolia	+	+	+
115	Zannichellia palustris	–	+	+
	Total Species	78	83	68
	+ = Recorded – = Unrecorded			

of the latter species, particularly poplar, hawthorn and sycamore, were to be found because of mans' influence, whether it be for field boundaries in the case of hawthorn or as wind breaks in the case of poplars.

ii) Aquatic Plants

a) Species ubiquitous throughout the area

Two species, namely Sparganium emersum and Phalaris arundinacea, were recorded throughout the study length, although both were less common in the lower section towards Chester. Both are usually widespread in temperate climates.

S. emersum is a rooted plant with long, strap-like leaves that float in the current of the river. It prefers faster flowing reaches up to 2m deep and where the substrate is silty. In the Dee, it was found in distinct patches where silt banks developed or where some firm substrate allowed fixation, often between banks of trees in mid-channel. Ham et al., (1982) suggested that it prospered in faster flows because of lack of competition. Certainly on the Dee the distribution had fluctuated little in the previous decade and only Nuphar lutea shared the same type of habitat, though usually further inshore, where flow was not as rapid.

Phalaris arundinacea, although common, was found in locations that prevented it being of direct benefit to fish. It certainly populated areas where other species had difficulty in colonising, being found between willows and alders and invariably at the base of steep banks. It had value for amenity and conservation purposes, because it provided visually attractive bankside cover which was used by birds, but rarely extended into the channel at normal water levels. P. arundinacea had increased in abundance in the Farndon to Ironbridge area in the 10 year period, following the reduction in cattle grazing. Haslam (1978) reported that it was highly tolerant of grazing and trampling and, consistent with this, where it had persisted on the Dee, it was quick to flourish with the change in farming practice.

b) Emergent Species

Although there was a high diversity of emergent species to be found in selected locations, most were in small quantities. At the lower end of the river, Typha latifolia dominated with P. arundinacea, although in areas damaged by cattle it was often Juncus effusus and Juncus articulatus that were able to survive. Glyceria maxima was prominent in some locations, especially backwaters or tributaries where its floating rhizome system could spread in the slacker flow. Aldford Brook was one such area where it grew prolifically.

Sparganium erectum was often associated with T. latifolia in composite stands of vegetation which escaped intrusion from cattle. Where vegetation of a substantial nature secured a hold on the bankside, there was invariably a diverse range of smaller broad leaved aquatic plants within the protective zone of the larger plants. With time, the larger species such as P. arundinacea and T. latifolia totally dominated and the smaller plants succumbed to displacement. Examples of smaller plants were Polygonum hydropiper, Rumex hydrolapathum, Rorippa nasturtium-aquatica, Veronica beccabunga, Alisma plantago-aquatica, Myosotis palustris and Lycopus europaeus. Although these species did not individually contribute greatly to the aquatic ecology of the river channel, they did collectively provide a seasonal diversification of colour and interest to the margins and also probably contributed to the creation of microhabitats from which further food chains could develop.

One notable species, which is relatively new to the river and has not as yet spread to the lower end of the study area, is the terrestrial Indian Balsam (Impatiens glandulifera). This has the ability to populate relatively harsh terrain on the steep banks of the river corridor. Its rapid invasive characteristics, noted from its increasing spread higher up the catchment, need to be monitored but on the lower Dee where the banks are largely protected by tree roots rather than smaller plants, it may not be a problem.

c) Floating-leaved rooted plants

These species provide important cover to young fish and also create an area of potential food supply on which fish can feed (Eaton et.al., 1988). The three main ones are Nuphar lutea, Sparganium emersum and Ranunculus fluitans.

Nuphar lutea has probably been most severely affected by recreational boats in the Chester area, either by direct destruction from propellor damage or indirectly by severe wave action. Pearce (unpublished) demonstrated the extent of this damage by trials where stands of N. lutea, consisting only of submerged leaves, were protected by booms and almost immediately developed extensive canopies of floating leaves. Once the booms were removed, the floating leaves were quickly destroyed and the clumps returned to the pre-trial condition.

Distribution of N. lutea along the study length was patchy, with small beds being more in sheltered locations near the banks, largely protected from the rigours of channel flow. Moss (1983) indicated that they are important to juvenile fish as feeding area and on the Dee particularly productive zones are found at confluences of slow flowing tributaries where the weed extends into the river channel. Aldford and Pulford Brooks are good examples.

The ubiquitous distribution of S.emersum indicated that the preferred location was out in the channel, away from the margin, where velocities were consistently higher. Its value as a food supply microhabitat was much less than its importance as a protective screen for young fish. This was apparent at the Caldy sampling area for juvenile fish, where fry were frequently in abundance in the weed beds but zooplankton and phytoplankton were in short supply probably because the flow through the vegetation was sufficient to prevent their accumulation (Chapter 4). R.fluitans was extensive in the river corridor in the upper reaches between Bangor-on-Dee and the Dee/Worthenbury brook confluence. Apart from the main river it was also to be found in the River Alyn close to its confluence with the Dee. It favoured the shallower and less turbid areas of the river and in mid summer it choked the shallower riffles.

The surveys revealed that it had become more widespread in recent years, probably as a consequence of a succession of mild springs, warm summers and fewer extreme floods.

d) Submerged Plants

Perhaps the most fundamental aquatic weed change on the lower Dee was the rapid spread of *Elodea nuttallii*. This species has only spread into Cheshire since 1970 (Eaton, *et.al*. 1988), but its expansion did not take place on the Dee until the 1980's. By 1991 it was to be found from Heronbridge to Chester Weir on the left bank and from Caldy Brook down to Chester Weir on the right. In midsummer it covered large areas of the 4-6m width of margin, which only a few years earlier had been completely barren of vegetation. Previously, aquatic vegetation within the Chester boundary had been largely limited to isolated clumps of *N.lutea* and *S.emersum*.

5.2.3.2 Habitat Utilisation by Plants

Table 5.2 compares the bankside changes and Table 5.3 the area margin changes in vegetation coverage between 1981 and 1991. Table 5.4 details differences between respective banks and also the area of weed coverage and tree canopy within the deeper river channel.

5.2.4 Discussion

Old photographs of the Dee in the Chester area indicated that marginal vegetation was much more abundant in the past and this has been generally supported by species lists that have been compiled at different time intervals over the last 150 years (Baillie, 1878; DeTabley, 1899; Waterfall, 1915; Dallman, 1920; Newton, 1970 and Eaton, Pearce and Hodgson 1988).

Historically, the flood plain of the River Dee was dominated by deciduous woodland of *Quercus robur* and *Quercus petraea*. (Newton, 1970). Increases in human settlement and development of more structured farming practices over the centuries probably changed the character of

Table 5.2

Quantities of Vegetation along the River Dee

Worthenbury Brook - Chester Weir

	Length of Bank					Length of Bank with Emergent Vegetation						
	1991		1981			1991		1987		1981		
	km	%	km	%	%Change in 10years	km	%	km	%	km	%	%Change in 10years
Worthenbury Brook-Farndon												
Open (No Cattle)	11.6	48	15.9	66.5	-27	3.6	31	*	*	1.8	11.3	100
Open (Evidence of Cattle)	7.4	31	3.4	14.1	117	<0.01	<0.1	*	*	<0.01	<0.1	0
Boat Moorings	0	0	0.1	0.5	0	<0.01	<0.1	*	*	<0.01	<0.1	0
Shaded with Trees	5	21	4.5	18.9	11	<0.01	<0.1	*	*	<0.01	<0.1	0
TOTAL	24	100	24	100		3.6	15	*	*	1.8	7.5	
Farndon-Ironbridge												
Open (No Cattle)	4	20	5.8	29.1	-31	3.5	88	*	*	0.6	10.3	483
Open (Evidence of Cattle)	2.2	11	3.4	17.2	-35	<0.01	<0.1	*	*	<0.01	<0.1	0
Boat Moorings	1.4	7	0.9	4.6	56	<0.01	<0.1	*	*	<0.01	<0.1	0
Shaded with Trees	12.4	62	9.9	49.1	25	<0.01	<0.1	*	*	<0.01	<0.1	0
TOTAL	20	100	20	100		3.5	17.5	*	*	0.6	3	
Ironbridge-Chester Weir												
Open (No Cattle)	1.6	8	4.1	20.3	-61	0.6	37.5	0.5	12.5	0.3	7.9	200
Open (Evidence of Cattle)	3.6	18	2.8	13.8	29	<0.01	<0.1	<0.01	<0.1	<0.01	<0.1	0
Boat Moorings	2.5	12.5	1.8	8.9	39	<0.01	<0.1	<0.01	<0.1	<0.01	<0.1	0
Shaded with Trees	12.3	61.5	11.4	57	8	<0.01	<0.1	<0.01	<0.1	<0.01	<0.1	0
TOTAL	20	100	20	100		0.6	3.2	0.5	2.5	0.3	1.6	

Table 5.3

Changes in Margin and its Colonisation by Plants

River Dee (Worthenbury Brook-Chester Weir)

	Water Area < 2m deep					Extent of Vegetation Coverage						
	1991		1981			1991		1987		1981		
	ha	%	ha	%	%Change in 10years	ha	%	ha	%	ha	%	%Change in 10years
Worthenbury Brook-Farndon												
Open	19.1	78.9	19.6	81.1	-3	13.4	70.2	*	*	6.5	33	106
Shaded with Trees	5.1	21.1	4.6	18.9	11	<0.01	<0.1	*	*	<0.01	<0.1	
TOTAL	24.2	100	24.2	100		13.4	55.4	*	*	6.5	26.3	
Farndon-Ironbridge												
Open	4.3	38.4	5.7	50.9	-25	2.3	53.5	*	*	1	17.4	130
Shaded with Trees	6.9	61.6	5.5	49.1	26	<0.01	<0.1	*	*	<0.01	<0.1	
TOTAL	11.2	100	11.2	100		2.3	20.5	*	*	1	8.9	
Ironbridge-Chester Weir												
Open	5.5	38.5	6.2	43.1	-11	3.2	58.2	1.2	18.7	0.7	11.2	357
Shaded with Trees	8.8	61.5	8.1	56.9	9	<0.01	<0.1	<0.01	<0.1	<0.01	<0.1	
TOTAL	14.3	100	14.3	100		3.2	22.4	1.2	8	0.7	4.9	

Table 5.4

Bank Availability and Vegetation Distribution

River Dee - 1991

	Left Bank	Right Bank	Total	%
Worthenbury Brook-Farndon				
Open - No Cattle	6.1km	5.6km	11.7km	48.3
Open - With Cattle	3.8km	3.6km	7.4km	30.7
Boat Moorings	0	0	0	
Bank with Trees	2.2km	2.9km	5.1km	21
Terrestrial Weed	1.2km	2.4km	3.6km	
Channel Weed	0.93ha	0.74ha	1.67ha	
Tree Shade >2m	0.85ha	1.45ha	2.3ha	
Farndon-Ironbridge				
Open - No Cattle	2.7km	1.4km	4.1km	20.3
Open - With Cattle	1.5km	0.7km	2.2km	10.7
Boat Moorings	1.1km	0.2km	1.3km	6.8
Bank with Trees	4.7km	7.8km	12.5km	62.2
Terrestrial Weed	2.3km	1.2km	3.5km	
Channel Weed	0.12ha	0.16ha	0.28ha	
Tree Shade >2m	2.61ha	3.57ha	6.19ha	
Ironbridge-Chester				
Open - No Cattle	1.0km	0.6km	1.6km	8
Open - With Cattle	2.3km	1.5km	3.8km	18.5
Boat Moorings	0.05km	2.4km	2.45km	12.2
Bank with Trees	6.7km	5.6km	12.3km	61.3
Terrestrial Weed	0.4km	0.3km	0.7km	
Channel Weed	0.08ha	0.32ha	0.4ha	
Tree Shade >2m	3.14ha	2.65ha	5.78ha	

the Cheshire Plain to such a degree that the only established areas of woodland that survived, were those on the steeper fringes of the valley and on the river banks. The channel itself has meandered naturally for centuries consequently isolated banks of trees have become established outside the present channel. It is also noticeable that at the upper end of the flood plain, between Overton and Bangor-on-Dee, where winter floodwater has had greatest effect, tree colonisation is not so abundant. Since regulation and the construction of flood embankments, throughout most of the flood plain, there is now more stability and greater likelihood of trees extending their range.

It can be seen from the sectional profiles of the river channel in Fig 1.4 that, from Worthenbury Brook confluence to Chester Weir, only limited marginal area exists for aquatic plant colonisation. This extends to just 49.7ha of water margin less than 2m in depth, out of an estimated total water surface area of 275 ha. From Farndon to Chester it has been established from Table 5.2 that the available area for weed growth at the margins has also become more restricted in the 10 year period from 1981 to 1991. The greatest influence on the present marginal aquatic habitat within the river corridor comes from willow (Salix sp) and alder (Alnus glutinosa), because their distribution has increased from 25.8 to 29.7km or 46% of the river bank between Worthenbury Brook confluence and Chester (Table 5.2). It is also pertinent to note that it is not just the longitudinal spread of trees at the bankside that affects the rivers' ecology but also the extent to which the canopy expands out over the channel. This creates a extensive area of shading, which has been shown to have increased from 18.2 to 20.8ha over the 10 year period. Newton (1970) recorded that tree-fringed ponds often had plant species lists about half that of other ponds where tree cover was less complete. Deposition of leaf litter also accummulates beneath trees and although removal of leaves by river flow reduces this effect, during still warm summer periods, acidic leaf litter could accrete and further limit marginal plant communities.

The comprehensive list of smaller marsh and aquatic plants with its seemingly wide diversity of species would suggest that the Dee contains a very rich and varied flora. By comparing with other catchments, it becomes apparent that the Dee is not particularly unusual for rivers in the same geographical range. Holmes (1980,1983) concluded that the Dee contained plant species typical of a lowland river in the North West of the country, especially when the river flowed from a predominantly upland catchment into a slow, meandering flood plain. In such locations, the fine suspended solids carried in the flow creates soft marginal substrates, which are then colonised by the plant species. Haslam (1982) also suggested that the Dee flora was fairly typical of a river flowing through an area where rich alluvial deposits were to be found and also where suspended solids settled out in soft deposits at the margins. Since the construction of Chester Weir in the 17th century, the river has also remained deep downstream of Farndon and therefore it is unlikely that the Dee has ever supported a very large cover of vegetation over the past few centuries.

Regulation in the mid 1960's has been shown to have influenced major environmental change on the river corridor, as in winter the severity of peak floods have decreased and in summer the number of flood events has been reduced. Consequently conditions for vegetation development should be more favourable, especially in shallower, marginal locations towards Chester, where floating-leaved and submerged plants would be more likely to colonise. The earlier studies by Pearce (Eaton et.al. 1988), however, showed a scarcity of vegetation during the 1970's, even in those shallow margins where flows conditions were very slow. Therefore, in this part of the river, other factors were influencing aquatic weed growth.

It can be seen from Table 5.2 that in 1981 the quantity of aquatic flora between Ironbridge and Chester was extremely small, with only 0.3km (1.5%) of the 20km having emergent vegetation. Similarly the mid water species were also sparse, with only 0.7ha (4.9%) of the available 14.3km area of margin < 2m in depth. By comparison, along the 24km length between Worthenbury Brook and Farndon, 1.8km (7.5%) of the river was populated with emergent fringes and 6.5ha (26.9%) of the available margin by floating-leaved or submerged plants. At this time, plants were having difficulty in colonising the available area and restrictions on the proportion of margin colonised, increased downstream. It was considered by Hodgson et.al.(1988) that boat traffic was a major influence of vegetation loss near Chester. Murphy and Eaton (1983) have shown that quantities of aquatic vegetation decrease as boat traffic density increases, with submerged and floating leaved species more severely affected than reeds.

By 1991 a very different picture was emerging, with a consistent increase in vegetation cover in both the upper and lower reaches. At Chester the reed fringe had doubled 0.6km (3%) and colonisation of the shallow margin had also increased to 3.2ha (22.4%). This change could have been considered as a direct consequence of the hot summers of 1989 and 1990, when temperatures and sunshine levels had been unusually high (Fig 4.12 and 4.13) and conditions were ideal for the expansion of vegetative growth. Although this may have been part of the reason, the fact that a sharp increase had been observed in the interim survey of 1987, prior to the warm years (Table 5.2), supported the view that the experimental plantings undertaken at Caldy and Heronbridge (See 5.3 and 5.4) had also increased the emergent vegetation, in a relatively barren section of river.

At Chester, the increase of submerged vegetation is almost wholly due to the progressive development of dense beds of Elodea nuttallii in shallow areas. This change may well have developed as a result of decreased boat traffic since 1980 (Fig 3.10), although the concurrent general increase in macrophytes throughout the river indicates that this may not be the only the reason.

In all areas there has been a progressive increase in aquatic vegetation since 1981, but this has been most extensive between Worthenbury Brook and Farndon, where the ponding effects of Chester Weir are not present. The river throughout this length is a comparatively shallow, meandering channel and largely devoid of shading from trees and hence subject to greater warming in sunny periods (Table 5.2 and 5.4). Enrichment from sewage-contaminated tributaries like Worthenbury Brook and the River Clywedog (Chapter 1) probably enhanced the development of submerged macrophytes and as gravels have not been cleansed by severe floods in recent years, it is likely that this has also encouraged an expansion of macrophytes, especially Ranunculus fluitans.

Even though the available margin for macrophytic expansion is reducing in size due to tree encrouchment, the prospects for the future are not totally discouraging because, while the available area may have become smaller, recreational boating has decreased (Fig 3.10), making re-establishment of vegetation easier.

Investigations have been undertaken to assess the variables that affect macrophytic development on the river channel and these are reported next. From these, the scope for increasing vegetation will then be considered.

5.3 Factors affecting Colonisation of Aquatic Plants

5.3.1 Light

5.3.1.1 Introduction

The distribution and spread of macrophytes in rivers is dependent on the availability of suitable bed substrates in which they can become rooted and also adequate light penetration of the water to the depth at which they are growing. Berrie (1972) working on the River Thames established that 2-8% of surface irradiation penetrated down to 2m depth. Sculthorpe (1967) suggested that sufficient light (up to 1%) could in fact penetrate to 3m. Haslam (1978) also concluded that the maximum depth that plants could grow to in rivers was 3m and no further, because below this many variables came into play to prevent consistent light conditions. These included intermittent sunshine, variable cloud cover and fluctuating turbidity and water levels, particularly during spate run off.

Kirk (1983) comprehensively detailed the way plants respond to varying light intensities in aquatic systems. He indicated that visible light, in the range 400-700nm, was essential for photosynthesis and its intensity and duration would dictate the extent to which submerged plants could flourish.

Light penetration into pure water attenuates with depth but suspended solids, along with colour of the water, also greatly increase that attenuation. As the lower Dee is subject to variations in suspended solids, according to river flow, recreational disturbance, or tidal incursion (Fig 3.9 and 1.14), it was necessary to assess light attenuation under different conditions and thereby establish its implications to the colonisation of plants in this section of river.

It was also necessary to assess the extent to which the tree canopy influenced the amount of light reaching the water surface and thereby limited the extent of aquatic weed growth beneath the canopy.

5.3.1.2 Method

Using a Macam submersible light sensor, a survey of the variations of light penetration into the deeper water of the lower river was undertaken at six points from 5km above Farndon down to Chester Weir. Optical filters on the light sensor confined measurements to the 400-700nm waveband used by plants for photosynthesis (photosynthetically active radiation, PAR). The meter measured the combined effects of colour, mineral and organic detrital suspended solids as well as zooplankton and phytoplankton. As it is the total attenuation that affects the growth of plants, it gives a true perspective of potential impact. Measurements of light penetration into the river channel during a spring tide period and also the degree of light exclusion by the tree canopy, were also taken. Light intensity readings (uE PAR) were recorded at river depths of 0.5m, 1.0m and 1.5m at each location and the calculation of the % light transmission/metre through water was calculated from the following formula:

$$T_{0.5} = \frac{L_{1.0}}{L_{0.5}}$$

where :

$T_{0.5}$ = Light Transmission at Depth 0.5m.

$L_{0.5}$ = Measured Light (uE) at Depth 0.5m.

$L_{1.0}$ = Measured Light (uE) at Depth 1.0m.

Since light absorption in water is exponential (Beer - Lambert Law), assuming optical homogeneity, percentage transmission over 1m depth ($T_{1.0m}$) can be calculated as :

$$T_{1.0m} = (T_{0.5m})^2 \times 100 \quad \text{(Expressed as \% m}^{-1}\text{)}$$

5.3.1.3 Results

The light transmission rates recorded in the channel at successive depths are presented in Table 5.5. Readings were taken at 5km intervals close to the right bank, left bank and in mid channel. A selected mid-channel measurement during a 9.5m tidal event, 5km from Chester Weir, was also included.

Table 5.6 below presents the results for measurements in respect of the way tree canopy affects light projection on to the water surface and also at successive depths, the percentage penetration through the water column of the available light remaining.

Table 5.6

Impact of trees on light transmission to the water surface

	Light Intensity (uE)	Light Transmission/m^{-1} (% m^{-1})
Open Atmosphere	98.33	
Under Trees		9.15
i) Above Water Surface	9.0	
ii) 0.1m Depth	8.0	
		34.1
iii)0.5m Depth	4.7	
		22.2
iv) 1.0m Depth	2.2	
		32.3
v) 1.5m Depth	1.3	

Table 5.5

% Light Transmission / metre depth of River Water
River Dee (Chester Weir - Farndon)

7th September 1990

Distance from Chester Weir	Depth (m)	Right Bank				Middle of River				Left Bank			
		1	2	3	Mean	1	2	3	Mean	1	2	3	Mean
1km	0.5-1.0	8.8	7.75	5.87	7.47	5.03	3	2.21	3.41	3.16	0.99	0.87	1.67
	1.0-1.5	5.25	11.92	8.85	8.67	4.13	4.95	3.39	4.16	1.88	1.4	0.73	1.34
5km	0.5-1.0					17.15	16.5	16.97	16.87				
	1.0-1.5					20.8	21.35	22.99	21.71				
10km	0.5-1.0	19.37	17.33	21.81	19.5	17.6	23.51	19.85	20.32	21.07	23.89	24.59	23.18
	1.0-1.5	32.5	30.86	15.79	26.38	30.05	33.24	26.16	29.81	24.22	22.99	23.13	23.45
15km	0.5-1.0	15.29	22.21	15.21	17.57	23.96	27.06	29.79	26.94	49.22	21.19	31.49	33.97
	1.0-1.5	15.69	24.41	24.32	21.47	33.56	44.76	32.4	36.91	42.19	38.93	44.38	41.83
20km	0.5-1.0	14.83	23.29	26.2	21.44	28.33	27.53	31.43	29.1	25.65	21.4	44.19	30.41
	1.0-1.5	24.69	33.2	33.56	30.48	34.6	37.98	37.69	36.76	25.07	27.67	25.95	26.23
25km	0.5-1.0	26.56	25.02	26.17	25.92	28.15	43.55	30.85	34.18	28.51	31.85	33.05	31.14
	1.0-1.5	35.02	36.83	34.65	35.5	32.73	36.62	34.41	34.59	31.73	29.52	31.96	31.07
5km With Tidal Intrusion (9.5m Tide)	0.5-1.0	1.93	1.77	2.51	2.07	0.98	0.47	0.32	0.59	0.74	0.33	0.32	0.46
	1.0-1.5	1.18	0.29	0.28	0.58	0.85	0.1	0	0.32	0.32	0.34	0.07	0.24

5.3.1.4 Discussion

From Table 1.5 it can be seen that Dee water carries little colour and therefore, for the most part it is unlikely that there is any limitation on aquatic plant growth in shallow water where there is no disturbance. In disturbed areas, water clarity (Fig 3.9) has been shown to decrease with the activities of boat traffic and similar effects are likely with tidal intrusion to the lower river.

From Table 5.5 it can be seen that the percentage light transmission with depth is around 35%.m^{-1} in mid channel 25km upstream of Chester Weir, which compares to just 4%.m^{-1} near Chester Weir. This suggests 65% and 96% attenuation of light occurs through the water at these respective locations. While no examination of the actual requirements of plants was made, the large exclusion of light in the lower reaches is likely to preclude weed growth in all but the shallowest of margins. The presence of Sparganium emersum in mid channel at a depth of 2m, 10km upstream of Chester Weir, but absent below this point, would suggest that light attenuation rates of 70-80%.m^{-2} through the water space do permit plant development from the bed substrates to take place. In undisturbed areas these levels are likely to be typical in the summer months on account of the consistent flows, but disturbance by boat traffic has been shown to impact for long periods and therefore the extent of weed growth in deeper water will be dependant on the level of recreational activity taking place (Garrad and Hey, 1988).

Tidal incursion above Chester Weir also attenuates the majority of light to the lower depths (Fig 5.5) but this is to be expected because high tides have been shown to carry high suspended solid loadings (Fig 1.13). Although the incursions are of short duration, the extent to which they are detrimental to plant growth will be dependent upon the time the sediments remain in suspension, which is related to the size of sediment particle in the substrate (Garrad and Hey, 1987). Indications from boat disturbance (Chapter 3) suggest that this could be quite a protracted period and therefore the extent of impact to macrophytes will depend upon the frequency of extreme episodic tidal events, which occur on average, 10 tides /month.

The rapid variation in light penetration through the water column that can occur from sediment disturbance, whether it be from flood water, tidal events or recreational boat traffic, will limit the potential for aquatic plants to develop in deeper water near Chester.

Results from the measurements of transmission on to the water surface under trees (Fig 5.6), show how effective the trees are at excluding light. Levels of 91% reduction were recorded beneath the canopy, while projection on to the water surface in the channel immediately outside the tree line recorded a mean of just 2% reduction, presumably due to shading from the banks themselves. There was 66% reduction through the surface water beneath the trees, which was similar to that recorded for the open channel. This indicates that trees can be the primary cause of reduced light to the margins and even in spaces between trees, reduction in light penetration may be sufficient to limit colonisation by aquatic weeds (Spence, 1967 and Wright et al., 1982).

As trees extend to almost 46% of the study area the imposition on aquatic vegetation at the margins is considerable. It has also been established that the tree line is gradually increasing and therefore, if progress is to be made to increase aquatic bankside vegetation, selected lengths should be felled and the margins replanted with more suitable vegetation. Methods of developing habitats, which will be of greater benefit to fish and other forms of wildlife, will be considered later in this chapter.

5.3.2 Sediment Variations

5.3.2.1 Introduction

As well as suspended solids influencing the extent of light penetration into the river channel, the composition and stability of the sediments in the littoral areas are also important in influencing the ability of plants to colonize the river. The way plants are able to establish is very much dependant upon the substrate composition and the level of its stability. From Fig 1.5, the margins have been shown to be quite narrow, and it is likely that they are also unstable and highly mobile where plants have difficulty in colonising. The marginal substrates were investigated to establish if this was the case.

In order to assess composition and degree of stability, studies were undertaken on a typical littoral bank at Caldy near Chester and compared with the sediment composition of the channel along the study area.

5.3.2.2 Method

i) River Channel Substrate Composition

Substrate samples were extracted from the river channel from the Clywedog confluence to Chester Weir (Fig 1.2), using the technique described for invertebrate analysis in Chapter 4. The composition of the sediments was calculated by using graded sieves and a scale of particle size modified from Cummins (1962). This related to particle diameter size of Clay <0.01mm; Silt 0.01 - 0.16mm; Sand 0.16-2mm; Gravel 2-16mm; Pebbles 16-64mm Cobbles 64-256mm.

ii) Silt Movements at the Margin

To investigate whether there were major changes in the levels of silt at the margins, a protected and an unprotected area of bankside was monitored at the same location, each being pegged out with four depth marker posts. The site was considered to be a sensitive area for fluctuations in silt movements and was strongly exposed to the effects of wave action by boats. The number of posts had to be kept to a minimum to reduce the risk of premature removal, but despite this, during the second summer they were damaged or removed, which prevented any further observations.

The protected area had wooden pallets along the waters' edge to reduce wave action and intrusion by boats and was fenced from the landward side to prevent ingress by cattle. The unprotected area was left open.

5.3.2.3 Results

i) River Channel Substrate Composition

From the longitudinal trend in Fig 5.1 it can be seen that the upper section of the study area had less sand and silt and contained a mixture of the larger substrates which included cobble, pebble and gravel. The gravel and pebble progressively decreased downstream and between Farndon and Chester, finely divided substrates, especially sand, predominated. At Chester Weir the barrier probably increased localised scouring at flood times, explaining the reducion of smaller substrates and the presence of larger components. The increase of silt in the margins reflects the settlement of suspended solids carried down river from higher upstream and the accretion of rotting vegetation litter.

ii) Silt Movements at the Margin

Details of the measurements are given in Table 5.7 below, which reveal that there were no major shifts of silts during the summer but there was displacement over the winter period. The maximum observed shift was from a protected area, where 14cm was lost over the winter months. Within the same test area and same time period, at another measured point, there had been an opposite accretion of 3cm, suggesting dynamic movement within the marginal area.

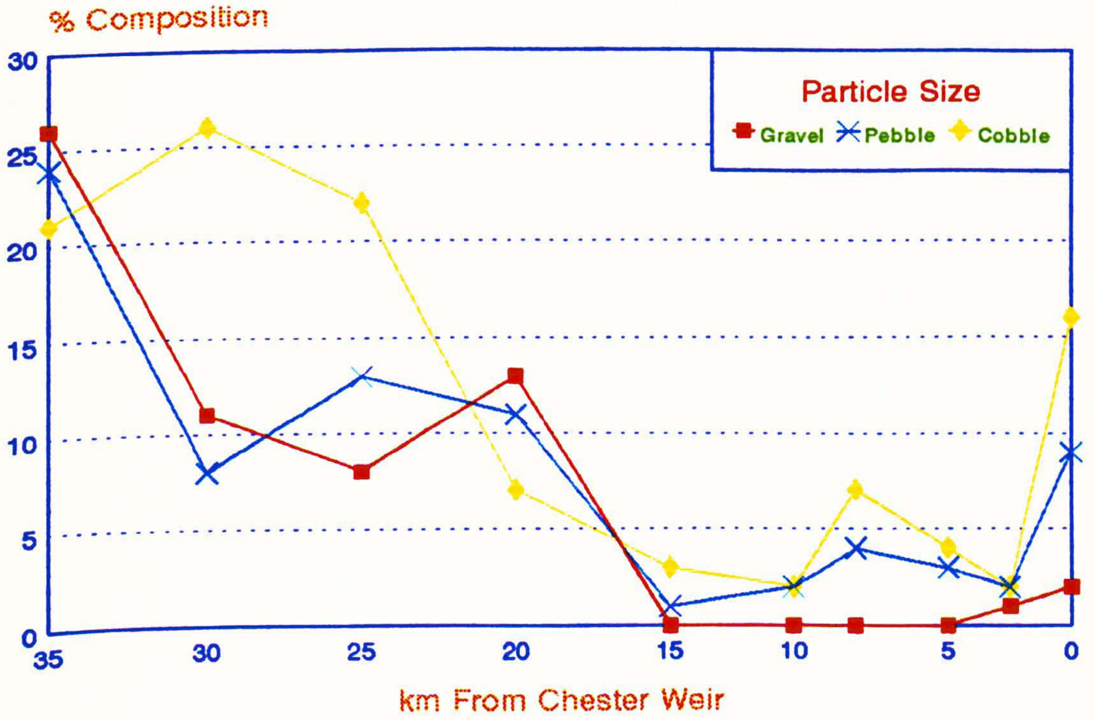
There was a small but gradual accumulation of silt during the summer months and greater losses over the winter period. The outer edges of the sediment bank were more variable and the degree of change probably related to the higher velocities further into the channel, either from river flow or from wave action. The protected areas showed the greatest fluctuation, suggesting that accretions had taken place since the introduction of the pallets in 1986 and perhaps as a consequence of their presence, but such gains were still vulnerable to winter floods. The unprotected areas varied little and therefore were considered to be relatively stable and tolerant of the extremes of change that could occur, although again it was likely that this stability was a dynamic one with small gains and losses occuring frequently.

Channel Substrate

River Dee (Clywedog confluence-Chester Weir)

Large Particles

Fig 5.1



Small Particles

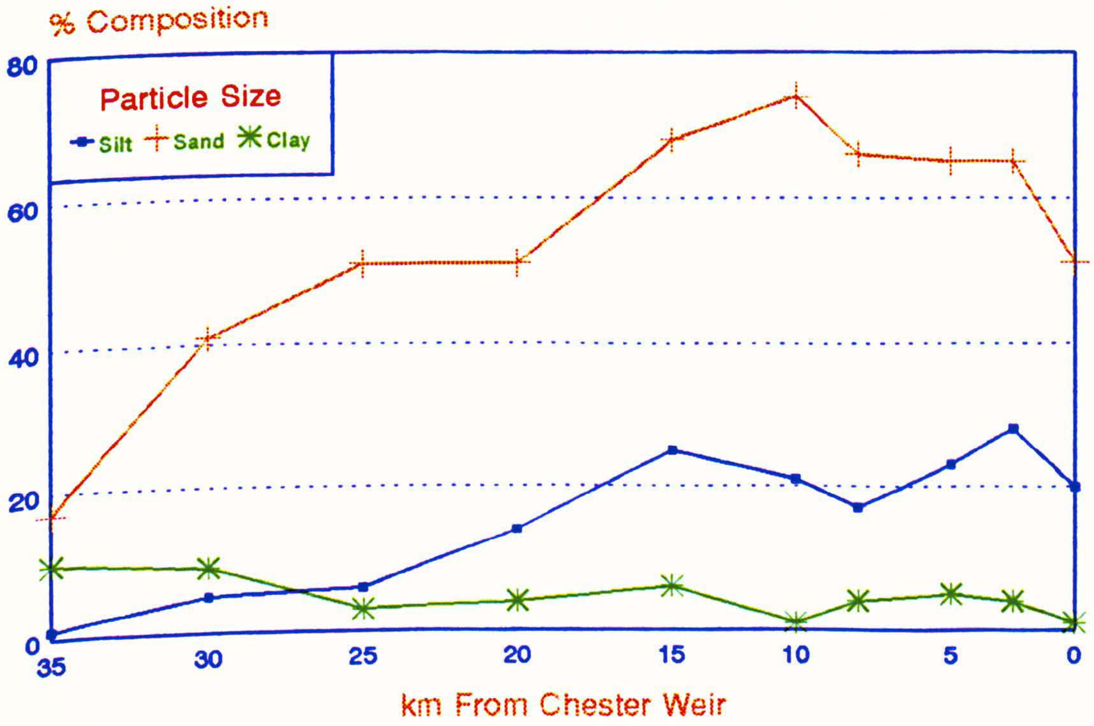


Table 5.7

Variations in Sediment Levels at the Margins (cm)

		Protected Area				Unprotected Area			
		Outer (4m)		Inner (1m)		Outer (4m)		Inner (1m)	
		U/S	D/S	U/S	D/S	U/S	D/S	U/S	D/S
1987	April	0	0	0	0	0	0	0	0
	May	1	-1	-1	-1	1	3	1	1
	June	1	-3	-2	-2	1	4	1	2
	July	2	-2	0	-1	3	4	1	2
	August	6	-1	2	0	3	6	1	2
	Sept	5	-3	0	-3	1	4	1	1
	Oct	4	-3	0	-5	1	3	1	0
1988	April	3	-14	0	-2	-1	0	0	-4
	May	4	-13	0	0	0	1	0	-4
	June	5	-13	0	0	0	2	0	-4

The constituent elements of the sediment indicated that it would remain unstable and continue to make it difficult for plant propagates to establish. The stabilisation of the sediment, for example by the presence of stone may assist macrophyte colonisation and it is notable that in areas of the river where stone, is available in the margins, greater abundance of plants is observed (See Plate 5.1).

Plate 5.1
Limitation of Spread of Marginal Vegetation into the River Channel

5.3.2.4 Discussion

The sheer stress forces described in Chapter 3 govern the extent of sediment movement that takes place within a river corridor. At Chester the upper few centimetres of silt deposits have been found to in a mobile state and remain unstable both within a single summer and during the winter period. Hynes (1970) indicated that movements in silts and coarse sands could be initiated by current velocities of 60cm.sec^{-1} and Graf (1971) suggested that mud beds would be eroded at current velocities of 10-30cm.sec^{-1}. As the channel frequently experiences velocities from river flow and tidal intrusion in excess of this, the marginal substrates are likely to remain mobile. From research on the Norfolk Broads by Garrad and Hey (1988), wave velocity from a single pleasure craft could exceed 76cm.sec^{-1} and therefore even during more stable flow periods of the summer, disturbance of the substrates by boats will likely continue. Major changes in the distribution of the marginal sediments can occur within a few weeks, but during the summer growing period for plants, the substrate levels were more consistent. This suggested that wave activity caused localised resuspension and deposition of the marginal substrates at this time, rather than redistibution or loss from the system that probably occurred in the winter or during high flow periods.

Geodata Institute (1993) also indicated that the dominant discharge for sediment transport in the sand-gravel-pebble size ranges at Worthenbury was 20-50m^{3}.s^{-1}. However, estimates of the change of sediment transport frequency resulting from regulated in comparison with naturalised flows, indicated enhanced transport frequences centring on discharges of the order of 45-70 m^{3}.s^{-1} in that area. Such conditions will have comparable impact on sediment deposits further downstream, particularly as substrate size ranges are smaller.

Throughout the time of the trials there was no colonisation of the sediments by aquatic vegetation, despite the protected area having reduced impact from wave action. It can be deduced that the unstable nature of the marginal sediments, caused by the effects of wave action and river flow probably limits natural settlement of aquatic plants in the river channel. Therefore, if increased plant growth in the water space is to be achieved, the planting of deeper-rooted, larger species needs to be considered in any management programme, or alternatively the surface substrates need to made more stable to allow colonisation by smaller aquatic species (Haslam <u>et al</u>, 1981).

5.3.3 Influence of Cattle on Bankside Vegetation

5.3.3.1 Introduction

Most open banks along the lower Dee do not support a rich and diverse flora and one of the possible reasons for this is damage to the margins by cattle entering the river for drinking water. It is rare for access to the water to be restricted by fencing, except where the banks are unstable or considered too steep. Consequently most of the open bankspace has been subject to cattle intrusion at one time or another (Table 5.2).

Damage takes place principally from physical compaction by trampling and also from grazing (Plate 5.2). To determine the extent of the disturbance to the vegetation, a trial was initiated using the same site as for the sediment study, which adjoined fields where cattle were frequently present.

Plate 5.2 Damage of River Margins by Cattle

5.3.3.2 Method

The area at Caldy Fig 1.2 was chosen because it had a uniform bank with a slope of 1:10 throughout. It measured 200m in length, averaged 5m in width and was conveniently sectioned into two. Fencing was erected along a 100m length and where necessary down into the water to prevent cattle intrusion. The remaining 100m length remained unfenced.

A full baseline study of the aquatic and marsh type macrophytes was undertaken in both sections, just prior to the erection of fencing in 1987 and then monitoring was repeated over a 6-year period when species presence was recorded. Photographs of the site were taken at intervals, to show progressive changes in subsequent years.

5.3.3.3 Results

The details in the botanical changes are indicated in Table 5.8 and 5.9. Most change occurred in the protected site and this not only included an increase in plant abundance but also, initially, an increased diversity of species. The greatest change occurred in the first year, when the number of species increased from 13 in 1987 to 34 in 1988. After this, competition between the major species was starting to develop, with Typha latifolia becoming progressively dominant and starting to displace smaller marsh plants amongst its increasingly dense clumps. Similarly large plants like Iris pseudocorus, which had initially benefited from the protection from cattle, were becoming displaced by the hardier T.latifolia and by the sixth year I. pseudocorus was reduced to a small clump. It was noticeable that willow sp (Salix alba, S.caprea, S.fragilis and S.viminalis) started to invade the protected area by the fourth year, displacing the established flora by its stronger growth, shading and soil occupancy.

By the fifth year the number of plant species started to decline as competition became more intense for the available substrate. During the first two years the smaller marsh plants were interspersed with the larger species throughout the marginal territory. As time progressed, the distribution of the smaller plants was pushed to the waters' edge,

Table 5.8

Bankside Vegetative Colonisation

River Dee - Caldy, Chester

WithinProtected Area

	1992	1991	1990	1988	1987
Emergent Species					
Agrostis stonifera		x			
Alisma plantago-aquatica		x	x	x	
Alnus glutinosa	x				
Angelica sylvestris	x	x			
Apium nodiflorum		x	x	x	x
Bidens cernua		x		x	
Bidens tripartita		x	x	x	x
Epilobium hirsutum	x	x	x	x	
Filipendula ulmeria	x	x	x	x	
Glyceria maxima	x	x	x	x	
Iris pseudocorus	x	x	x	x	x
Juncus articulatus	x	x	x	x	x
Juncus bufonius		x	x		
Juncus effusus	x	x	x	x	x
Juncus inflexus	x	x	x	x	
Lycopis europaeus	x	x	x	x	
Lysimachia nummularia		x	x		
Lythrum salicaria	x	x	x	x	
Mimulus guttatus			x	x	
Myosotis palustris			x	x	x
Myosotis scorpioides		x			
Phalaris arundinacea	x	x	x	x	
Plantago major	x	x		x	x
Polygonium amphibium	x				x
Polygonium hydropiper		x	x	x	x
Rorippa amphibium		x	x	x	
Rorippa islandica			x	x	
Rorippa nasturtium-aquaticum			x	x	
Rorippa sylvestris			x		
Rumex conglomeratus		x			
Rumex crispus		x		x	x
Rumex hydrolapathum			x		
Rumex obtusifolius	x				
Salix viminalis/fragilis/caprea/alba	x	x	x		
Solanum dulcamara	x		x	x	
Sparganium erectum	x	x	x	x	
Tenacetum vulgare			x		
Typha angustifolia	x			x	
Typha latifolia	x	x	x	x	x
Veronica anagallis-aquatica			x	x	
Veronica beccabunga			x	x	x
Floating Leaved Species					
Nuphar lutea		x	x	x	
Submerged Species					
Callitriche stagnalis	x	x	x	x	x
Elodea nuttallii	x		x	x	
Ceratophyllum demersum				x	
Ranunculus sceleratus			x	x	
Vaucheria sp			x	x	
Sagittaria sagittifolia		x	x		
Lemna gibba		x			
Lemna minor	x				
Total Species	23	32	36	34	13

Table 5.9

Bankside Vegetative Colonisation

River Dee - Caldy, Chester

Outside Protected Area

	1992	1991	1990	1988	1987
Emergent Species					
Agrostis stonifera	x	x			
Alisma plantago-aquatica		x			
Alnus glutinosa	x				
Apium nodiflorum	x			x	x
Bidens cernua	x	x	x	x	x
Bidens tripartita		x			x
Carex paniculata	x	x			
Carex remota		x			
Carex riparia			x		
Epilobium hirsutum	x	x			
Filipendula ulmeria		x			
Gnaphalium uliginosum		x			
Juncus articulatus	x	x		x	x
Juncus bufonius		x		x	x
Juncus effusos	x	x	x	x	x
Juncus inflexus		x		x	
Lycopis europaeus	x	x	x		
Lythrum salicaria	x	x			
Mimulus guttatus		x			
Phalaris arundinacea	x	x	x	x	x
Plantago major		x	x		x
Polygonium amphibium		x		x	x
Polygonium hydropiper	x	x	x	x	x
Polygonium persicaria			x		
Rorripa palustra		x			
Rorripa sylvestris	x	x			
Tenacetum vulgare		x	x		
Veronica anagallis-aquatica		x			
Veronica beccabunga	x	x	x	x	
Submerged Species					
Callitriche stagnalis		x		x	x
Elodea nuttallii	x				
Ranunculus sceleratus	x	x	x	x	
Total Species	16	27	11	12	11

where light intensity was greater and progress for the larger plants was slower, on account of the channel pressures detailed in Chapter 3. With the accelerating advance of willow, herbaceous plants were displaced, probably through the effects of increased shading. As can be seen from Plates 5.3-5.6, if succession is permitted the initial range of emergent aquatic species is likely to be replaced totally by the dominant willow flora.

In the unprotected area there was a reasonable degree of consistency from year to year with limited species diversity, as well as a restricted spread of those that were able to colonise. This situation changed in 1991, when a change in farming practice reduced the frequency of cattle in the fields adjoining the test site. The reduced activity led to more stability in the unprotected area and species diversity and numbers increased, but not to the same level as experienced in the protected area in the first year. These observations were, however, a further pointer to the way livestock can impact on bankside habitats.

5.3.3.4 Discussion

It has been demonstrated that if cattle are excluded from river margins in areas which have a shallow gradient, then a natural colonisation of a diverse flora can be rapidly achieved. In the trial, the greatest increase in species occurred in the first year and was maintained for a further two years, but within four years marsh plants were being excluded. Competition first increased dominance of T.latifolia, which was progressively invaded and replaced by willow which after six years was dominating and starting to exclude the T latifolia.

It has been shown in Table 5.2, that the increasing dominance by trees has been occurring throughout the study area over the 10 year period from 1981 to 1991 and the trial demonstrated the speed at which it took place. The natural competition of plants has probably influenced the way the ecology of the Dee has developed in the past. With the dominance of trees and the problems of channel erosion pressures, the availability of suitable margins in the lower river, which cyprinid fish can utilise, will continue to be limited without management intervention.

Plate 5.3 - <u>Caldy Site</u>

<u>Prior to erection of Fencing and Instream Pallets</u> (June 1987)

Plate 5.4 - <u>Caldy Site - October 1987</u>

87 10 3

Plate 5.5 - Caldy Site - September 1990

Plate 5.6 - Caldy Site - September 1992

In the six year period of the trial, the bankside plant succession was incomplete, so if management control was required to maintain the standing crop at peak diversity, there would be sufficient time to implement maintenance programmes using selective removal techniques at predetermined time intervals. Dominance of the larger littoral plants is not in itself a problem, because they provide an aquatic habitat that has the greatest possible chance of extending into the marginal shallow water where the substrates have been shown to be unstable. Where this occurs there is an opportunity for beneficial microhabitats to develop. Eaton, Hodgson and Pearce (1988) indicated that such areas provided a diverse microflora and fauna which was important to fish.

Bankside macrophytes such as T.latifolia, also provide an ideal habitat for wildlife, particularly ducks and other waterfowl, as well as providing refuges for other vertebrates such as otters and water voles.

5.4. Main River Habitat Improvement

5.4.1. Introduction

The study has shown that the River Dee, in its lower reaches, is a comparatively deep channel with narrow, shallow littoral areas, which are predominantly populated by alder (Alnus glutinosa) and willow (Salix sp). It has also been shown that the extent of the tree line and the shading that results from its canopy, prevents weed growth developing to any appreciable degree. In littoral areas, that are not populated by mature trees, there is potential for aquatic macrophyte colonisation, both within the water space itself and also up the bank as far as the level of extreme high water. There is not only the habitat value of the ecology to be considered, but also the benefits to amenity and landscape, which are elements that can influence management decisions on changes that might eventually be required on any river corridor.

Haslam (1978) indicated that any modifications to channel width, depth and slope could influence plant colonisation. In Chapter 3 it has been demonstrated that the Dee has experienced major changes in flow regime and land drainage developments in the past, as well as recreational activities that have all affected the ecology of the river.

The number of potential aquatic plant species that can occur in running water systems, as opposed to slack backwaters or side channels off a main river, is also very limited. Gessner (1955) lists only 61 such species recorded in three intensive studies of rivers and streams in Western Europe.

Colonisation by plants in any particular locality is dependant upon substrate suitability and in the lower section of the study area, the marginal substrates have been shown to be predominantly fine sands and silts, which are largely unstable and frequently come into suspension with only moderate channel disturbance (Fig 3.9). The mobile nature of the marginal area, along with more physical disruptions eg cattle damage, has been seen to restrict the colonisation of higher plants in the lower river and consequently the diversity and general distribution is not great. If aquatic vegetation development is to be increased, then it is necessary to establish the most satisfactory way of achieving it.

Proposals were therefore advanced to evaluate ways of establishing littoral vegetation in a location where the river channel pressures were typical of the lower end of the catchment so that, if successful, the methodolgy could be applied elsewhere on the river to enhance conservation interests.

5.4.2. Method

A site of 120 metres single bank was chosen at Heronbridge (Fig 1.2). The choice was made because it was an area of open bank of shallow profile, which was within the area affected by boat traffic and had margins almost largely devoid of any marsh type plant communities (See Plate 5.7).

Although initially it had been intended to experiment with a number of different plant species, including Typha latifolia, Phalaris arundinacea,

Plate 5.7 - Heronbridge Site

Prior to Tensar Mat being laid - 3rd May 1988

Plate 5.8 - Heronbridge

Tensar Matting and stone used in the trial

Glyceria maxima and Phragmitis australis, this was rejected because of the potential interaction between the species.

T. latifolia was therefore chosen as the most suitable species, since in the study at Caldy, it had been effective in assisting the development and protecting smaller and more vulnerable plant communities. It was also a species that would advance into the water space and therefore provide the microhabitats that were important for juvenile fish.

Tensar Mat, manufactured by Netlon Limited, was chosen as the material to consolidate the bank. It was a comparatively new product, principally designed to counter the problems of scour from flow and wave action in river systems and thereby prevent destabilisation of the bankside substrates. The mat is a geotextile reinforcement product made of polyethylene, which consists of four separate layers of non-corrodible polymer mesh combined to form a three dimensional structure.

The mat has a flat lower surface and with its' excellent draping qualities it conforms to the soil surface profile and thus maintains a close contact. ("Draping" is a manufacturers' test to assess the extent to which a product will conform to an irregular slope.) This aspect was considered a positive advantage on a river system like the Dee because winter floods can be severe. Under such circumstances severe erosion properties can be generated and if undermining develops and the matting does not adhere to the new bank profile, then there is a risk that exposed, loose matting could be ripped out prematurely. The comparatively high strength of the material and dimensional stability also allowed it to be effective on steep banks.

The upper surface of the mat is made up of a three dimensional, network of pockets or holding cavities and because of its stretching qualities, soil or gravel could be brushed into it easily, creating a firm base on which rapid colonisation by vegetation could take place.

The trial site at Heronbridge had a uniform profile along the whole 120 metre length, which had an approximately 1:10 uniform slope. The removal of overlying vegetation, was achieved by means of a Hymac excavator and when complete, 10 cm of top soil was spread over the whole area to ensure sufficient medium for plant root systems to penetrate. Work was undertaken during the late spring when the river level was low, to ensure that the area planted projected into the waters' edge throughout the plant growing season.

The Tensar matting, in rolls of 4.5m, was then laid by means of a Hymac, controlled by a skilled operator. This was achieved by unrolling the mat down the graded slope into the water margin and then cutting at the appropriate length. At the upper and lower ends the mat was anchored into pre-dug trenches, which was back-filled with soil at the upper end but to prevent fringe scour at the lower end, consolidation with stone >20cm in size was used. Adjacent rolls were overlapped by approximately 25cm and then the whole section was pegged down with fixing pins at 2m centres. The fixing pegs were "U" shaped, with dimensions of 35cm x 10cm x 35cm, made of 10mm mild steel.

When the Tensar matting had been laid along the whole trial site, 2-5mm gravel chippings were brushed into the matting layers. If soil had been used there was a risk of it being washed out by high water before the area had become consolidated. Plates 5.8-5.10 show the Tensar matting being introduced to the trial area after terrestrial vegetation had been removed and the profile of the bank had been graded.

The trial area was then split into plots measuring 4 metres square. 3meshed and 3 unmeshed were randomally selected along the bank and each was planted with 25 T.latifolia at one metre intervals. In the case of the plots with Tensar Mat this was achieved by cutting into the mesh. Fig 5.3 shows the position of where Tensar Mat was laid and also the situation of the individual plots along the site.

From the time of the completion of the trial area in May 1988 until September 1992, monitoring of the growth spread of T.latifolia was assessed each year; this included measurements in width and in breadth along the bank. The average number of plants m^{-2} was also calculated from each plot by taking 5 random counts in each plot using a half metre

Plate 5.9 - Heronbridge

Preparing the ground for mat laying - 7th May 1988

Plate 5.10 - Heronbridge

Following mat laying and introduction of stone - 11th May 1988

wire frame. Assessments were made of other plant species presence within the meshed and unmeshed areas in 1990, 1991 and 1992.

5.4.3 Results

Fig 5.2 shows the actual expansion of the plots both in width and in depth of Typha latifolia, over a four year period between 1988 and 1992.

Tensar Mat was found to be effective at consolidating the margin of the trial area but not for promoting the growth of a large reed like T. latifolia. Although the matting was found to make the sediments more stable, the mesh restricted the expansion of the larger shoots. Constrictions occurred around the base of the stems, which at times of higher river flows made the plants more susceptible to breakage. From Plots A,B and E in Fig 5.3, it can be seen that growth from meshed areas expanded more rapidly into the water margin areas which was unmeshed, suggesting the mesh impeded larger plants. This result, and the greater success of growth expansion in the unmeshed plots, also revealed that T. latifolia established well once the roots were dug into the marginal substrates, regardless of whether matting was used. In the unmeshed plots C and D, the area of growth achieved was 3X that for meshed plots A,B and E after the 4 year period and this expansion created >3 fold increase in plant numbers, from 880 to 2800/plot. Slower development was however, recorded for unmeshed plot F. This could be explained because the plot adjoined a meshed section and therefore lateral spread was restricted in one direction, but perhaps more importantly rapid advancement of willow had taken place at the rear of the plot which, as was seen at Caldy, gradually excluded other plants by a combination of vigorous growth and increased shading.

From examination of Table 5.10 it can be seen that there was a greater range of species in the area where Tensar mat was absent, especially larger macrophytes such as reeds. Smaller marsh plants however, did well in the meshed areas where their root systems were able to penetrate the meshes and use it to provide greater stability, while the stems were unaffected by constrictions of the mesh. Lateral growth of the species was easier to accomplish, which probably accounted for the smaller

Plant Recolonisation Trial using Tensar Matting

Fig 5.2

River Dee - Heronbridge, Chester

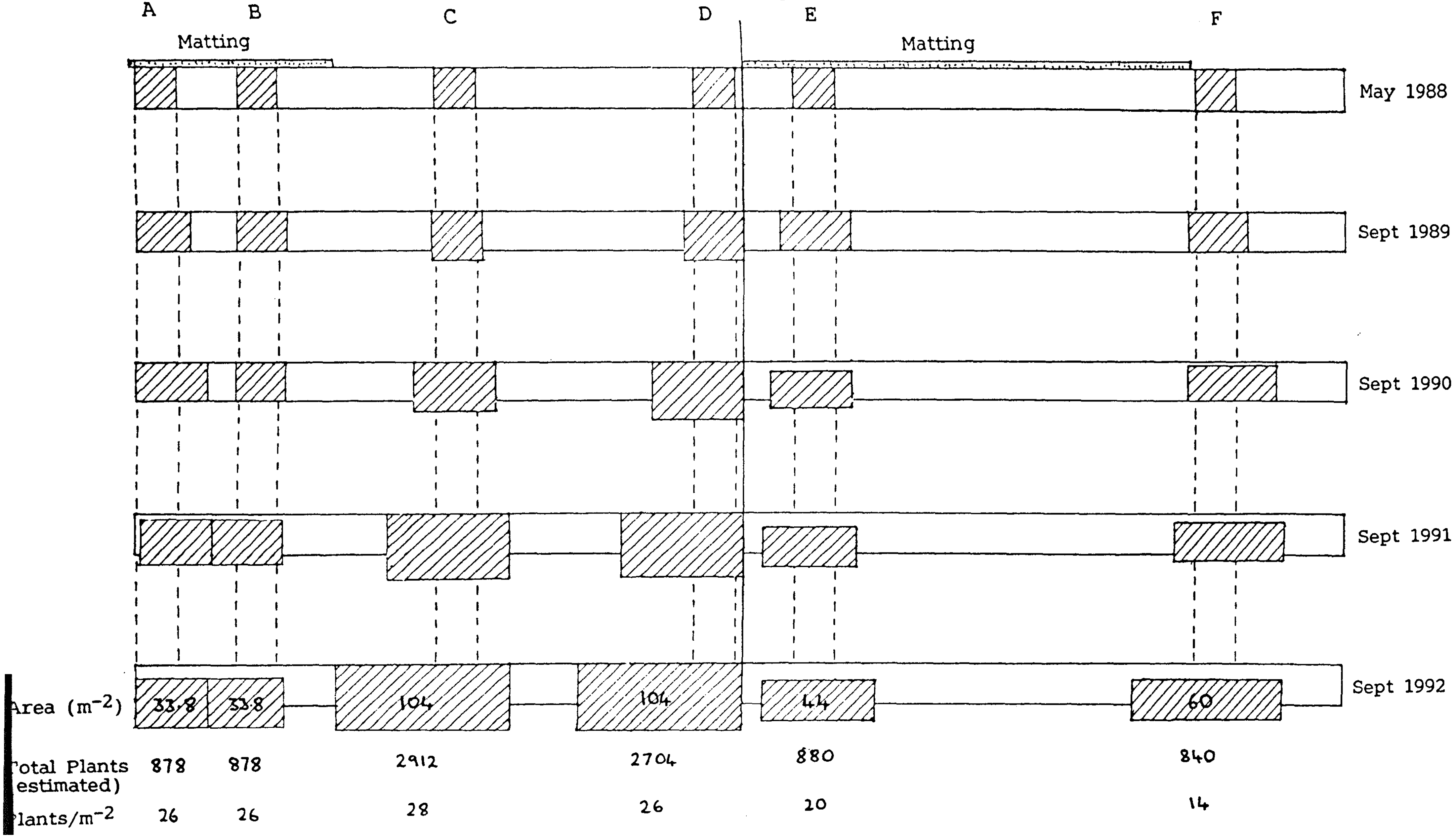


Table 5.10

Tensar Matting Experiment - Vegetative Colonisation

River Dee - Heronbridge, Nr Chester

	1992		1991		1990	
	Tensar Mat	No Mat	Tensar Mat	No Mat	Tensar Mat	No Mat
Emergent Species						
Agrostis stolonifera	x	x				
Alisma plantago-aquatica						
Alnus glutinosa	x					
Apium nodiflorum	x		x	x	x	
Aster tripolium	x					
Bidens cernua	x		x		x	
Bidens tripartita			x	x		x
Callitriche platycarpa		x				
Carex remota				x		
Carex hirta		x				
Epilobium hirsutum	x	x	x	x	x	
Galium palustra	x					
Glyceria maxima	x		x		x	
Iris pseudacorus	x					
Juncus articulatus		x	x	x	x	x
Juncus bufonius			x	x	x	x
Juncus effusos	x	x	x		x	
Lycopus europaeus	x	x		x		x
Lysimachia nummularia			x			
Lythrum salicaria	x	x	x	x	x	
Myosoton aquaticum	x					
Nymphaea alba	x					
Oenanthe crocata	x			x		
Phalaris arundinacea	x	x	x		x	
Phragmites australis	x		x			
Plantago major	x	x		x		
Polygonum hydropiper	x	x	x	x	x	
Rorippa nasturtium-aquaticum					x	
Rorippa sylvestris			x		x	
Salix viminalis, fragilis, caprea	x	x	x	x		
Scirpus maritimus	x		x		x	
Scrophularia aquatica	x	x				
Solanum dulcamara	x	x				
Sparganium erectum	x		x	x	x	
Tanacetum vulgare	x	x			x	
Typha latifolia	x	x	x	x	x	x
Veronica anagallis-aquatica			x			
Veronica beccabunga	x	x				
Floating Leaved Species						
Lemna Minor		x				
Nuphar lutea	x	x	x	x	x	x
Ranunculus flammula					x	
Sparganium emersum			x	x		x
Submerged Species						
Elodea nuttallii	x				x	
Total Species	29	19	21	16	19	7

macrophytes extending further into the water margins in such areas. The use of mesh in this way would actively prevent larger plants and would likely slow down or prevent the ingress of willow.

The initial success of smaller plants in the unmeshed plots was probably due to the protective shield provided by the large macrophytes, which was similar to the initial development at the Caldy site. Their scarcity, in the more exposed areas in front of the Typha latifolia, only confirms this. Progressive spread of T. latifolia in the open area followed a similar trend to that recorded at Caldy but, by the end of the third year, willow was also developing and, although not dominating at this stage, was starting to encroach and displace other plants. The extent of weed growth by the third year and the initial development of willow can be seen in Plate 5.11.

5.4.4 Discussion

The trial with Tensar matting has demonstrated that the bankside margins can be consolidated by the meshing and that it will enhance the development of smaller plants, whether marsh type or terrestrial. There are however, limitations to its value for larger emergent aquatic plants because of problems of root penetration and plant stability. The trial revealed that consolidatory mesh was not required to successfully establish Typha latifolia at the margins. This could be adequately achieved by digging the plants into the substrate and once introduced, they were not easily displaced. The extent of expansion into the channel would however depend upon the intensity of erosive forces from the river. This suggests that the problem phase of colonisation of tne margins by plants is the initial one of becoming rooted in the marginal substrate. The unstable nature of the benthic substrates probably prevents this process occurring naturally.

It can be seen from Plate 5.12 that following establishment of T. latifolia, aquatic microhabitats, that are likely to be of value to juvenile cyprinids, have been created. The maintenance of this situation is, however, worthy of further investigation, because advancement of willow Salix sp,

Plate 5.11 - Heronbridge

Fully developed Aquatic Vegetation - August 1991

Plate 5.12 - Heronbridge

Aquatic Microhabitats for Juvenile Fish within the Vegetation

was found to be causing similar displacement problems to those experienced in the experimental site at Caldy.

5.5 Summary

From the results achieved at Caldy and Heronbridge, the prospect of improving instream aquatic vegetation for juvenile cyprinids is going to be limited because the areas most suitable at the margins are small, have fragmented distribution and are subject to pressures that will impact on their development. Areas that are selected for improvement will require active management, involving financial commitment and a programmme of continued maintenance. This will be necessary to prevent plant succession progressing to the final stage where there is total dominance by trees, particularly willow (Salix sp).

On account of the limitations to both the amount of marginal main river channel and the scope for increasing and improving such habitat, an examination of suitable alternatives was pursued, which included the potential for improved utilisation of available tributaries and the development of off-stream recruitment sites. These are reviewed in the next chapter.

6.0 Off Channel Recruitment Areas for Roach

6.1 The Dee Tributaries

In the study length of the river between the Clywedog confluence and Chester there is a scarcity of tributaries that can offer possible recruitment and sanctuary areas for cyprinid fish. It is therefore important that the water flow and quality of those that exist are maintained to a high standard. An examination of the tributaries was undertaken, to establish how they interrelated with the main river and whether there were particular problems that affected them as fish habitats.

The five main tributaries along the study length of river are: Aldford Brook, Pulford Brook, River Alyn, River Clywedog and Worthenbury Brook. Their water quality and potential as fish habitats will be discussed individually.

6.1.1 Aldford Brook

6.1.1.1 Introduction

Tagging results in Chapter 2 showed that roach move between the study area at Chester and Aldford Brook and Barnabus (1971) indicated that spawning took place in the lower section of the brook. On account of the sluice, built in 1974, only 1000m of the brook is now freely accessible to fish. Mature dace also move into this length, but often their duration of stay is short, as anglers' catches have suggested that the brook functions as a refuge from the main river at times of winter spate.

6.1.1.2 Method

A limited survey of the brook was undertaken to establish its water quality and ecology so as to assess its suitability as a fry rearing refuge. Monthly fry sampling, using a micromesh seine net from a boat was undertaken during the summer of 1988 to establish fry distribution within the 1000m section between the sluice and the Dee.

One litre monthly water quality samples were taken and analysed in 1989 and 1990. Dissolved oxygen levels and temperatures were taken at the same time of dayin each sample, at different depths along the section by means of a portable meter. Monthly one litre phytoplankton samples were also taken from June to October 1987 and assessed for species presence. The main aquatic weeds were also recorded.

6.1.1.3 Results

The netting results showed that both dace and roach fry used the area for feeding, to an extent probably dependent upon the water quality at different times of the season. Table 6.1 shows mid month water quality samples samples in 1989 at the sluice immediately downstream of Aldford. In Fig 6.1, 6.3 and 6.5 the respective concentrations for dissolved oxygen, ammonia and orthophosphate are shown for 1989 and 1990. Monitoring of the section between the sluice and the river gave an indication of the variability of quality in mid-summer, both longitudinally and vertically within the water column. Oxygen levels depleted regularly in mid summer as a result of low flows and enrichment from farm land in the catchment. The concentrations demonstrated in Table 6.1 are daytime figures and therefore during the night and early morning, when oxygen demands from aquatic organisms are higher, then oxygen concentrations will become lower. Fry dispersion was influenced by these quality variations because at times of poor quality, if fry were found, they were congregated in the surface layers (Table 6.2). Although the recruitment area is relatively limited, any deterioration in water quality could be detrimental to fry presently utilising this area in their first summer.

The monthly phytoplankton samples showed that there was a rich diversification of species, which was greater than the main river (Chapter 4), with the consistent presence of filamentous algae (Table 6.3). The brook also contained an abundance of aquatic weed which was dominated by Nuphar lutea, Glyceria maxima and Typha latifolia. This periodically requires removal to aid the drainage of surrounding land.

Chemical Analysis

Table 6.1

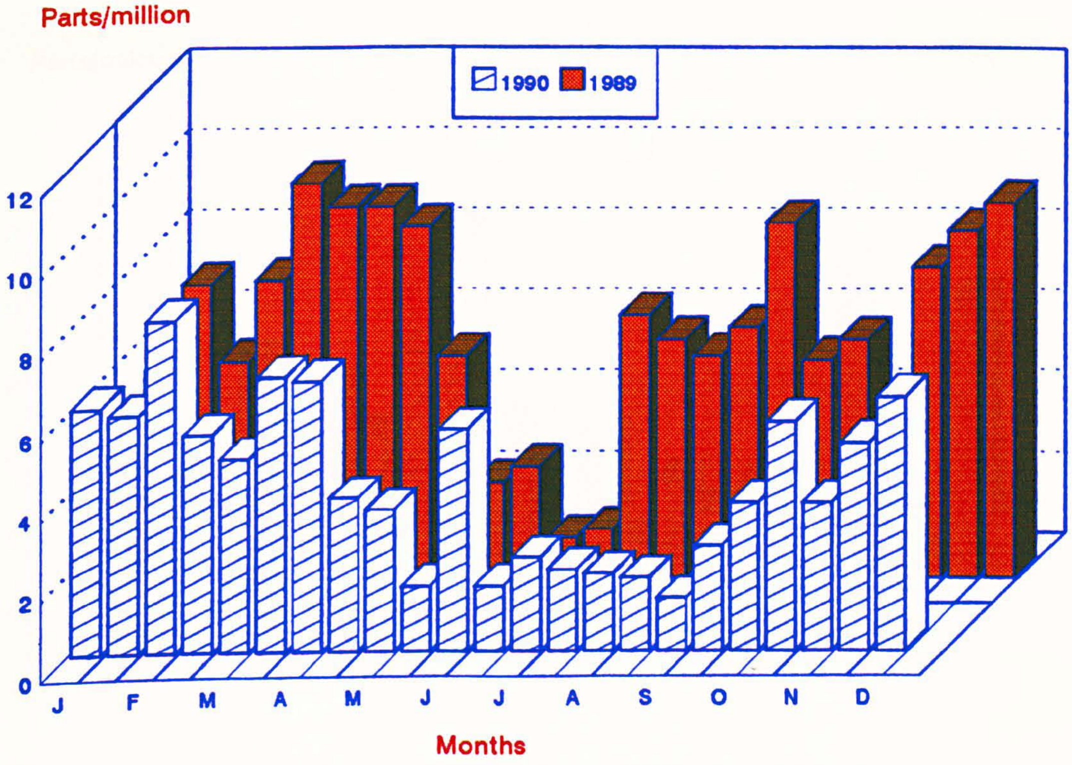
Aldford Brook-Sluice

1989

	pH	Cond mmhos/cm	Temp %C	DO %	DO mg/l	BOD mg/l	Ammonia mg/l	Nitrogen mg/l	Nitrate mg/l	Sus Solids mg/l	Chloride mg/l	Phosphate mg/l	Chloro a ug/l
January	7.2	667	2.4	53	6.4	1.7	0.7	1.6	0.5	25	127	0.7	4.5
February	7.8	866	7	45	5.4	2.4	1.5	1.4	0.1	26	150	0.8	3.2
March	7.4	169	6.6	80	9.8	1.4	0.2	1.7	0.03	47	19	0.2	6.2
April	7.6	515	7.1	76	9.2	4.5	0.9	2.2	0.13	30	58	0.4	7.6
May	8.1	902	11.7	51	5.5	2.7	0.3	1.7	0.2	22	150	1.1	13.1
June	8.3	1009	18.2	11	1	3.5	0.2	0.3	0.2	24	203	0.4	108
July	8.3	992	19.1	71	6.5	1.4	0.3	0.7	0.1	29	194	0.9	8.6
August	8.2	932	15.7	56	5.5	2.2	0.5	0.4	0.1	19	191	1.3	3.8
September	8.1	968	14.2	61	6.2	1.9	0.3	0.5	0.1	9	205	1.3	4.1
October	7.9	1007	9.7	52	5.9	1.3	0.2	0.5	0.1	20	208	1.2	3.8
November	7.2	1037	8.6	27	3.1	1.9	0.5	1.6	0.3	12	154	0.5	3.5
December	7.7	1134	3.7	65	8.6	4.9	1.9	0.8	0.1	204	213	1.3	88.5

Aldford Brook - Dissolved Oxygen

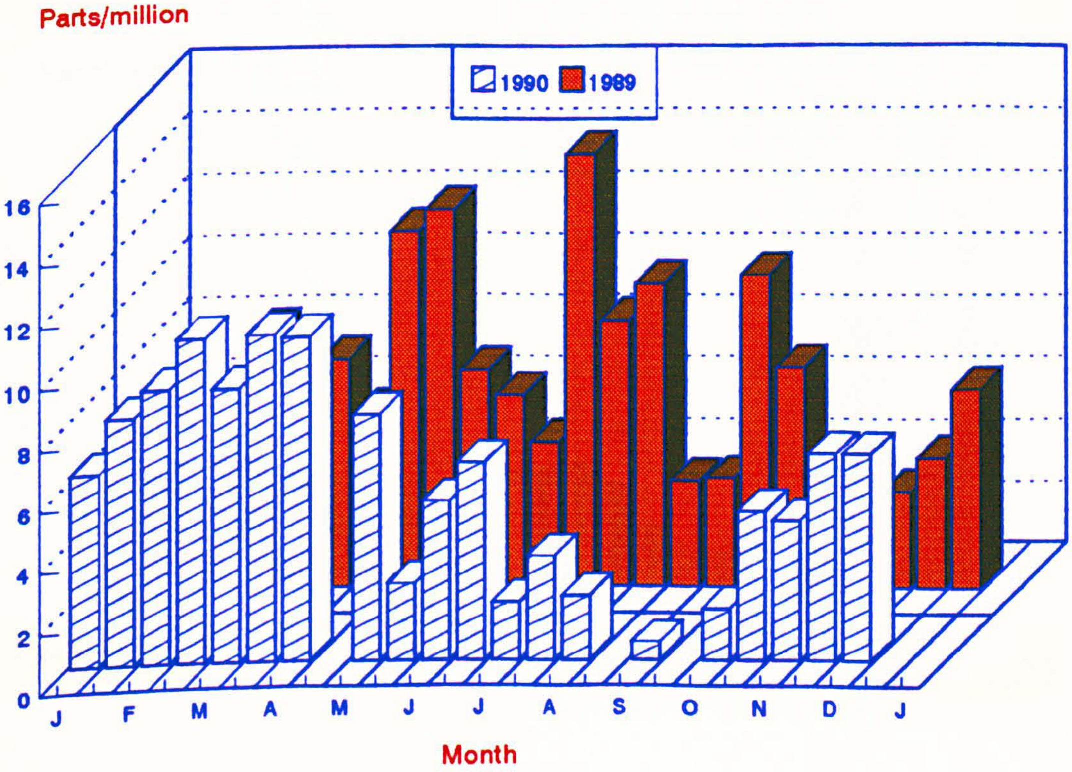
Fig 6.1



Sluice Gate

Pulford Brook - Dissolved Oxygen

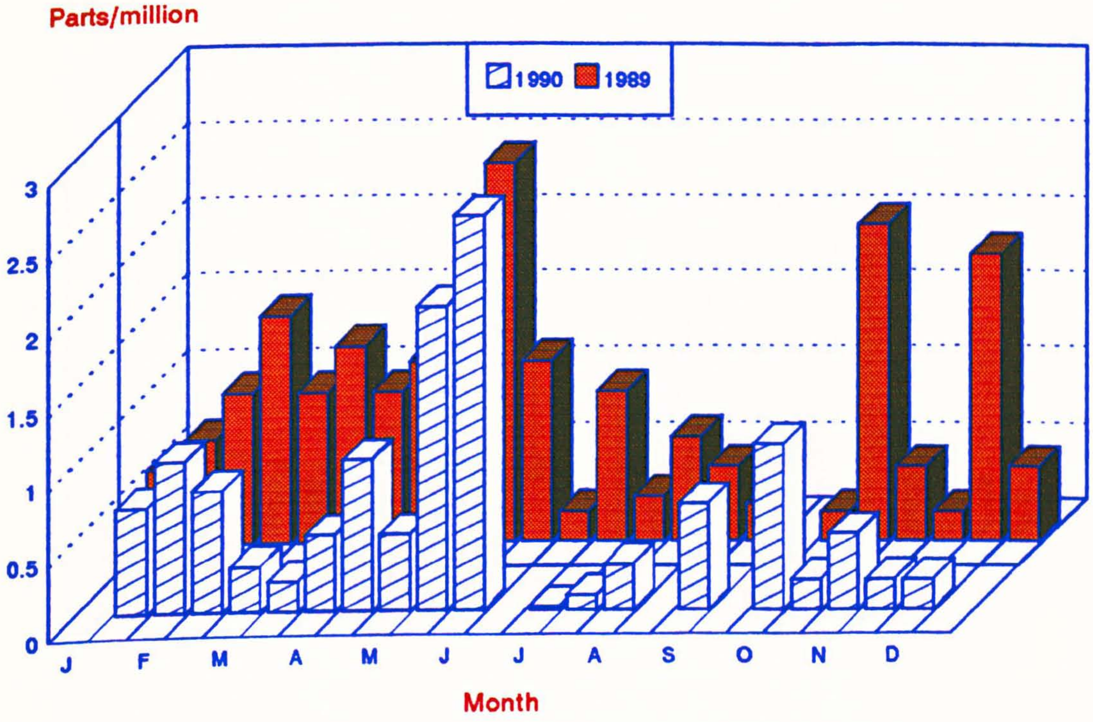
Fig 6.2



Pulford Bridge

Aldford Brook - Ammoniacal Nitrogen

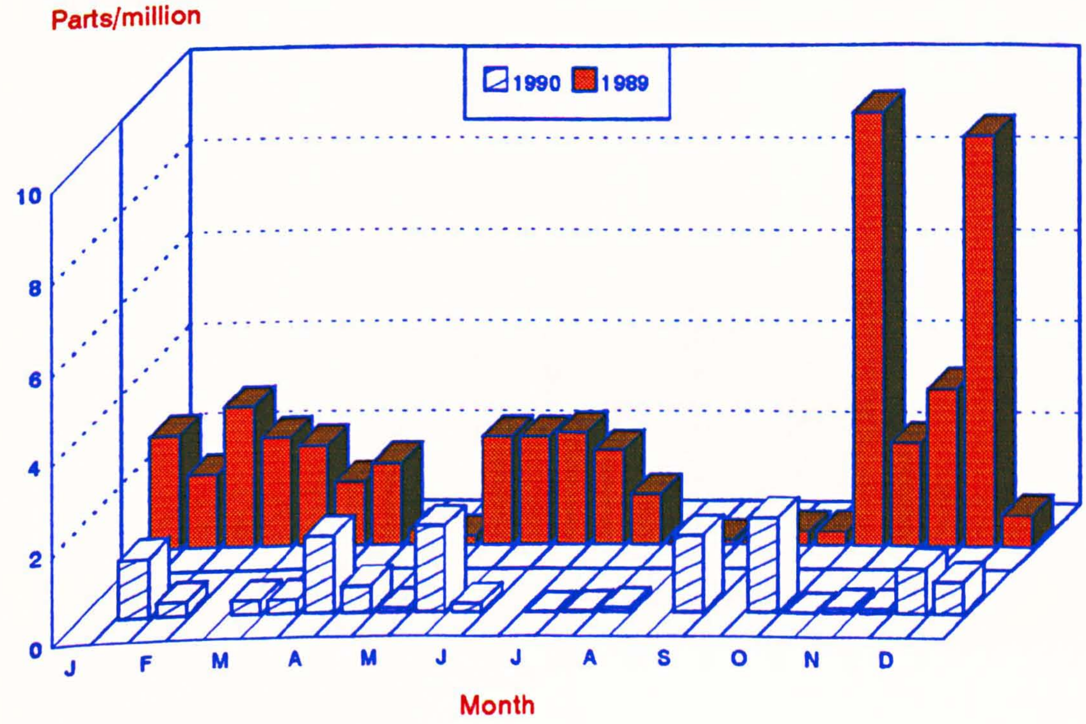
Fig 6.3



Sluice Gate

Pulford Brook - Ammoniacal Nitrogen

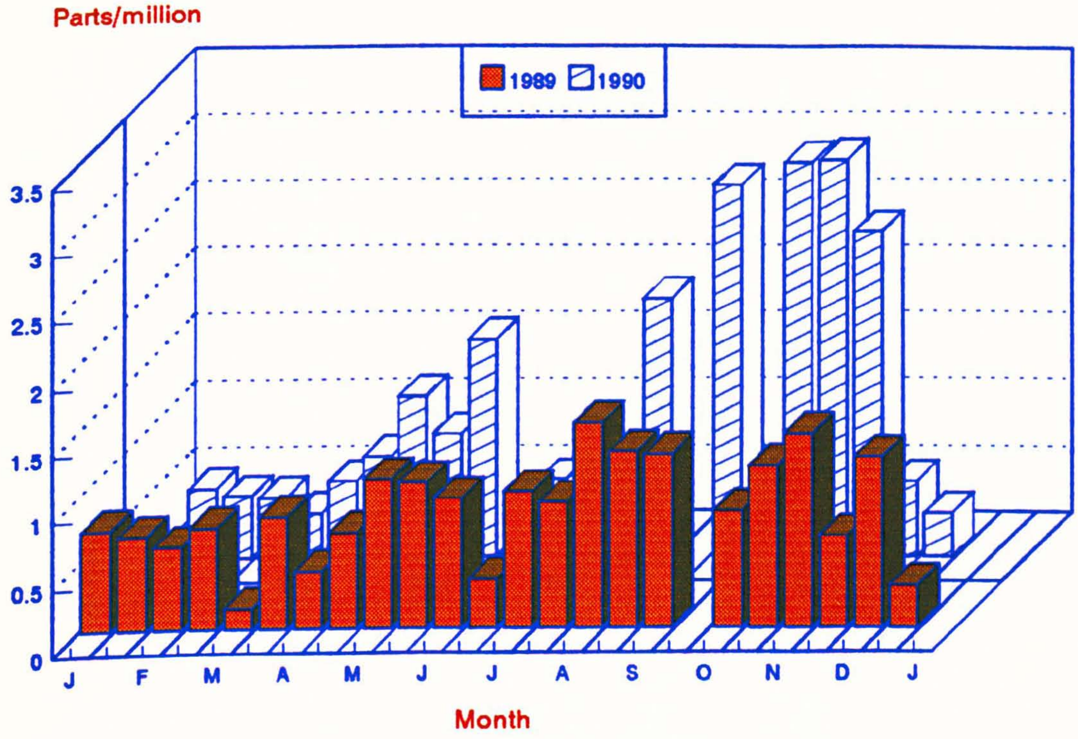
Fig 6.4



Pulford Bridge

Aldford Brook - Orthophosphate

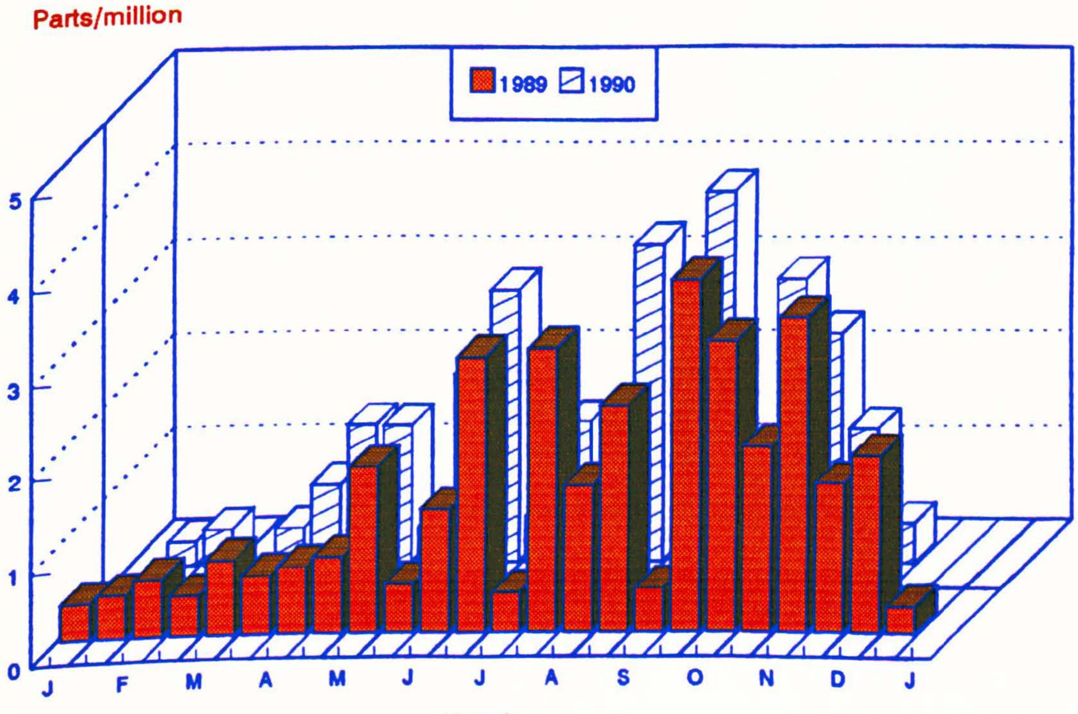
Fig 6.5



Sluice Gate

Pulford Brook - Orthophosphate

Fig 6.6



Pulford Bridge

Table 6.2

Aldford Brook

Water Quality with Fry Distribution

Dissolved Oxygen (%)

	River Channel	Brook Entrance	150m	300m	450m	600m	750m	Aldford Sluice
30/06/88		Fry	Fry	No Fry	No Fry	No Fry	No Fry	No Fry
Surface	75	52	25	7	7	6	5	4
Middle	76	12	11	2	2	2	3	3
Bottom	76	3	1	1	1	1	1	1
15/07/88		Fry	Fry	Fry	Surface Fry	No Fry	No Fry	Surface Fry
Surface	86	65	46	20	19	8	9	11
Middle	85	11	7	10	4	2	1	5
Bottom	87	1	2	6	5	4	2	5
02/08/88		Fry	Fry	Fry	Fry	No Fry	Surface Fry	Fry
Surface	85	51	35	18	16	14	14	13
Middle	85	15	11	10	9	8	7	11
Bottom	85	14	11	8	8	6	7	11

Water Temperature ° C

	River Channel	Brook Entrance	150m	300m	450m	600m	750m	Aldford Sluice
30/06/88		Fry	Fry	No Fry	No Fry	No Fry	No Fry	No Fry
Surface	17.5	18	18.4	17.6	17.9	17.6	17.5	17.3
Middle	17.5	17.8	17.8	17.6	17.5	17.4	17.3	17.2
Bottom	17.5	17.7	17.7	17.5	17.4	17.3	17.2	17.1
15/07/88		Fry	Fry	Fry	Surface Fry	No Fry	No Fry	Surface Fry
Surface	14.6	15.3	16	16.2	17	15.4	14.9	14.8
Middle	14.5	14.6	14.6	15.3	14.3	14.1	14.1	14.6
Bottom	14.5	14.6	14.6	14.3	14.3	14.1	14.1	14.6
02/08/88		Fry	Fry	Fry	Fry	No Fry	Surface Fry	Fry
Surface	14.3	15.3	16.1	16	16.9	15.9	16.4	14.9
Middle	14.3	15.5	15.5	15.6	15.7	15.4	15.1	14.7
Bottom	14.3	15.4	15.5	15.6	15.6	15.3	15.1	14.7

Table 6.3

Phytoplankton in two tributaries of the Lower Dee

1987

Species	Aldford Brook					Pulford Brook				
	June	July	August	Sept	Oct	June	July	August	Sept	Oct
Microcystis		x	x	X	x		x	x	X	x
Closterium			x		x	x	x	x	x	
Staurodesmus										
Chlorella			x		x					
Gleocystis							x	x		
Pediastrum										
Scenedesmus	x	X	x			x	x	x	x	x
Staurastrum	x	x							x	
Filamen Algae	x	x	x	x		x	x	x		x
Ankistrodesmus	x	x	x		x			x	x	x
Chlamydomonas			x	x						x
Dinobryon		x								x
Cryptomonas			x	x	x			x	x	x
Pandorina		x								
Euglena type	X	x		X			x	x		x
Small Flagellates		x			x				x	
Mallomonas		x	x	x				x	x	x
Diatoma	x	x	x				X		x	
Tabellaria		x				x	x			
Fragillaria	x		x	x	x	X	x	x	x	x
Synedra	x				x	X	X	X		x
Astrionella					x					
Cyclotella	x	X	x	x	x	X	X	X	x	x
Navicula	X	X	X	x	X	x	x	X	x	X
Nitzschia	x									
Surirella			x		x					x
Cocconeis	x	x	x	x	x		x	x	x	x
Meridion	x		x	x	x			x	x	x
Cymbella	x		x		x					
Gomphonema									x	
Pinnularia								x		x
Melosira	x		X			x	x	x		x
Meriamopedia	x									
Phacus		x						x		
Actinastrum		x	x							
Amphora				x	x					x
Melompedia						x				

x = Present X = Abundant

6.1.1.4 Discussion

Only a small section of Aldford Brook is accessible to mature fish but in this area juveniles are frequently found. The algal feeding regime was favourable for juvenile fish but distribution of fry was influenced by the water quality variations which deteriorated markedly in mid summer, particularly in respect of dissolved oxygen.

Aldford Brook has water quality designation of Class 3 (National Rivers Authority, 1991) and the pollution problems have mainly come from Tattenhall Sewage Works and from dairy farms along its length. Recent upgrading of the treatment plant have largely eliminated the risks from sewage effluent, but dangers from intermittent farm spillage pollution still rank as a high risk and constitute an ever-present problem because of the large number of farms in the catchment.

Although pollution risks can be combated by vigilance, a newer threat which is exacerbating the problem is the decreasing water flow within the system as a whole. A comparison of recent flows (NRA archives) with those in Lambert (1976), indicate almost a halving of the mid-summer dry weather flow from 127 $l.sec^{-1}$ in 1959, to just 76 $l.sec^{-1}$ in 1991, at the Lea Hall weir 6km upstream of Aldford. This decline has been progressive and while the reasons for it are unclear, they could be associated with lower ground water conditions consequent upon successive dry summers and winters and overabstraction of borehole supplies in the Cheshire plain.

The variable water quality, seasonal flow problems and restricted access to coarse fish, limit the potential for Aldford Brook to be used as a fish refuge and fry rearing habitat.

6.1.2 Pulford Brook

At present this brook does not play an important role for coarse fish recruitment in the lower Dee, because when water levels fall in the main river in early summer, it becomes too shallow and macrophyte-clogged for adult fish to enter. Juvenile dace are to be found at its lower end but, like Aldford Brook, it suffers periodic contamination from sewage and farm discharges. On account of its shallowness this makes it a unfavourable habitat at such times.

Water samples were taken at the same time as for Aldford Brook. Table 6.4 shows the monthly chemical analysis for the brook in 1989. Fig 6.4 shows the variation of ammonia level experienced in 1989 and the improvements that were made by the National Rivers Authority in 1990 to reduce this problem. Nevertheless, despite these changes it remains a shallow, highly eutrophic tributary, which becomes very warm and continues to experience high phosphate levels from sewage contaminant (Fig 6.6) and oxygen depletion from increased enrichment in mid summer (Fig 6.2). This limits its ability to be utilised by coarse fish. Considerable deepening and widening might improve the capability, but existing flood embankments largely restrict this possibility.

6.1.3 River Alyn

The Alyn, unlike Aldford and Pulford Brook, is faster flowing with a hard, stony bottom rather than more typical soft substrate. It also has a different flora, at the confluence with the Dee, than the other lowland tributaries with Rorippa nasturtium-aquaticum (Water Cress) and Ranunculus sceleratus in abundance. Higher upstream it suffers from water quality problems in summer, resulting from a combination of low flows and inadequate dilution of sewage discharges. Lower flows result from serious water losses through a natural limestone fault near Mold (Humphreys and Partners, 1991), but despite this, angling clubs maintain the river as a brown trout fishery. On the lower section between Rossett Weir and the confluence with the Dee, only dace and grayling are periodically found. An augmentation scheme to enhance flows was investigated in 1991 by the National Rivers Authority, but not pursued on cost grounds. The volumes of water involved would have had little influence on conditions at the lower end of the river.

Table 6.4

Chemical Analysis

Pulford Brook-Speed's Bridge

1989

	pH	Cond	Temp	DO	DO	BOD	Ammonia	Nitrogen	Nitrate	Sus Solids	Chloride	Phosphate	Chlor a
		mmhos/cm	%C	%	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	ug/l
January	7.6	829	1	52	6.4	2.1	0.9	2.1	0.2	43	52	0.7	4.7
February	8	701	7.9	36	4.2	2.2	0.8	2	0.1	37	73	0.8	4.9
March	7.7	570	7	77	9.3	5.9	2	1.9	0.2	43	51	0.7	12.2
April	7.6	526	9.3	125	14.3	2.8	1.6	3.3	0.1	20	43	0.4	3.6
May	8.2	729	10.7	138	15.3	2.4	0.8	2.4	0.3	13	55	1.3	8
June	8.1	684	16.5	61	5.9	6.7	0.5	0.9	0.2	29	57	1.2	128
July	8	678	17.2	65	6.2	2	0.5	1.3	0.1	18	55	1.1	6
August	7.1	625	14.9	46	4.6	10	0.3	1	0.1	36	52	1.8	35.2
September	7.8	640	18.1	68	8	1.6	0.1	1.2	0.1	26	51	1.9	6.6
October	7.7	659	8.5	36	4.2	1.8	0.1	1.2	0.1	12	54	1.9	3.2
November	7.5	819	8.8	9.5	1.1	2.9	1.9	2.5	0.7	10	67	0.8	9.3
December	7.7	817	3.4	59	7.8	4.1	2	1.3	0.1	308	87	1.9	70

6.1.4 River Clywedog

The river drains the industrial development areas of Wrexham and although in its headwaters it is a high quality trout stream, contamination from industrial premises and sewage treatment plants on the River Gwenfro tributary and from Five Fords Sewage Works on the Clywedog itself, limit its potential for coarse fish at the present time (Chadwick, 1984). Improvements to industrial discharges, storm overflows on the Gwenfro and a redirection of the Five Fords outfall directly to the Dee, planned in 1992, should improve quality to Class 1B.

Despite the present shortcomings of water quality and social misuse from a serious rubbish problem eminating from the urban expanse of Wrexham (Hodgson, 1993), fish populations at its lower end are good, with mature dace being the main component. A fish kill, resulting from an industrial cyanide release in November 1990 (See Chapter 2), provided an accurate indicator of fish standing crop under present water quality conditions. This revealed that the population was principally mature dace with juveniles having limited presence, consistent with the findings of Wilkinson (1974) on other lowland tributaries of the Cheshire plain. The anticipated improvements in water quality in the next few years should bring about favourable changes to its fishery status, although the river is unlikely to become a spawning tributary, particularly for roach.

6.1.5 Worthenbury Brook

This brook is more a network of drainage streams on the upper section of the Cheshire Plain which includes Wych Brook, Emral Brook and Carden Brook as well as Worthenbury Brook itself. Fish populations include dace, chub, eels, flounder and grayling. Wilkinson (1974) examined fish distribution and population dynamics within the system.

Like Aldford Brook, the network of streams that supply the Worthenbury Brook system, drain rich farmland and are similarly affected by water abstraction problems and periodic farm pollutions. On occasions these incidents have resulted in serious fish mortalities (eg Wych Brook fish kill 1991). Improvements in vigilance have progressively improved the water quality and reduced the frequency of incidents. Wilkinson and Jones (1977) determined that the fish populations mainly comprised of adult dace and was unsuited as spawning or rearing habitat and therefore not populated by juvenile fish. The faster flow regime was similar to that found in the River Clywedog which determined that it was not favoured by adult roach.

6.1.6 Summary

A brief appraisal of the lower Dee tributaries has indicated that they are few in number and the ones that are utilised by juvenile fish are, at the present time, subject to periodic contamination and low flows particularly in the summer months when juvenile recruitment is taking place. The habitat and flow regime dictates that the River Clywedog, River Alyn and Worthenbury Brook system have limited value for roach and juvenile fish and according to Varley (1967), as these streams are <5m in width they are probably not suitable for other species such as barbel, grayling and chub. Aldford and Pulford Brook have greater potential for environmental improvement but the extent to which this can be achieved appears to be limited. Therefore the development of an off-stream recruitment area was pursued to establish if such a scheme for fry rearing was a more viable alternative to boost fry production for the main river.

6.2 Serpentine Lake Scheme

6.2.1 Introduction

The study on the lower River Dee has shown that conditions within the channel could be deleterious to fish, particularly roach, perch and bream, which are dependant upon favourable marginal habitat in which their progeny can survive and develop. A number of factors have been examined and regulation is one which has caused more detrimental impact to the well-being of the fishery. The extent to which practical management change can influence improvements for cyprinids within the river corridor, was examined in the development of an offstream recruitment area. This was undertaken to establish whether there were alternative ways of producing juvenile roach in a stable environment that was protected from the rigours of a riverine system. This is because natural lowland rivers invariably have a diversity of offstream habitat on the floodplain that is often used for recruitment purposes.

It was required to produce roach that would achieve a faster growth rate than those in the river and thereby be capable of competing once introduced. The choice of location was of importance in order to reduce acclimatisation requirements when the stock was released to the river, to prevent them from being immediately washed from the system. Development costs of the rearing facility also had to be minimized and therefore an existing waterbody close to the river within the Cheshire Plain was considered to be the most appropriate option.

The Serpentine Lake was considered suitable because it adjoined the River Dee within the area of study and, although quite large (5 hectares) at its discharge point to the river, it narrowed in a way that it could be partitioned to create a manageable trial pool (Fig 6.7). Only a part of its length was used for the trials, but this gave the option, that if this limited section proved successful for fry production, then rearing could be extended further in the future. Another advantage of using the lake was that it was situated within the grounds of the main residence of the Duke of Westminster, so public interference with the rearing programme was minimized.

6.2.2 Methods

6.2.2.1 Creation of the Trial Pool

Fig 6.7 shows the design layout of the trial pool, which measured 300m in length and 20m in width. Initially the site was very overgrown with trees and fallen timber and within the water space there were thick deposits of mud and debris (Plate 6.1). In March 1989 the whole length was dredged to an average water depth of 1m and the banks were trimmed, as far as permissible, so that light incidence on to the water surface was improved (Plate 6.2). Beneath the soft benthic substrates, it was found that the bed was made of clay and therefore there was little risk of water losses during the summer months, apart from by evaporation.

Clay dams were introduced at both ends and boarded penstocks were installed into each so that the water level could be controlled to meet requirements (Plate 6.3). A small section was maintained between the main river sluice and the first new penstock, which was necessary to allow drainage from the adjoining land and also to provide an area that was intended to be used in the future, for conditioning fish prior to their eventual release to the river.

Being on the Cheshire Plain, the difference in level between the lake and the river was small, but use of the main river sluice and the integral penstocks of the trial pool, gave the opportunity to manipulate levels so that fish could be released at most river levels.

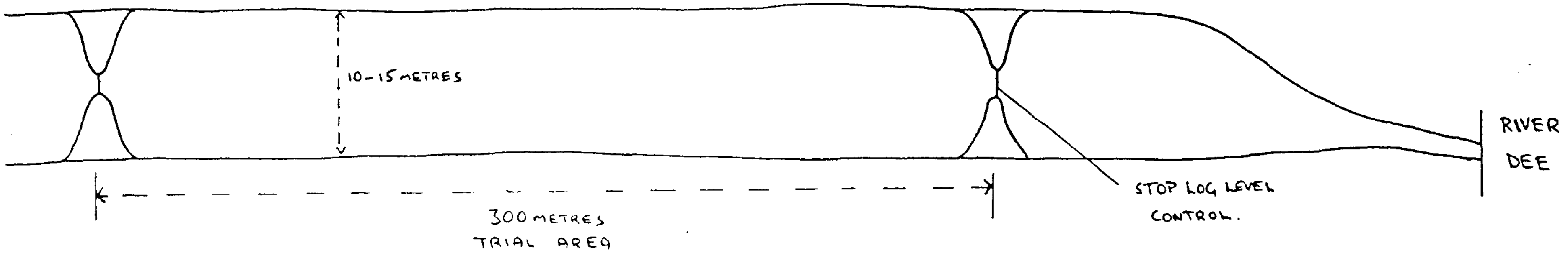
Plate 6.4 shows the completed trial section.

6.2.2.2 The Rearing of Roach Fry

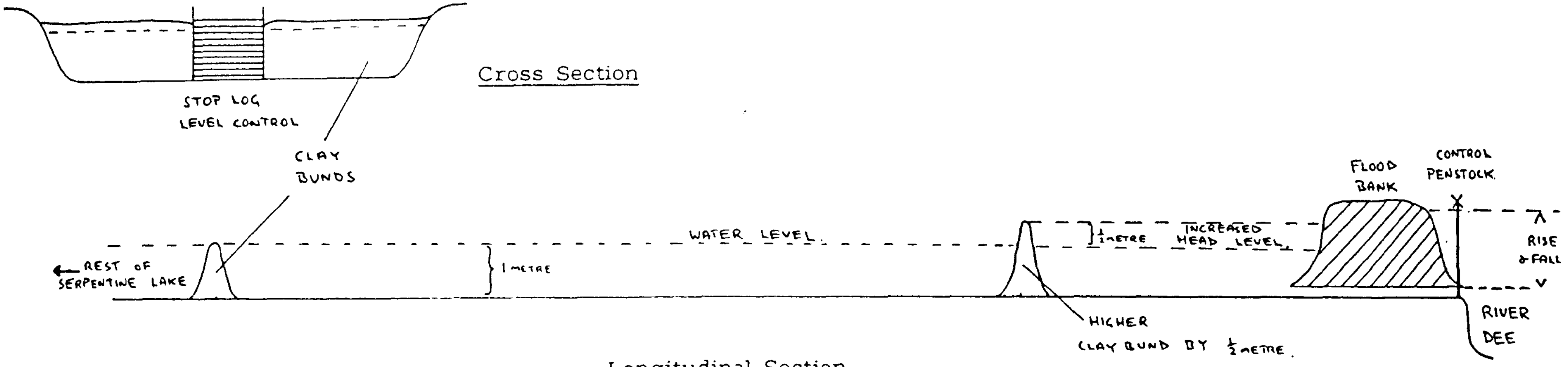
After the construction of the trial pool, as many resident fish were removed as possible by seine netting. Disturbance from excavation brought clay particles into suspension and therefore time was allowed for settlement before fish were introduced. As roach eggs could not be acquired locally, natural recruitment from brood stock was pursued.

Fig 6.7

Trial Area in Serpentine Lake



Plan View



Cross Section

Longitudinal Section

Not to Scale

Plate 6.1 Serpentine Lake Trial Site - Prior to Dredging

Plate 6.2 Serpentine Lake Trial Site - During Dredging

Plate 6.3 Serpentine Lake Trial Site - Stop Log Control


89 3 31

Plate 6.4 Serpentine Lake Trial Site - Completed

Stocks of mature roach were collected from the Shropshire Union Canal and transferred to the pool at the end of April, to allow acclimatization before the spawning period. Approximately 100 fish were introduced.

As the pool had been dredged of all vegetation, spawning medium was deficient and therefore it was necessary to deposit in the water suitable substrates, in the form of cut willow branches. These were removed following the hatching of the fry.

As a precaution against spawning failure in the first year of the trials (1989), 50,000 newly hatched roach fry were acquired from Anglian NRA Region and introduced to a 50m sectioned off area of the trial pool, which was initially partitioned by micromesh netting.

Monitoring of the fry development in the pool continued during the summer months in 1989 and 1991, but unfortunately it was not possible to undertake fry studies in 1990 because of the total failure of fry production. The unexpected failure in production was later attributed to the removal of roach brood stock by cormorants, prior to spawning. This had occurred because, in 1990 spawning fish were introduced to the pool somewhat earlier than in 1989, ie in February instead of late April, which gave the opportunity for the fish to be eaten. The shallowness, clarity of water and the roosting of approximately 130 cormorants nearby, had made the adult fish vulnerable to capture in the time period allowed. Later introductions of brood stock in 1991 enabled successful recruitment to take place once again because by this time the birds had undertaken their seasonal migration down to the sea.

From the time of the first introduction of fish from East Anglia and the first hatch of fry spawned within the pool, monitoring of growth rates and diet of the fry was undertaken. Temperature, dissolved oxygen levels and monthly chemical analysis samples were taken, together with plankton samples which were used to assess the organisms that could form part of the food chain to the fry.

6.2.2.3 Plankton

i) Increasing Phytoplankton Bloom

In each of three summers, efforts were made to increase the amount of phytoplankton within the water space of the trial pool by fertilising, using inorganic chemicals, at the recommended dosage rates for fry production, as specified in the Food and Agricultural Organisation (1985).

The fertilisers used were ammonium nitrate at 150 $kg.ha^{-1}$ and superphosphate at 100 $kg.ha^{-1}$. Application of the granules was by hand from a boat. The granular compounds were not dissolved in water beforehand because application was easier and more accurately dispersed in dry form and both compounds were highly soluble. The only disadvantage of this was realised in the second year, after macrophytes had become more widely established. At this time the plants probably absorbed the nutrients very effectively, because the granules, being heavy, tended to dissolve close to the bed sediments and therefore reduced the chance for mid-water plankton to develop. Although increase in macrophyte growth was anticipated, the speed at which colonisation took place was faster than expected. The inability to drain the pool during the early years of the programme prevented the use of a fallow period to slow the spread of macrophytes. Plate 6.5 shows the pool following production of the algal bloom and Plate 6.6 the spread of macrophytes.

ii) Measurement of the Plankton

Plankton samples were collected in the same way as those from the river, but a detailed measurement of abundance was made for the Serpentine, as opposed to the simple measure of species presence or absence, as was undertaken in the river.

Although methods for counting plankton are often described as being applicable to both zooplankton and phytoplankton, much depends upon the size of the organisms being examined as to whether the same

Plate 6.5 Serpentine Lake Trial Site - With Algal Bloom

Plate 6.6 Serpentine Lake Trial Site - Macrophyte Dominance

techniques can be applied to both groups. In this study Sedgewick-Rafter cells were found to be convenient for measuring all samples. The slides measured 76mm x 26mm x 1mm and the counting chamber itself was 22mm in diameter and 4mm in depth with a volume 1.3cm^{-3}.

For phytoplankton, the litre sample was shaken until any sediment was uniformly suspended and then a pipette was used to quickly transfer a small amount of the suspension to fill the Sedgewick-Rafter cell, to which had been added a drop of Lugol's Iodine. This substance stained the algae to assist subsequent identification and counting. A cover slip was carefully lowered on to the cell and surplus liquid was removed with absorbant paper. Speed of preparation was important so that the organisms did not become concentrated in any particular area and thereby lead to biased estimates. Centrifugal distribution of organisms was minimized by holding the pipette at a large angle from vertical.

A Unilux-II, binocular microscope with a x4 lens and x10 eyepiece was then used to count the number of organisms in 10 fields of view, located approximately equidistantly along a radial transect of the cell. The number of single celled individuals were counted but, in the case of colonies or filamentous algae, the number of strands or groups was recorded. Results were expressed as algae cm^{-3}, after taking account of the area of the microscope field of view and the volume of the counting cell.

For zooplankton, a total count within the whole Sedgewick-Rafter cell was made with the assistance of a tally counter and as the same volumes were involved, the counts were recorded as animals cm^{-3}.

6.2.2.4 Control of Zooplankton

In order to limit the development of zooplankton, so that phytoplankton would continue to flourish and be available as food for the roach fry, selective removal by insecticide was pursued. Easton and Dolben (1980) had used insecticide for controlling zooplankton in the case of carp farming, but as roach are more susceptible than carp to toxic effects of chemicals (Alabaster and Lloyd, 1982), it was necessary to specifically calculate levels at which zooplankton would be selectively removed and the roach would survive.

Dipterex 80, with 80% active Trichlorphon was chosen for this purpose and laboratory screening procedures were adopted to establish the dosage that would be required in the trial pool. A variety of tests have been developed for acute toxicity of substances to fish over the years and several have become widely used, either as they were originally formulated or with slight variations. In the case of the trial pool the procedure adopted by the Polish Institute of Water Economy, Warsaw, (Alabaster and Lloyd (1982) was the most suitable because it was developed principally to test toxic effects on coarse fish, using test fish and water from the river catchment rather than artificially reared fish and prepared solutions.

Toxicity testing using manufactured solutions has advantages because the accuracy of results is not affected by the variable levels of salts that can occur in a natural watercourse. In these tests it was not necessary to follow such procedures because the purpose was to establish the effects in a single waterbody and not to provide data for universal application as an LC50 for the product.

Dipterex is highly soluble, so its application and mixing in test tanks was not a problem and dispersion could be quickly achieved by stirring. Two tests were undertaken, the first to establish the lethal concentration of the chemical to fish fry and the second to establish the concentration at which zooplankton were killed.

The apparatus consisted of six 20 litre tanks made from clear plastic and to each were added 15 litres of water from the trial pool. Both salmon and roach fry were used as test fish because, as salmonids are usually more susceptible to toxins than coarse fish (Alabaster and Lloyd, 1982), it provided a guide to the levels of toxicity in a more sensitive species and therefore an extreme case.

Ten similarly-sized fish of each species were chosen at random from batches that had acclimatised to the test medium for seven days. The average weight for salmon and roach was 2.0gm. Temperature is an important parameter in toxicity experiments because extremes can lead to undue stress and therefore seriously jeopardise the results. Salmonids have a narrower temperature tolerance than cyprinids, so in order to minimise thermal stress, water temperature had to be compatible for both species, so 14.5^{0}C was chosen. The dissolved oxygen level was also held close to 100% saturation by a controlled aeration system to each tank.

In deciding concentrations of the test substance, it was necessary to have a range which was spaced at logarithmic intervals so that at the higher end a complete mortality took place within 24 hours and at the lower end no mortality occurred during the extent of the trial. Taking account of manufacturers' specifications on sensitivities of other insects to Trichlorphon (Bayer UK Ltd, 1990), it was decided that the concentration range for the tests on fish should be 0.05, 0.5, 1.0, 5.0 and 50 mg.l^{-1} with the sixth tank being the control. With the separate tests for zooplankton, an extra 3 tanks were included into the toxicity range which then included 0.05, 0.5, 1.0, 5.0, 10.0, 50, 100 and 500 mg.l^{-1}.

Observations on the fish tanks were then taken at one hour intervals to the 6th hour and then every 6hrs to the 24th hour and then at daily intervals until the 4th day which was the completion of the trial.

In the case of the zooplankton, the trial period extended to 24 hours only, but with proportional intervals up to this limit.

Tests were undertaken during two separate phases of phytoplankton development, one at high density approximately 50x10^2.cm^{-3} and the other at low levels 2x10^2.cm^{-3}

6.2.3 Results

6.2.3.1 Roach fry development

i) Diet of Roach

Monthly water quality data for the Serpentine in 1989 is presented in Table 6.5.

Soon after dredging, in the first summer of operation of the Serpentine trial rearing area (1989), the available water space was clear of macrophytes and the fertilisation programme was effective in producing the food organisms that were required for the newly hatched juvenile roach, namely rotifers and algae (Table 6.6).

From Table 6.6, Fig 6.8 and 6.9 it can be seen that initially small round algae were consumed but as the phytoplankton bloom developed, rotifers numbers increased in the diet up to a level of 26% in July, then subsided in August and disappeared by September. From Fig 6.12 it can be seen that the algal proportion in diet was principally round algae and diatoms and not filamentous algae as in the river. Even with the eutrophication process through addition of nutrient fertilisers, the abundance of filamentous algae remained low. As with roach from the river, some small crustacean nauplii were consumed in June and chironomids seasonally in September. For chironomids the increase in the diet was a month later than for roach in the river, this may be associated with the change from mid-water feeding to a benthic dominated feeding regime.

In the river, the regular disturbance of the marginal substrates from recreational activities or influence of tidal intrusion brought detritus into suspension frequently and therefore it was regularly found in diet. In the Serpentine there was no such disturbance apart from occasional surface wave action from wind and therefore benthic substrates remained stable throughout. For fry to consume detritus and benthic organisms, they had to actively forage for them. The change in diet from August onwards coincided with a reduction of algae as a result of the increased dominance of zooplankton and therefore the change was likely to be

Table 6.5

Chemical Analysis

Serpentine Lake

1989

	pH	Cond	Temp	DO	DO	BOD	Ammonia	Nitrogen	Nitrate	Sus Solids	Chloride	Phosphate	Chloro a
		mmhos	%C	%	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	ug/l
January	7	314	3.2	60	7.1	2.4	0.2	0.6	0.02	22	37	0.1	3.1
February	7.5	452	7.3	56	6.7	2.7	0.1	0.4	0.01	37	56	0.1	3.9
March	7.3	348	7.5	85	8.8	2.9	0.5	0.1	0.02	105	43	0.1	37
April	7.3	329	9.2	91	10.5	6.8	0.2	1.4	0.04	45	38	0.1	6.3
May	7.7	483	19.1	90	8.2	3.7	0.8	1.9	0.6	10	49	0.8	2.2
June	7.7	462	18.8	69	6.4	5.5	0.03	<0.1	0.02	46	53	0.6	65.5
July	8	499	18.6	37	3.4	5.3	0.06	<0.1	0.01	56	53	1.3	42.5
August	8	496	16.5	41	4	6.6	0.23	<0.1	0.01	98	55	0.8	53.3
September	7.8	489	17.5	95	9.1	3.9	0.18	<0.1	0.02	34	52	0.4	38.5
October	7.5	536	11.7	36	3.9	2.8	0.08	0.05	0.02	26	70	0.3	22.1
November	7.3	472	8.4	21	2.4	2.2	0.04	0.07	0.01	9	45	0.2	3.5
December	7.5	506	3.1	59	7.9	2.5	0.12	0.05	0.02	23	67	0.2	16.3

Table 6.6

Serpentine Lake

% Food items in diet of Roach

			1989						1991		
	June	July	August	Sept	Oct		June	July	August	Sept	Oct
Rotifers	6	26	18.7				6.7	65	4.5		
Algae	83	49	36.3	4	11		11.7	8	6	5.5	5.5
Chironomids	5	2		19			16.6	20	29	25	5
Crustacea	2			19.5				6	8	8	3
Detritus	2	3	42.5	57.5	81		30		46.5	48.5	71
Terrestrial Insects	2	20			2.5					4	10
Plant Material			2.5		5.5		35		6	9	5.5
Other								1			

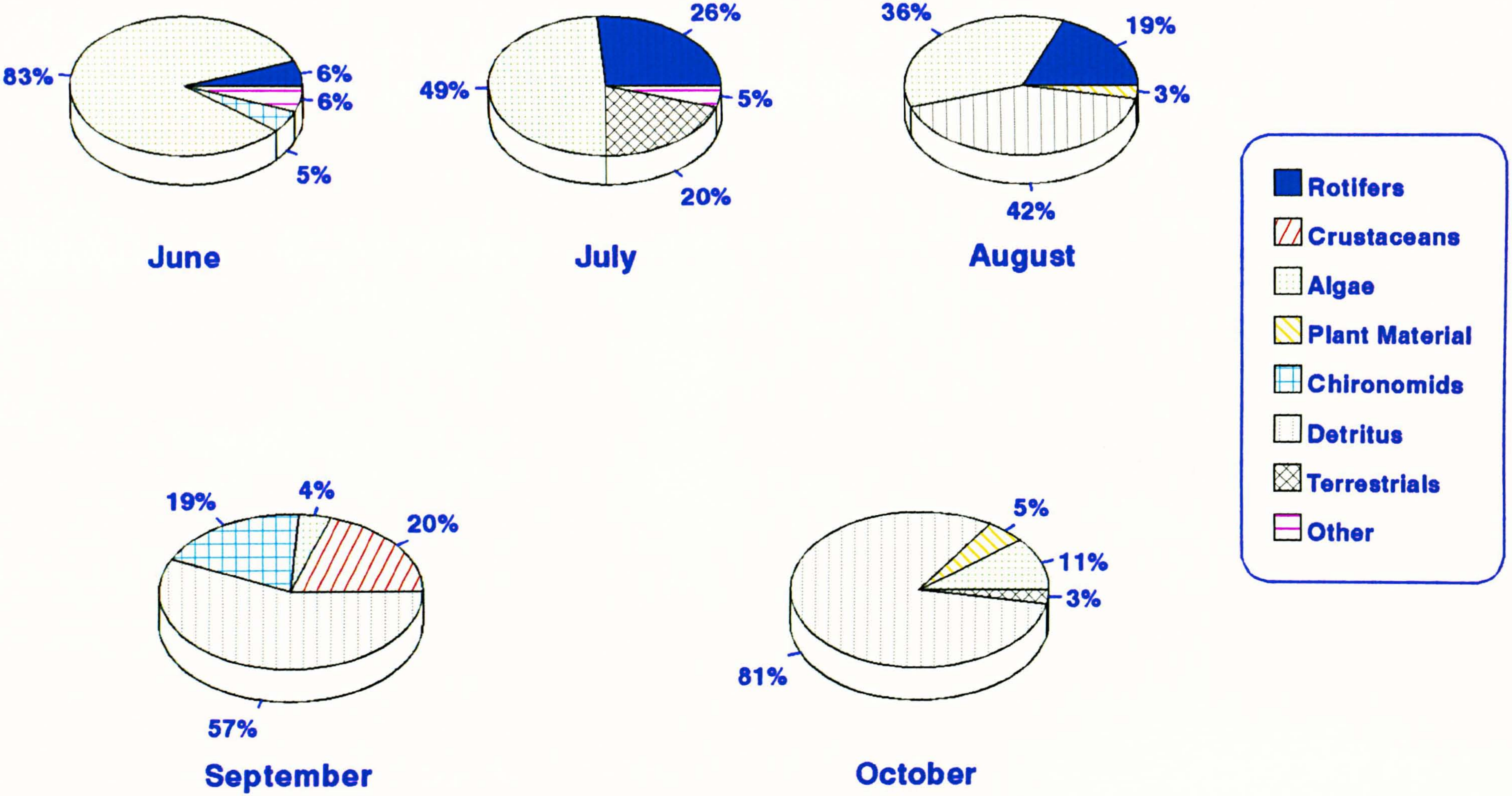
% Plant based constituents in diet

	June	July	August	Sept	Oct		June	July	August	Sept	Oct
Algae (Round)	100	80	77	12.5	67		25	100	25	14	36
Algae (Filamentous)		4									
Diatoms		16	16	87.5					25	24	14
Plant Material			7		33		75		50	62	50

Diet of Roach Fry

Serpentine Lake - Summer 1989

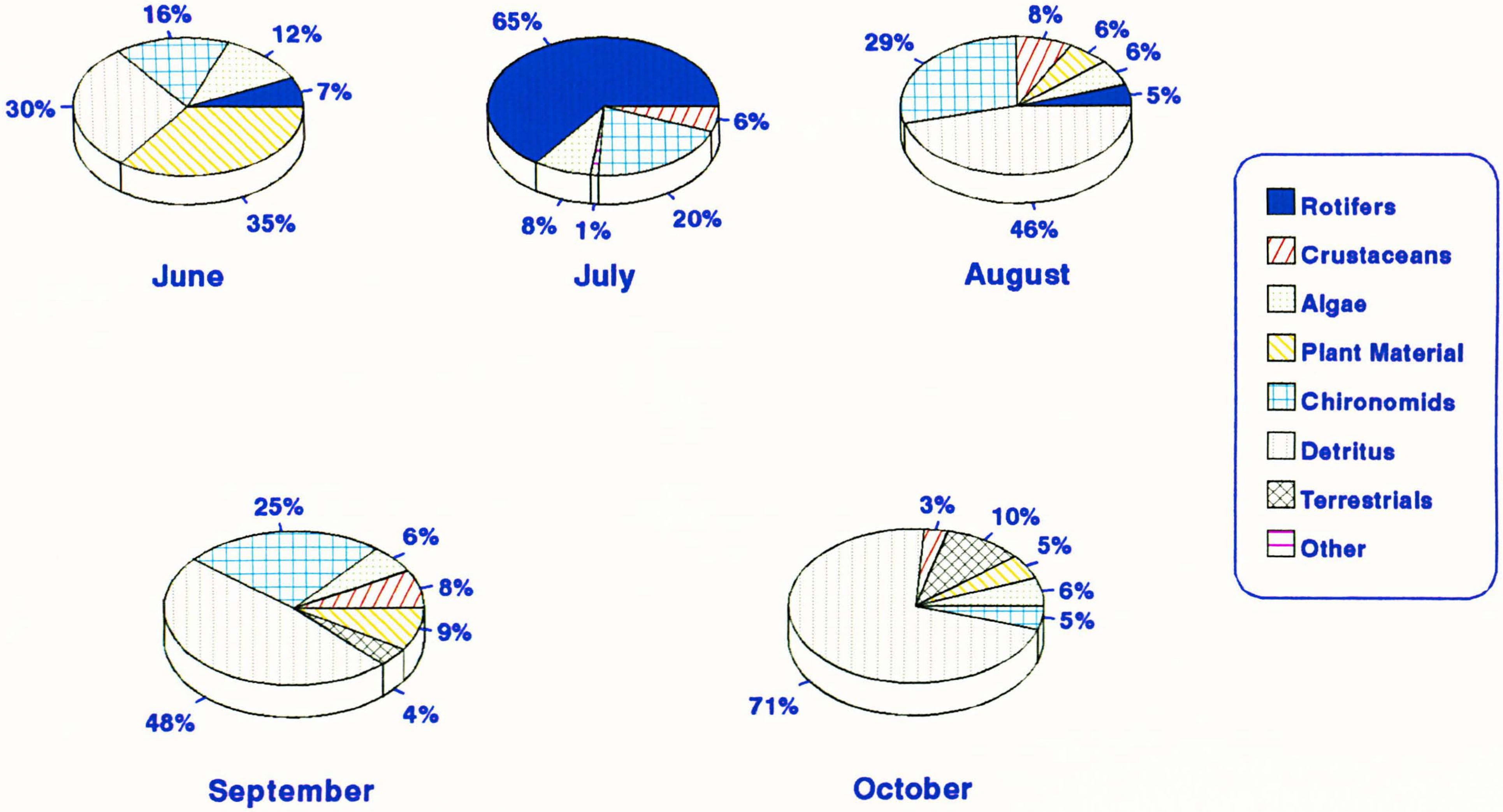
Fig 6.8



Diet of Roach Fry

Serpentine Lake - Summer 1991

Fig 6.9



dictated by a reduction in the preferred diet choice. The continued presence of crustaceans showed that some feeding took place within the water column, which may have been temperature or light related, according to weather conditions. This is because fry were frequently observed close to the surface when it was sunny and warm but disappeared during cool cloudy periods. Zooplankton represented only 20% of the diet at this time, even though it was very abundant and therefore the fish were either not actively seeking zooplankton or the fry were of insufficient size to take the prey consistently.

The second year that fry were produced in 1991 coincided with a period when macrophyte growth had become extensive and this resulted in an almost total failure to produce phytoplankton by fertilisation. Moss and Leah (1982) described the ecological successive changes that can develop within the water column in respect of plankton and de Nie (1986) described the way macrophytes can influence these changes. He stated that macrophytes increased shade, stripped out nutrients from the water column and encouraged predatory epiphytes on the vegetation created, which grazed on the phytoplankton. It is likely that this combination restricted the phytoplankton development in the Serpentine and limited the available food supply to newly hatched fry. The presence of rotifers suggests their development may not have been affected but the low abundance of algae indicates that the fry had to seek an alternative food source. Earlier grazing of benthos in 1991 than occurred in 1989 was shown by the presence of both detritus and chironomids from June onwards. This bottom feeding regime was maintained throughout the summer with continued minimal levels of mid water organisms being recorded. It was noticeable that a greater range of dietary choices were made in 1991 to that in 1989 and therefore the restricted development of phytoplankton may have influenced them to become more omnivorous.

ii) Growth of Roach

From Table 6.7 and Fig 6.10 the mean growth in length of roach fry was progressive and similar in both 1989 and 1991 but the mean weight gain (Table 6.7 and Fig 6.11) was not so consistent throughout the first summer of 1989. This may be because a change from predominantly algal

Table 6.7

Lake Serpentine
Roach Fry Development

1989/90

Date of Sample	31st May	8th June	22nd Jun	4th July	20th July	10th Aug	25th Aug	9th Sept	25th Sept	12thOct	19thJan	22nd Mar	22nd May
Fish Length mm (mean)	10.04	12.24	15.33	19.18	22.62	22.46	32.44	32.92	30.08	32.17	41.82	44.47	54.19
Fish Weight gm (mean)	0.0073	0.02	0.0312	0.0695	0.1149	0.1291	0.4034	0.3739	0.2566	0.3494	1.0212	0.9084	1.8726
Condition Coefficient	0.72	1.09	0.87	0.98	0.99	1.14	1.18	1.05	0.94	1.04	1.4	1.03	1.18
Mean Daily Weight Increase %		12.04	3.08	6.27	1.53	0.55	6.85	-0.52	-2.32	1.81	0.99	0.19	1.14
Stomach Fullness (%)		38	41	29	50	36	70	46	22	35	41	25	49
Food Volume (cu mm^{-1})		0.456	1.587	1.322	1.284	1.445	6.196	2.856	3.23	2.21	6.596	7.771	6.573
Food Volume/gm of Fish		19.41	49.8	18.17	13.14	11.3	16.01	11.34	12.94	6.13	6.6	6.99	3.64

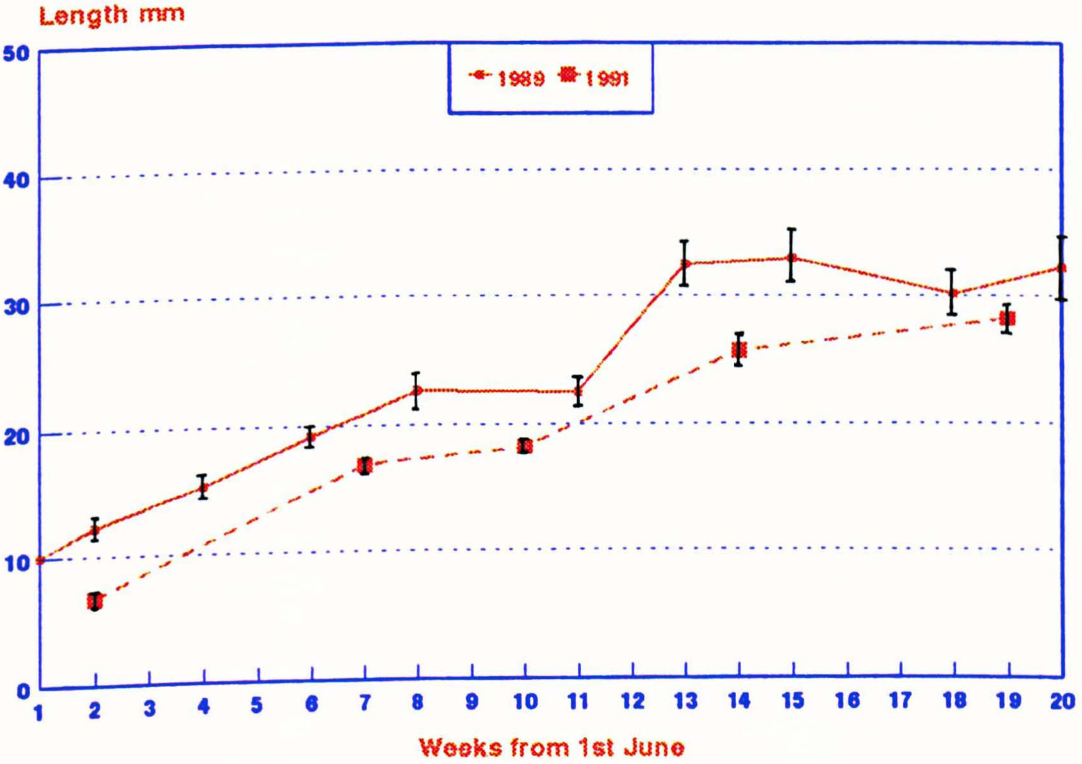
1990/91

Date of Sample	5th June	10th July	2nd Aug	2nd Sept	7th Oct	17th Jan	24th Mar
Fish Length mm (mean)	6.78	16.87	18.21	25.57	28.14	38.97	36.5
Fish Weight gm (mean)	0.0018	0.0477	0.0719	0.1553	0.2532	0.7025	0.53443
Condition Coefficient	0.58	0.99	1.19	0.93	1.14	1.19	1.1
Mean Daily Weight Increase %		5.26	1.74	2.36	1.37	0.92	0.41
Stomach Fullness (%)	5	60	31	39	37	36	31
Food Volume (cu mm^{-1})	0.068	0.907	1.284	2.754	2.584	8.636	4.21
Food Volume/gm of Fish	45.3	18.52	17.55	17.65	10.29	12.83	12.19

Lake Serpentine

Growth in Length of Roach Fry

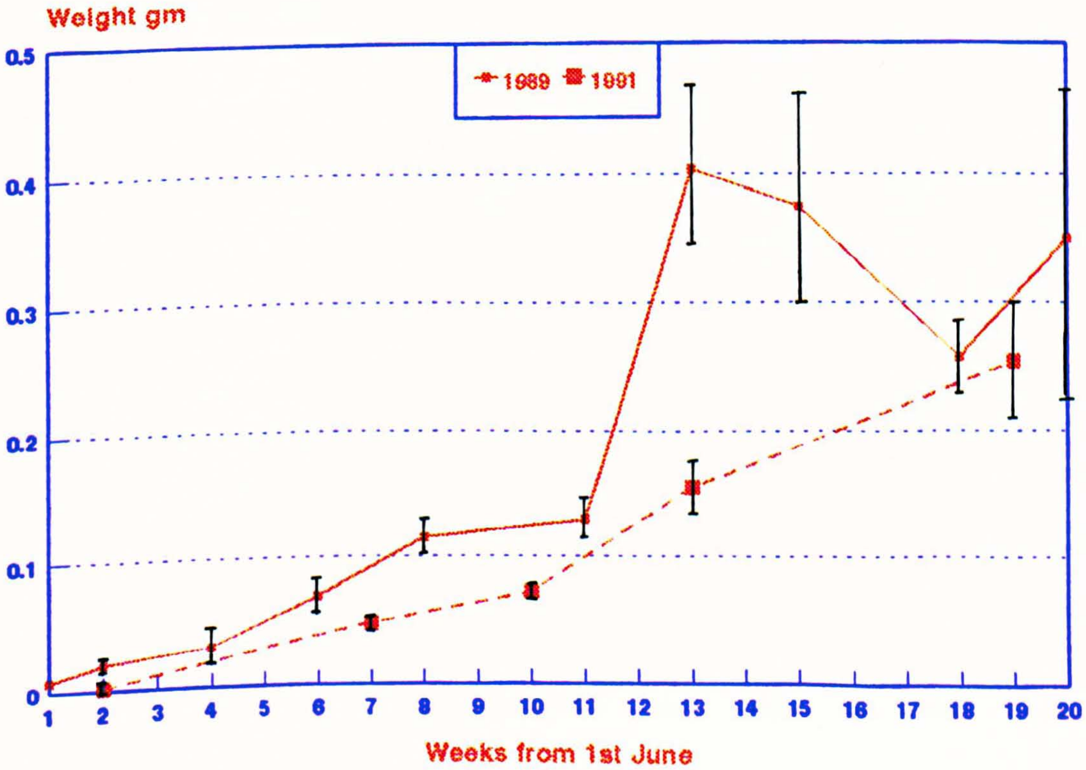
Fig 6.10



Lake Serpentine

Growth in Weight of Roach Fry

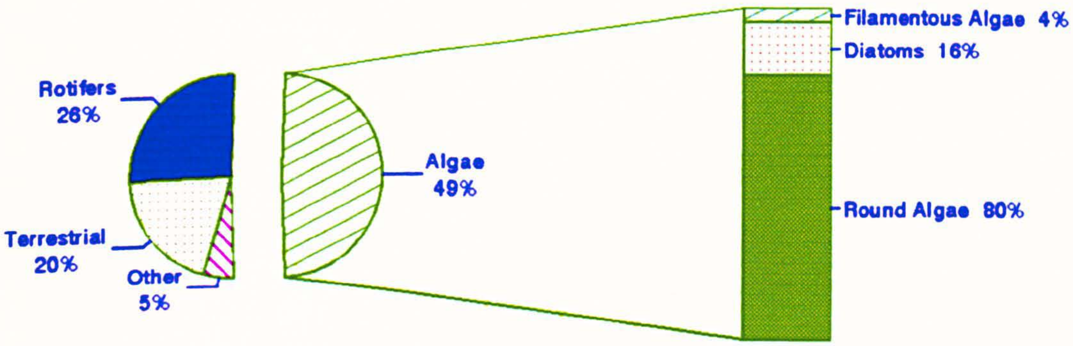
Fig 6.11



Food of Lake Serpentine Roach

Showing Algal Ratio

Fig 6.12

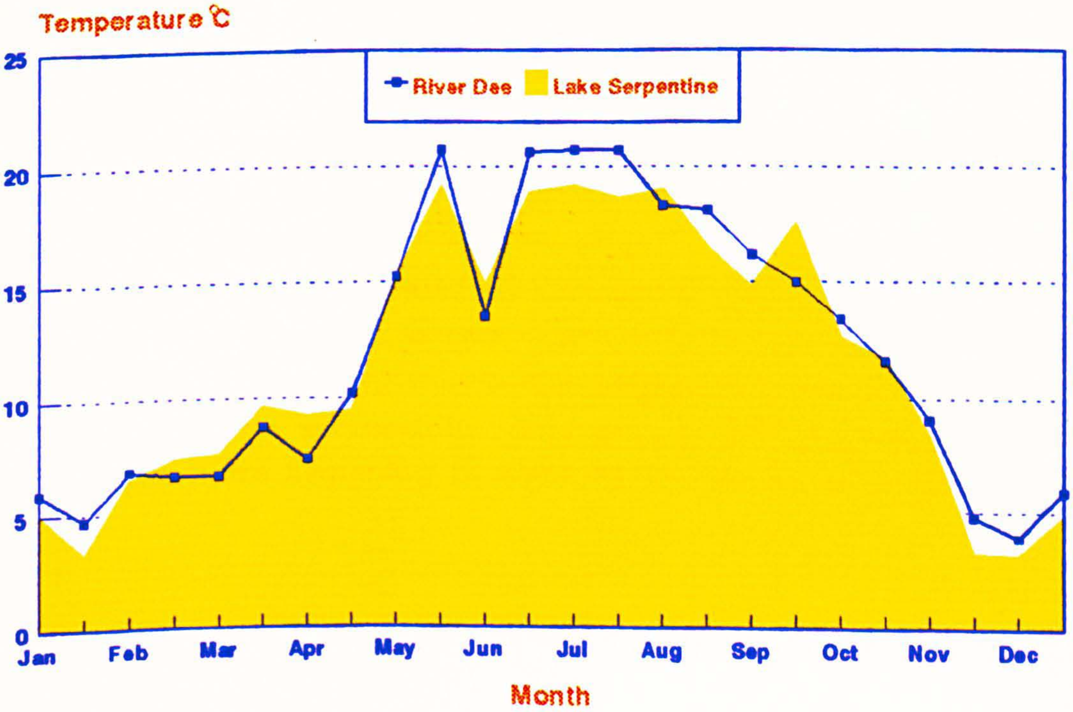


July 1989

Water Temperature Comparisons

River Dee / Lake Serpentine

Fig 6.13



diet to a chironomid diet in September resulted in a rapid increase in weight gain. The periodicity of chironomid presence and the shortage of benthic substrates, following dredging in April 1989, meant that this food source probably soon became depleted and, because algae had also been replaced by zooplankton, the gains made were lost during October. In 1991 both length and weight gain progressively increased throughout the summer. Despite the variation in weight that took place in 1989, the mean size of fry achieved at the end of the summer was similar both in length and in weight in the two years, this being approximately 30mm in length and 0.25gm in weight.

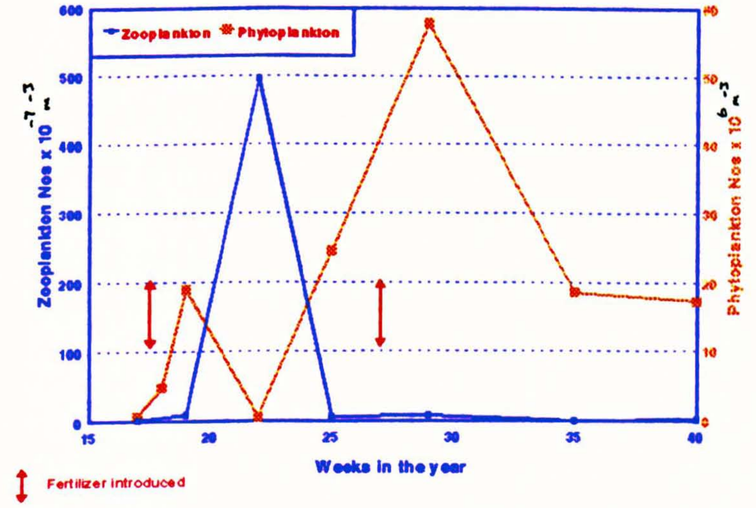
6.2.3.2 Phytoplankton Production

From Fig 4.12 it can be seen that sunshine levels in May and June were much higher in 1989 and 1990 than in 1991. The effect in these two years was to stimulate an algal bloom within a few days, which was principally made up of euglenoids and small round algae, together with rotifers.

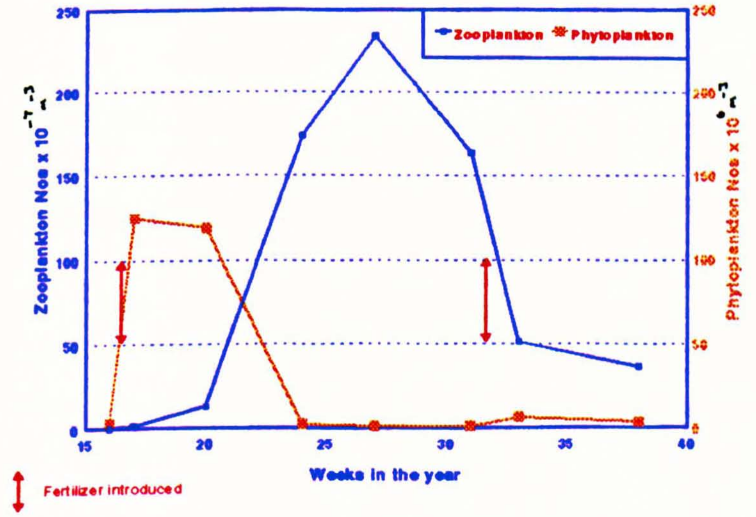
This was just prior to the build up of the zooplankton population which was predominantly cladocera. There were also some copepods which started grazing on the phytoplankton, which, by this stage had a preponderance of 50um sized individuals. Rotifers feed on organisms < 100 um^{-1} in size (Lund, 1965) and consequently were the first to actively graze on the phytoplankton. Unfortunately the cladocerans and copepods, which feed on a wide range of organisms (Reynolds, 1984), quickly consumed the available population of rotifers and continued to deplete the phytoplankton.

It can be seen from Fig 6.14 that in 1989 the fertilisation process was successful in producing a phytoplankton bloom within one week of introduction following warm weather (Fig 6.13), but the bloom was relatively brief as zooplankton started to dominate. In an attempt to re-create the algal bloom, a second injection of inorganic fertilizers was introduced after the zooplankton had subsided and in 1989 an increase in phytoplankton was successfully achieved. In 1990 by mid summer macrophytes were beginning to dominate and no second bloom resulted

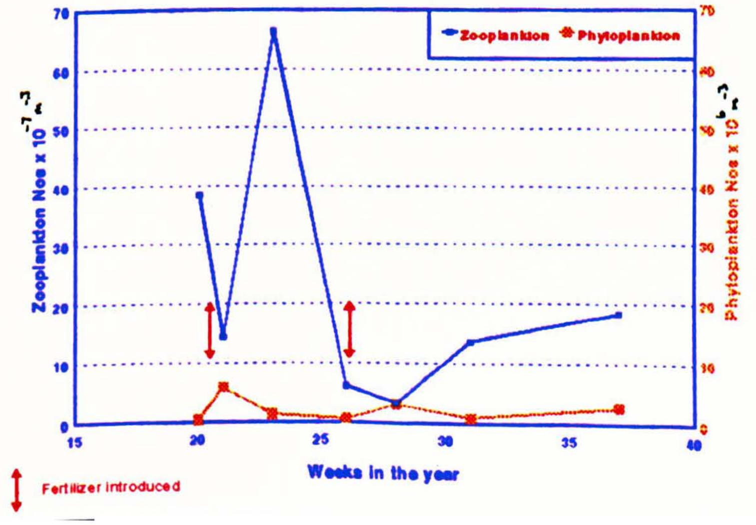
Lake Serpentine - Plankton Shifts 1989 Fig 6.14



Lake Serpentine - Plankton Shifts 1990 Fig 6.15



Lake Serpentine - Plankton Shifts 1991 Fig 6.16



(Fig 6.15). Even selected clearance of vegetation failed to stimulate a second phase bloom of phytoplankton. In the third year (Fig 6.16) both the first phase and the second phase failed and by this time the trial area was dominated by macrophytes.

In 1992, the final year of observations, macrophytic colonisation had subsided to pre-1990 levels after the withdrawal of fertilising procedures. No phytoplankton other than diatoms developed, but these were at levels $<3x10^2cm^{-3}$. Visual observations indicated that there was a preponderance of zooplankton, especially cladocerans, but this time the populations more localised, rather than dispersed throughout the water column.

Size-selective grazing can be used to control the sizes of phytoplankton bloom in a water body (Porter, 1973), but in this case the requirement was to produce a large population of phytoplankton so that it would be available to be exploited by the juvenile roach. The programme using natural development of planktonic organisms did not achieve stability of the required species.

6.2.3.3 Zooplankton Control

i) Toxicity of fish fry to Trichlorphon.

Details of the trials are given in Tables 6.8 and 6.9 and as had been anticipated in both sets of trials, salmon fry were more susceptible to the toxin Trichlorphon than roach fry, but at lower concentrations both species were unaffected.

In the case of salmon, concentrations 1.0 $mg.l^{-1}$ and greater were lethal within the trial period, but when phytoplankton was low, total susceptibility was observed down to a concentration of 0.5 $mg.l^{-1}$, with a single fish succumbing at 0.05 $mg.l^{-1}$.

In the case of roach, only 50 $mg.l^{-1}$ caused a total mortality but at 5 $mg.l^{-1}$ there was some mortality towards the end of the trial period, when phytoplankton was sparse.

Toxicity of Fish Fry to Dipterex (Trichlorphon)

Fry in Medium without Algae

Table 6.8

	Conc					
Time	0.05mg/l	0.5mg/l	1mg/l	5mg/l	50mg/l	Control
1 Hour	0	0	0	0	0	0
2Hours	0	0	0	0	0	0
3 Hours	0	0	0	0	0	0
4 Hours	0	0	0	0	0	0
5 Hours	0	0	0	0	0	0
6 Hours	0	0	0	1 Salmon	5 Salmon	0
12 Hours	0	0	0	2 Salmon	5 Salmon	0
18 Hours	0	0	0	3 Salmon	0	0
24 Hours	0	0	0	3 Salmon	0	0
48 Hours	1 Salmon	10 Salmon	9 Salmon	1 Salmon	10 Roach	0
				2 Roach		
96 Hours	0	0	1 Salmon	1 Roach	0	0
Survival	9 Salmon	0 Salmon	0 Salmon	0 Salmon	0 Salmon	10 Salmon
	10 Roach	10 Roach	10 Roach	7 Roach	0 Roach	10 Roach

Temperature 14.5° C

Fry in Medium with Algae

Table 6.9

1 Hour	0	0	0	0	0	0
2 Hours	0	0	0	0	0	0
3 Hours	0	0	0	0	3 Salmon	0
4 Hours	0	0	0	0	0	0
5 Hours	0	0	0	0	7 Salmon	0
6 Hours	0	0	0	0	0	0
12 Hours	0	0	0	6 Salmon	0	0
18 Hours	0	0	0	4 Salmon	0	0
24 Hours	0	0	4 Salmon	0	0	0
48 Hours	0	0	6 Salmon	0	7 Roach	0
96 Hours	0	0	0	0	3 Roach	0
Survival	10 Salmon	10 Salmon	0 Salmon	0 Salmon	0 Salmon	10 Salmon
	10 Roach	10 Roach	10 Roach	10 Roach	0 Roach	10 Roach

Temperature 14 ° C

ii) Toxicity of zooplankton to Trichlorphon.

Results for the zooplankton trial are given in Table 6.10 and show that high concentrations of Trichlorphon quickly eliminated all species of zooplankton. At moderate dosages, the time lag was longer but at 5.0 and 1.0 mg.l^{-1} the kill was complete within 3 - 6 hours of introduction. With lower dosages there were slight changes at the end of the trial period at 0.5 mg.l^{-1}, but the reduction of zooplankton was so slight that other factors, such as natural losses etc, may have been starting to influence the experiment.

Table 6.10

Zooplankton Control

Treatment with Dipterex (Trichlorphon) with few algae present

Showing % Survival after Treatment

	Concentration of Dipterex								
	0.05mg/l	0.5mg/l	1.0mg/l	5.0mg/l	10.0mg/l	50mg/l	100mg/l	500mg/l	Control
Time									
15 min	100%	100%	100%	100%	100%	100%	100%	100%	100%
30 min	100%	100%	100%	60%	100%	10%	0%	0%	100%
60 min	100%	100%	100%	10%	0%	0%	0%	0%	100%
90 min	100%	100%	50%	0%	0%	0%	0%	0%	100%
2 hours	100%	100%	10%	0%	0%	0%	0%	0%	100%
3 hours	100%	100%	0%	0%	0%	0%	0%	0%	100%
6 hours	100%	100%	0%	0%	0%	0%	0%	0%	100%
12 hours	100%	60%	0%	0%	0%	0%	0%	0%	100%
24 hours	100%	0%	0%	0%	0%	0%	0%	0%	100%

6.2.4 Discussion

The growth rate achieved for roach by the end of the first summer, in the protected environment of Serpentine Lake, was lower than for the River Dee in both the years the experiment was undertaken and was about the same as was achieved in the river in the cool year of 1986. 1989 was a very warm summer, comparable with the previous drought years of 1984 and 1976, and therefore it would be expected that the most advantageous conditions that could possibly be accomplished in the river, to give good fry growth rates were likely to be experienced in such warm summers. Mann (1991) has suggested that a positive correlation exists between water temperature in the year of hatching and the strength of year class. The better growth rate in the river, compared to the Serpentine in 1991, would however indicate that the rearing regime in the latter was deficient in creating larger roach fry by the end of the first summer.

Several problems have been highlighted in trying to effect the most advantageous feeding regime for juvenile roach and as the Serpentine is a natural system, these problems may be difficult to overcome. It had been expected that the temperature in the trial area could have been maintained at a higher level than that for the river and therefore allow a more favourable ecological regime to develop, which would benefit the growth of roach fry. It can be seen from Fig 6.13 that in the summer of 1989 the water temperature of the Serpentine was not appreciably warmer than the river. The level of shading that was present on the lake was believed to be the main problem, but because this was caused by mature trees it could not be avoided because of restrictions on felling.

The requirements to develop and retain the phytoplankton phase, prevent the zooplankton phase and restrict the growth of macrophytes are the opposite to those usually required for management purposes. Invariably it is the phytoplankton stage, influenced from eutrophication, which is out of balance and needing to be controlled, so that the development of aquatic invertebrates and growth of macrophytes can be achieved (Moss, 1977). The Serpentine is not naturally eutrophic and therefore fertilisation needed to be undertaken to create a phytoplankton bloom.

The maintenance of the phytoplankton bloom was difficult to achieve and therefore sustaining a natural food source, on which the roach could feed and develop, was problematical. In the trial area, natural grazers on zooplankton were absent, apart from some perch fry, which would not only reduce the zooplankton but would also heavily predate on the roach. In less productive water systems Persson (1988) has suggested that with an increase in submerged macrophytes and their attached macroinvertebrates, perch have a higher foraging efficiency than roach and therefore perch may be more easily reared in this type of environment.

Laboratory trials were undertaken to establish a concentration at which the insecticide Trichlorphon could be used to selectively remove zooplankton but would not be toxic to roach fry. It was considered that this would enable phytoplankton populations to continue to increase and provide a greater food source for juvenile roach following fertilisation of the water. The results revealed that $1 mg/l^{-1}$of Trichlophon was successful at killing the zooplankton and roach fry were not affected. Although the test offered an opportunity to selectively remove the zooplankton within the trial pool, this was not attempted because the Serpentine discharges to the River Dee and containment of the insecticide could not have been guaranteed. Consequently there were inherent risks to water quality conditions in the river and to water abstracted for public supply. The trials however provided the information for application in a more appropriate offstream recruitment area.

To obtain maximum growth in roach, in excess of that in the river, phytoplankton needs to be available from the earliest stages and as Weatherley (1985) stated that algae also contributed significantly to the diet of roach over their first winter, then this position needed to be continued beyond the summer. The natural ecosystem within such an area as the Serpentine does not allow algal dominance to take place because of the development of seasonal succession of micro-organisms. Such successions in waterbodies have been variously described by Reynolds (1984).

Therefore to establish whether an alternative food regime could be used to achieve more favourable and consistent growth rates of roach fry in the Serpentine, an alternative feeding programme was explored at a site where a controlled experiment could be undertaken.

6.3 Bretton Experimental Fry Rearing Scheme

6.3.1 Introduction

It has been shown that within a natural system, the creation of suitable food for fry is extremely difficult to achieve because of fluctuations in food organisms resulting from variations in life cycle, changes in dominance and the influence of climatic conditions.

In the development of roach fry in the Dee, it has been shown that filamentous algae were a principle component of diet but, depending on size of fish and time of year, other food items were found to be important. Easton and Dolben (1980) showed that rotifers were a necessary food constituent of first feeding fry, before the larger algal cells could be tackled. Northcote (1979) found cladocera increasingly present as copepods reduced in number. Therefore to achieve satisfactory growth of fry in a natural environment in the first summer, a range of food items need to be available at the different fry sizes. To create optimum growth, however, it is not only the food source that is important but environmental conditions and population size are also involved and a regime which controls most of the factors is following fish farming practices. In this study it was not intended to take this approach but the adoption of a controlled feeding programme, as an addition to the Serpentine trial area, was considered worthy of experimental trials.

Alternative feeding regimes, by the use of trout food as a substitute for the natural sources, was therefore explored. A trial was undertaken at a nearby water supply works at Bretton, to assess growth rates of first year roach fry under different feeding regimes.

6.3.2 Method

In June 1988, 12 temporary trial pools, measuring 2 m^{-2} by half a metre deep, were constructed using hay bales lined both above and below with plastic sheeting. This arrangement was pursued as it was a cheap option, costing less than £100 and also it was quick and easy to construct. The hay bales had to be screened from the weather in order to slow natural decomposition. With care and with the replacement of the occasional bale, two summer trials were completed.

Once constructed, the pools were filled with chlorinated mains water and allowed to stand for several days. Samples were removed and analysed to establish that the chlorine had evaporated. Random selection for feeding treatment took place in each of the 12 pools during consequative summers ie 1988 and 1989.

The treatments were as follows:

3 pools with fertilisation;
3 pools with trout food application;
3 pools with fertilisation and trout food application;
3 pools acting as controls, ie no treatment.

Fertilisation of the appropriate pools consisted of 20 $gm.pool^{-1}$ of a mixture of 60% ammonium sulphate fertiliser and 40% superphosphate, applied every two weeks from June to September.

Trout food applications were by a 24 hour clockwork feeder at $25gm.day^{-1}$, using Size 00, the smallest pellet available from BP Nutrition.

In July 1988 fifty 0+ roach fry were transferred to each pond from a neighbouring water body, but in 1989 a sample of the newly hatched roach fry from East Anglia, acquired for the Serpentine scheme, were used. Predation of the fish was avoided by draping micromesh netting over each pool. 10 fish were removed from each pool, at monthly intervals, for assessments on growth.

6.3.3 Results

It can be seen from Table 6.11 that roach acquired in 1988 were older and larger than the fry obtained for 1989. This was because of the favourable conditions in the supply pond from which they were collected. The results are graphically displayed in Fig 6.17-6.20 and it can be seen that there was a consistent difference between the different feeding regimes. The combination of fertilised pools with a feeding programme was the most advantageous for the larger fry in 1988, with the weight gain being almost 2gm more than other feeding regimes by the end of the summer. In 1989 the difference between feeding regimes was not large (5mm,0.25gm). The controls in both years operated effectively with minimal growth taking place.

To assess the significance of the feeding regimes an Analysis of Variance statistical test was applied to the data. The results are presented in Figs 6.21 and 6.22.

6.3.4 Discussion

The results revealed that faster growth could be achieved in roach fry during an intensive feeding programme, compared to that achieved in the river and Serpentine lake. All feeding regimes produced fry with better growth in both length and weight, which had been expected on account of the more favourable feeding regime and environmental conditions in each shallow pool. The aim, however, was to establish if the use of trout pellet food produced favourable growth rates and how this compared with natural foods under optimum conditions. The results revealed that in both years the best feeding regime was the combination of the two, but in the comparison of the natural food production and the pellet food with the larger fish, there was little difference. In 1989 pellet food produced slower growth to natural food but it is likely that initially the pellet size was too large for the small fry to consume. High sunshine levels in August 1989 (Fig 4.12) provided favourable conditions for algal development which possibly also favoured a diet of natural food.

Table 6.11

Bretton Pools

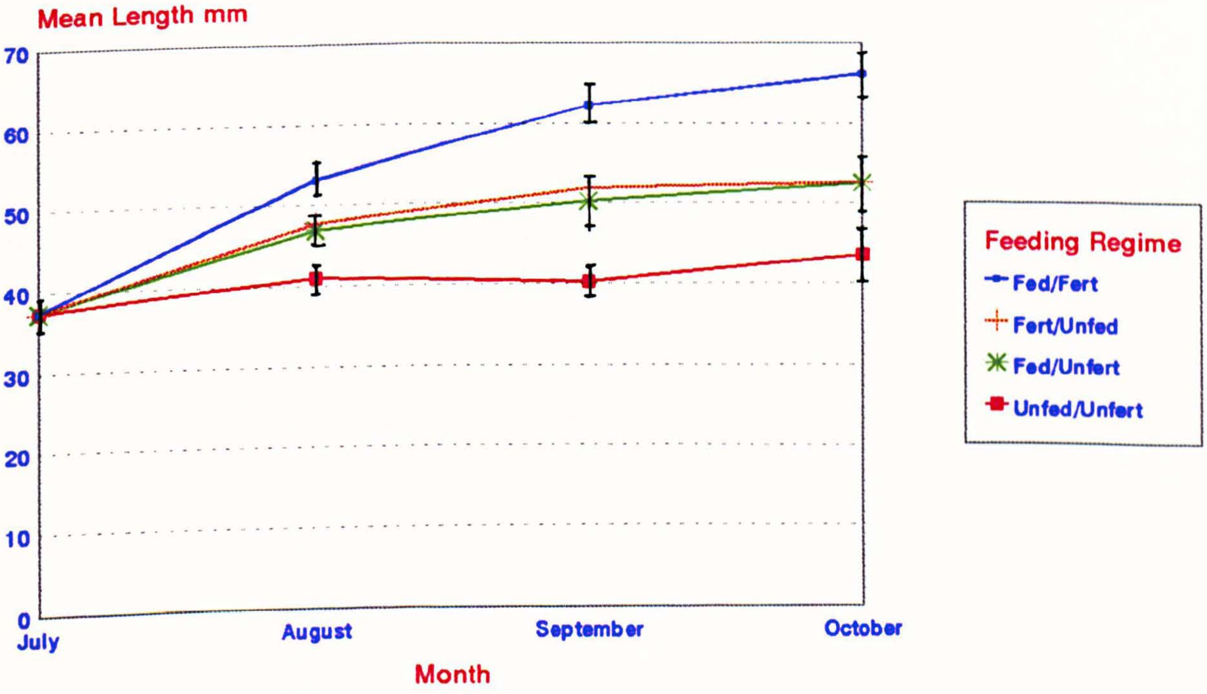
Roach Fry Feeding Experiment

	1988						1989					
	Length(mm)			Weight (gms)			Length (mm)			Weight (gms)		
	High	Low	Mean	High	Low	Mean	High	Low	Mean	High	Low	Mean
Fed and Fertilised												
June									7.4			
July			37.4			0.518	41.9	21.7	29.5	0.195	0.11	0.153
August	54.6	51.5	53.1	2.045	1.624	1.838	43.3	40.9	41.9	0.771	0.514	0.613
September	65.3	58.9	62.2	3.475	2.661	3.101	56.4	52.9	53.4	1.92	1.645	1.776
October	67.8	62.9	66.1	3.949	2.765	3.49						
Unfed and Fertilised												
June									7.4			
July			37.4			0.518	26.1	20.5	24	0.264	0.094	0.165
August	51.4	45.1	47.6	1.73	1.022	1.28	42.7	41.7	42.3	0.691	0.559	0.624
September	59.1	46.9	51.8	2.655	1.197	1.753	55.9	48.7	52.3	1.913	1.499	1.683
October	57.8	49.3	52.6	2.148	1.317	1.625						
Fed and Unfertilised												
June									7.4			
July			37.4			0.518	25.9	21.5	23.2	0.204	0.144	0.168
August	48.8	45.4	46.8	1.341	1.127	1.204	38.7	32.4	34.6	0.344	0.117	0.243
September	54.9	47.3	50.2	2.12	1.342	1.624	48.3	47.1	47.5	1.694	1.209	1.465
October	54.1	51.3	52.5	1.877	1.529	1.701						
Unfed and Unfertilised												
June									7.4			
July			37.4			0.518	24.9	13.2	19.1	0.19	0.107	0.134
August	41.9	39.8	41	0.797	0.659	0.728	27.3	13.5	20.3	0.088	0.059	0.065
September	41.3	39	40.2	0.837	0.573	0.672	38.3	12.2	25.2	0.193	0.128	0.17
October	49.1	38.5	43.5	1.394	0.585	0.921						

Growth Rate in Roach Fry - Length

1988 Bretton Pools Feeding Programme

Fig 6.17

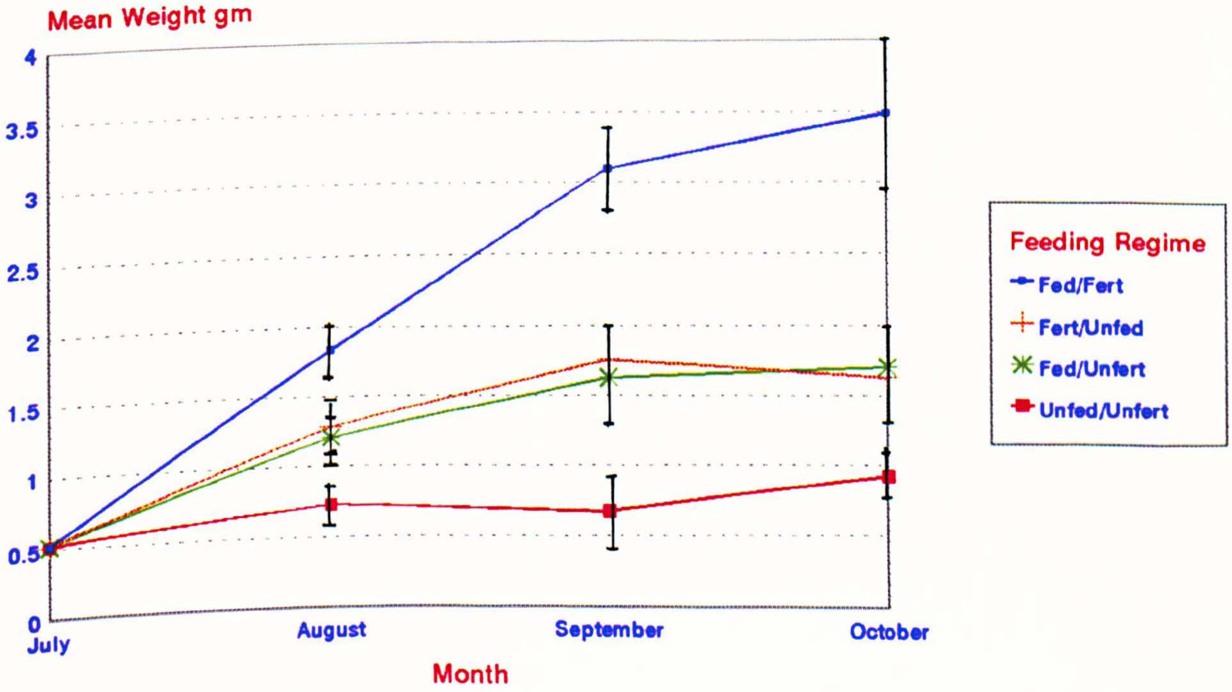


Large Fry introduced on 18th July

Growth Rate In Roach Fry - Weight

1988 Bretton Pools Feeding Programme

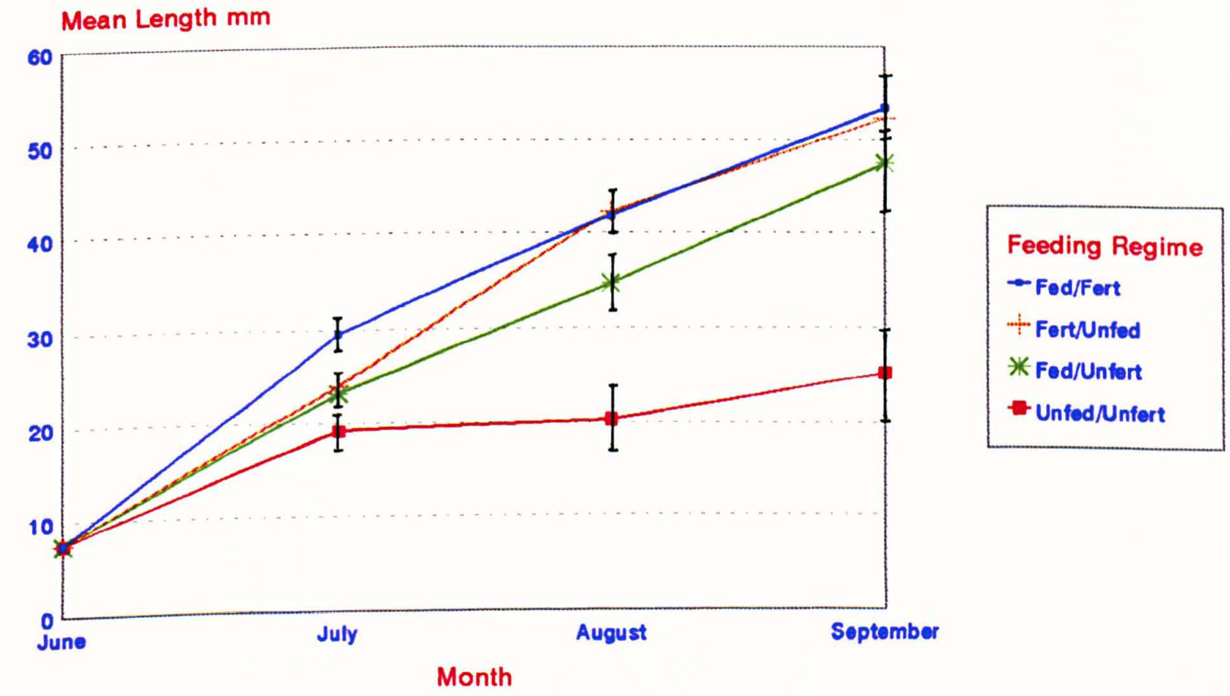
Fig 6.18



Large Fry introduced on 18th July

Growth Rate in Roach Fry - Length
1989 Bretton Pools Feeding Programme

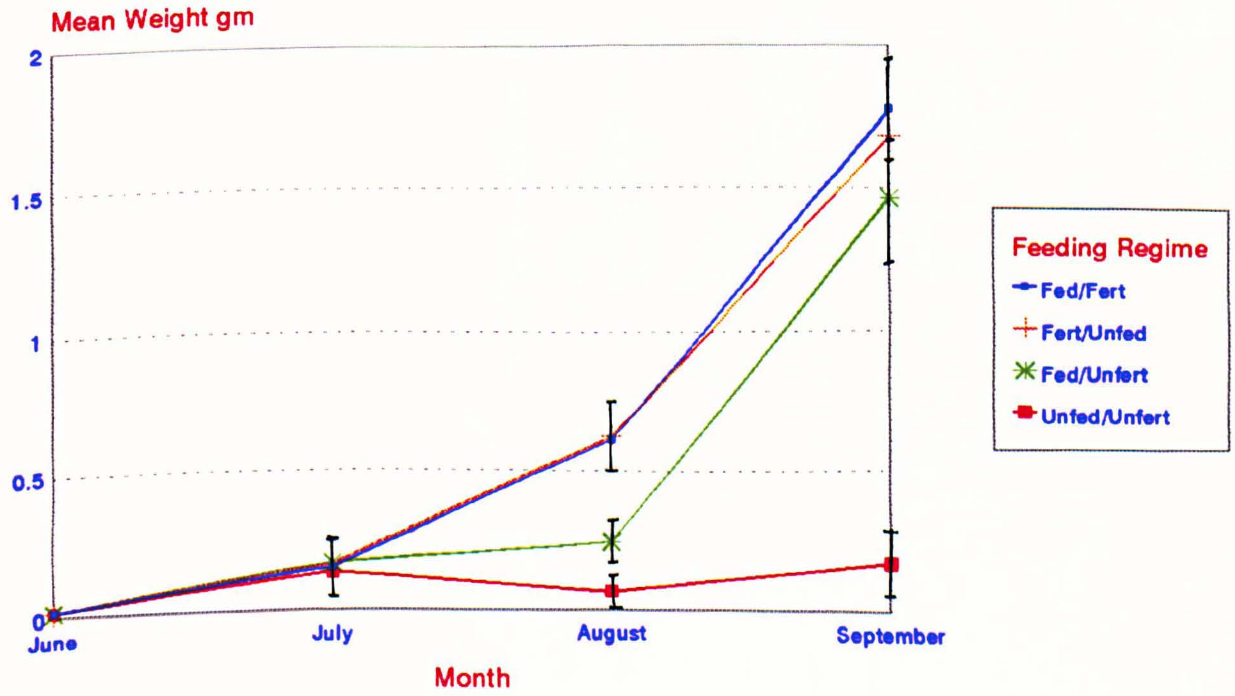
Fig 6.19



Newly hatched fry introduced on 6th June

Growth Rate in Roach Fry - Weight
1989 Bretton Pools Feeding Programme

Fig 6.20

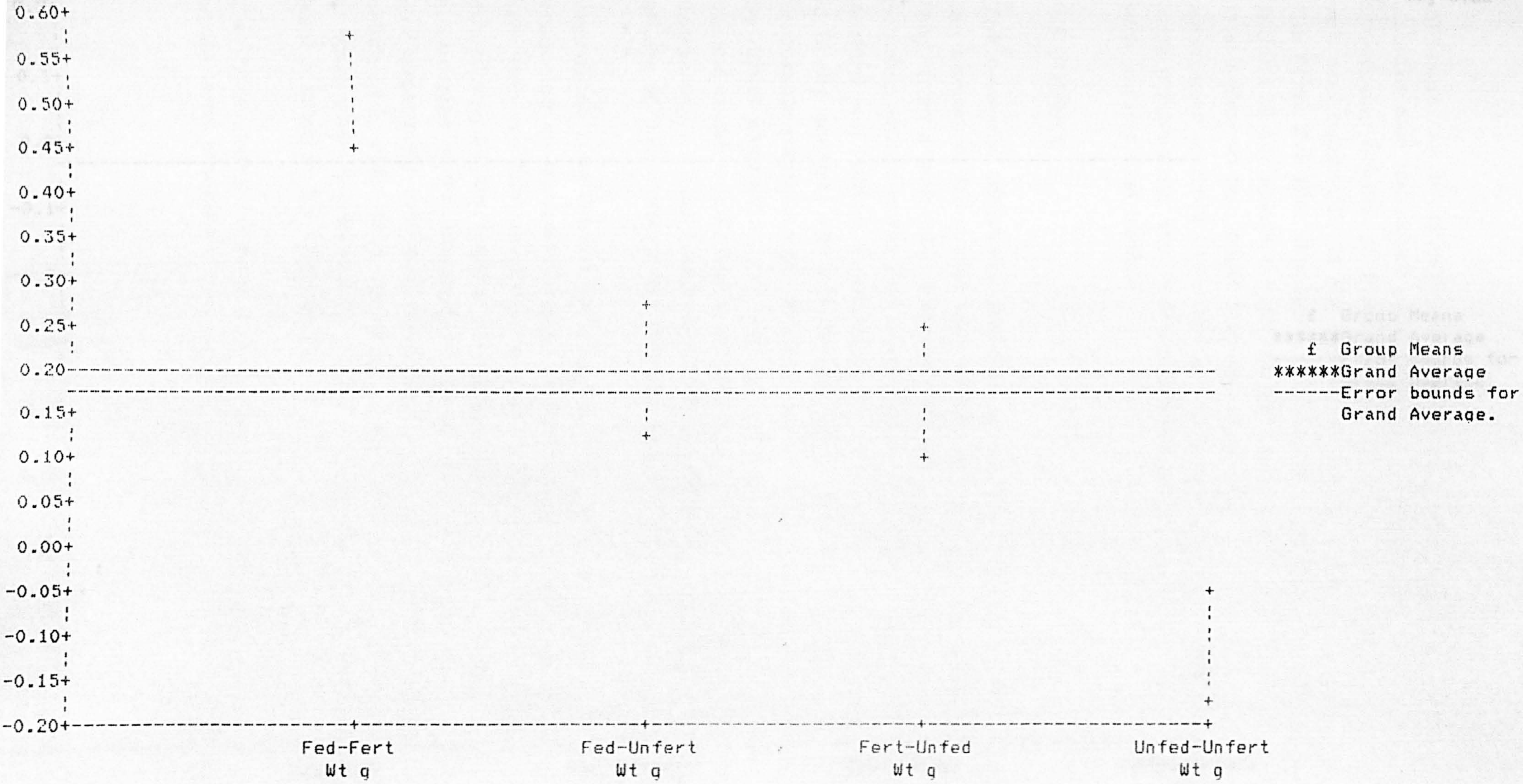


Newly hatched fry introduced on 6th June

Roach Growth Rate - 1988

Analysis of Varience Test

Fig 6.21

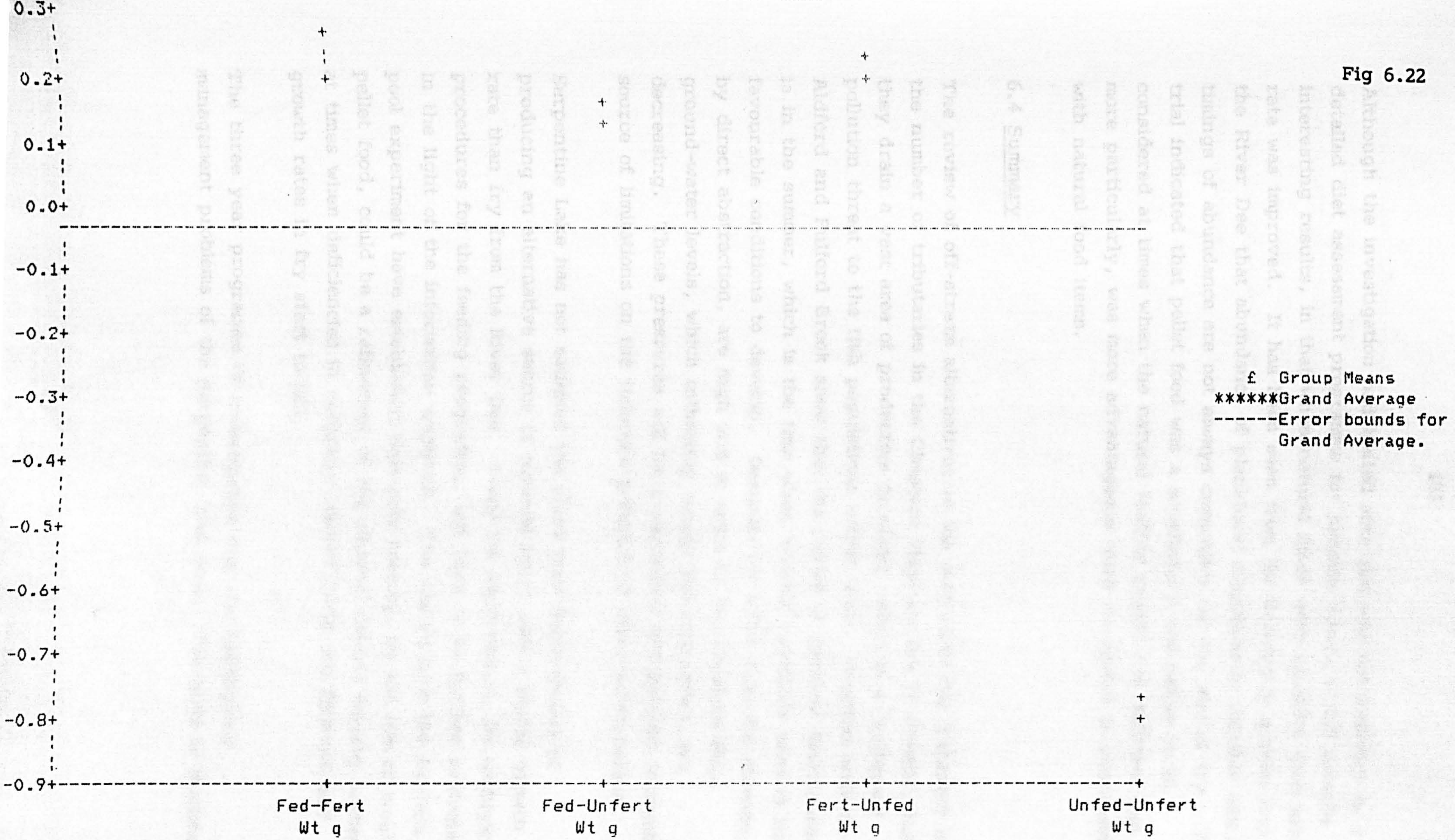


Error bars overlap if the difference between two means is not significant at the 5 percent level. If the error bars for the group mean overlap the dashed line, the group mean is not significantly different from the grand average. Significant differences are determined using Bonferroni simultaneous confidence intervals for all comparisons.

Roach Growth Rate - *1989*

Analysis of Varience Test

Fig 6.22



Error bars overlap if the difference between two means is not significant at the 5 percent level. If the error bars for the group mean overlap the dashed line, the group mean is not significantly different from the grand average. Significant differences are determined using Bonferroni simultaneous confidence intervals for all comparisons.

Although the investigation had limited aims and was not intended as a detailed diet assessment programme for juvenile roach, it did provide interesting results, in that when natural foods were plentiful then growth rate was improved. It has been seen from the Serpentine scheme and the River Dee that abundance of planktonic organisms is variable and the timings of abundance are not always compatible for the size of fry. This trial indicated that pellet food was a satisfactory alternative to be considered at times when the natural feeding regime was deficient and more particularly, was more advantageous when conducted in combination with natural food items.

6.4 Summary

The review of off-stream alternatives to the main river has indicated that the number of tributaries in the Cheshire Plain are few in number, but they drain a vast area of productive farmland, which is a continuing pollution threat to the fish populations within them. Chemical analysis on Aldford and Pulford Brook show that the period of greatest deterioration is in the summer, which is the time when juvenile cyprinids need to have favourable conditions to develop. Demands for water from the streams, by direct abstraction, are high and in areas of the Cheshire Plain ground-water levels, which ultimately supply the tributaries, are decreasing. These pressures will be a continuing and perhaps increasing source of limitations on the fisheries potential of these watercourses.

Serpentine Lake has not satisfied the short term requirements of producing an alternative source of juvenile roach with a better growth rate than fry from the River Dee. Scope for improvement, by modifying procedures for the feeding programme, will have to be further evaluated in the light of the information acquired. The results from the Bretton pool experiment have established that part feeding, by the use of trout pellet food, could be a refinement of the adopted natural feeding regime, at times when deficiencies in naturally created foods are detected and growth rates in fry start to fall.

The three year programme of investigation has also highlighted management problems of the Serpentine trial area. The level of shading probably limits water temperature increases and together with the uncontrolled development of macrophytes has been shown to curtail the development of planktonic algae, which are essential natural foods for young fry. Increased tree removal, seasonal draining and periodic dredging is an option that will also have to be explored to overcome these problems.

Chapter 7

Conclusions and Management Recommendations

7.1 Factors affecting the Coarse Fish Populations of the Lower Dee

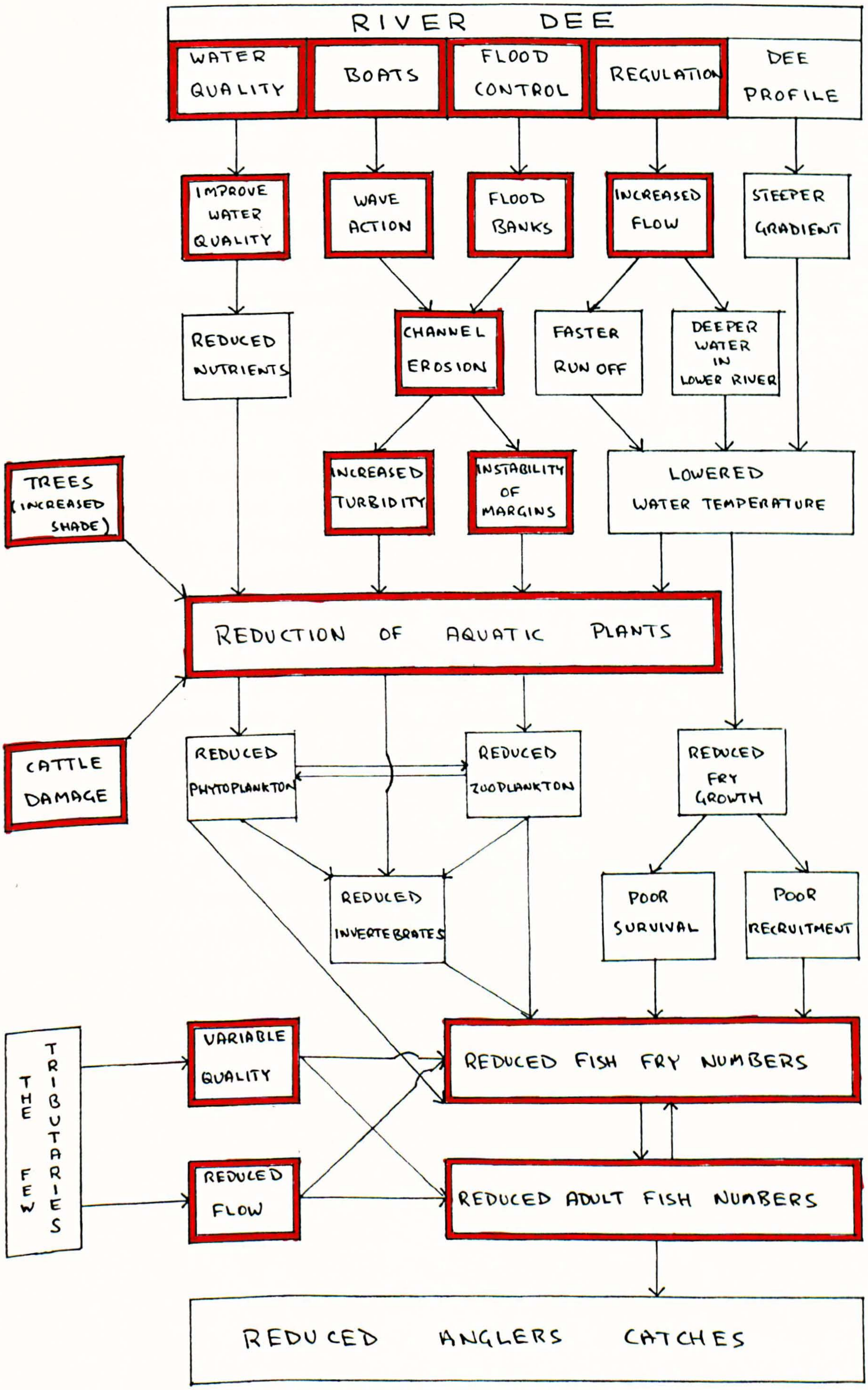
Coarse fish of the lowland section of the River Dee have been shown to be subjected to environmental and anthropogenic pressures that detrimentally affect certain species. Particularly vulnerable are roach, bream and perch, which have limited home range and are largely dependent upon habitats within the main river channel. The flow chart in Fig 7.1 summarises the key elements which may be involved in influencing roach and other lowland river cyprinids on the Dee. The flow chart demonstrates the complexity of interaction between the main elements and emphasizes the difficulty of establishing clear reasons to explain declining anglers' catches of certain species, that have occurred in recent years. This is because the range of pressures on fish are very much interrelated such that on the Dee, and probably on other lowland fisheries where there are similar constraints, no one element can be singled out as the primary cause. To bring about effective management improvements to a fishery, consideration of all the important factors influencing fish is necessary. Each successive stage must then be separately evaluated to establish whether it can be modified to assist the ultimate aim of improving fish stocks.

On the Dee the primary elements are:

7.1.1 River Location and Profile

i) The northerly location of the River Dee is almost at the limits of successful recruitment for roach (Wheeler, 1967) so this species has probably always been subject to year class failure at times of lower water temperatures in cold years. From the results on adult stocks, no strong year classes were detected but, although the sample size was small it was notable that there were few young fish, as the population comprised a mixture of older fish of various year classes.

Pressures affecting Coarse Fish of the Lower Dee Fig 7.1



ii) The profile and slope limits the potential for the Dee to be a good roach fishery, partly because it only has a short lowland section or bream zone (c40km), as defined by Huet (1959), compared to other good coarse fish lowland rivers like the Trent or Wye. Also the ponding effect created by Chester Weir keeps much of this section deeper, which restricts solar heating. It has been demonstrated that the greatest increases in water temperature along the river take place in the shallower and faster flowing, middle reaches of the Dee, where the gradient is steepest. Therefore any critical temperature increases that occur in the lower section are dependent not only on climatic conditions but also on the seasonal flow and frequency of flood events.

7.1.2 River Regulation

Since 1965 the Dee has been heavily regulated and it has been further demonstrated that river temperatures have been further lowered as a consequence of this. Large flows, whether natural spates or specific releases, also quickly suppress any temperature gains that take place in the lower river.

Water is stored in large, deep, high altitude water-bodies at the head of the catchment and releases are dictated by consumer demand and therefore, are greatest over the summer period. Although regulated releases are made from the warmer upper layers of both Llyn Celyn (Hunt, 1970) and Llyn Brenig, no temperature targets for discharges are defined in the management control rules, to take account of differentials with river temperatures downstream. The higher flows create faster run-off from the catchment and therefore equalisation of air and water temperatures, in the shallower middle reaches, is less effective and therefore lower water temperatures impact in the lower reaches more quickly. The controlled flows have reduced the frequency of flood events during the summer months but, the increased volume compounded by the deep channel profile in the study area, limits any potential temperature increases that may have developed from more stable summer flows.

Increases in dace (rheophilic species) and a decline roach and bream, which prefer lower current speeds, may be another long term response to the increased summer flow resulting from regulation. Lower temperatures have been shown to affect growth rate of juveniles in cool summers, and this could have an affect on overwintering survival and hence year class strength.

7.1.3 Flood Control

Flood protection and land drainage schemes have affected bank profiles, channel morphology, bank height and river vegetation. The construction of extensive flood banks in the study area has confined all but the most extreme flood flows within the channel. This has increased water volume and velocities within the corridor and probably increased the scale of erosion, all of which are likely to have had adverse effects on roach by destabilising and reducing the habitat in which they breed and develop. The resultant habitat has low heterogeneity, with relatively uniform cross-sectional profile and few sheltered pools, 'ox-bows' or holding areas. This possibly causes instability of juvenile and adult fish populations, creating constant mobility and increasing risk of fish being flushed from the system.

7.1.4 Impact on Bankside Margins

The flooded margins have been shown to provide an important food source for juvenile fish, but the results have revealed that the abundance of particular food items is dependent on favourable riverine and climatic conditions. Although juvenile dace and roach were found to be marginal grazers, with detritus, chironomids and crustacean being important diet components, the dace preference was for terrestrial insects while roach favoured filamentous algae. At the margins, aquatic macrophytes can provide sheltered areas where suitable food organisms develop, but on the Dee such area have been restricted because of the following:

i) Encroachment of Bankside Trees

The river has been found to be heavily canopied by the tree line for over 46% of the study area. Results have revealed that the tree line is increasing progressively and on account of the succession, that has been shown to be taking place at the river margins, any reed fringes that develop will ultimately be excluded and the tree line will continue to consolidate in the absence of management intervention. The canopy compounds the lowering of water temperature and almost eliminates light to the available marginal area. This further inhibits colonisation by both marsh and aquatic plants, which are necessary for the creation of microhabitats that fish can utilize for feeding and recruitment.

ii) Cattle Damage of Marginal Habitats

Cattle trampling and grazing have been shown to affect areas where the early stages of plant succession are apparent. In the 1991 survey, 13.2km of margins was found to be affected and where this damage occurs, sediments are disturbed and potentially stabilising vegetation are grazed or trampled. This leads to local increases in the abundance of unstable littoral sediments, greater erosion of bankside margins rendering the area unsuitable for the growth of aquatic macrophytes. In areas where young trees are developing it is unlikely that once they are established, cattle will control their development.

iii) Recreational Boat Traffic

Recreational boating has localised effects, mainly near Chester, by creating disruption of marginal substrates, raised turbidity and direct damage to aquatic weed by propellor damage. The continual movement of boat traffic in the summer months maintains instability of the margins and prevents colonisation by plants.

7.1.5 Water Quality

Water quality for the River Dee is high and no major coarse fish kills have occurred in the main corridor for many years. Periodically salmonid mortalities take place, in the tidal reach below Chester at times when neap tides coincide with very high air and water temperatures. Special regulatory releases are invariably used to minimize the scale of such incidents. The improved water quality standards achieved in the river by increased monitoring and surveillance in recent years may have decreased suspended organic matter and also lowered biological productivity, although evidence is not available to support this.

7.1.6 Tributaries

Tributaries of the lower Dee are few in number and have been found to be limited in potential for roach stocks. The River Clywedog, River Alyn and Worthenbury Brook systems have unsuitable flow and habitat regimes which are more favourable to adult dace populations, rather than juvenile fish or roach. Aldford and Pulford Brook have restricted access as well as periodic water quality and quantity problems and, at present, limited usage is made of this area by coarse fish.

7.2 Changes in Fish Population

Although the factors listed above have impacted on roach and probably bream and perch in the lower Dee, the dace population has been shown to be adaptable to the changing river conditions and has successfully expanded and extended its range. Dace have advantages over roach because they spawn earlier in April, in gravelled areas of the river upstream of Farndon. This is because they are less eurythermal and therefore not so dependant on temperature for the reproductive phase. Also, unlike roach, they are not phytophilous and therefore do not require aquatic vegetation for spawning.

On the River Exe, Cowx (1988) found that roach and dace distribution conformed to the classic theory of zonation in rivers (Huet 1959,1962) and that growth rates in both species were optimum in their preferred locations. In the case of roach, this was the slower flowing reaches and with dace the faster sections. On the Dee, roach are to found in greater numbers in the slower deeper section towards Chester, but dace have been shown to migrate from this slack water area to the faster flowing reaches between Overton-on-Dee and Farndon. Therefore, by this movement, dace probably benefit from the richer food sources associated with the abundant channel weed growth which occurs in the upper reaches of the Cheshire Plain.

The success of the dace can also be explained by applying the migratory strategy principles of Northcote (1978) to the study area. In Fig 7.2 it can be seen that his defined 1-4-5-6 migratory pathway sequence is applicable to dace on the Dee.

Northcote (1978) states that the main elements dictating the survival of freshwater fish are the growth and abundance of the spawning stock and its resultant production. He also adds that feeding migrations occurring early in the life cycle of the fish have maximum impact on the eventual production of the species, because both population numbers and the growth rates being attained are then at their maximum.

In respect of dace in the Dee, the migratory steps are likely to be as follows:

i) Following spawning near Farndon, both adult and juvenile dace migrate to alternative summer feeding habitats which in the case of adults have been shown to be the main river (Bangor-on-Dee to Shotton) and some tributaries. Juveniles principally disperse passively downstream and populate the main river channel (Fig 2.32).

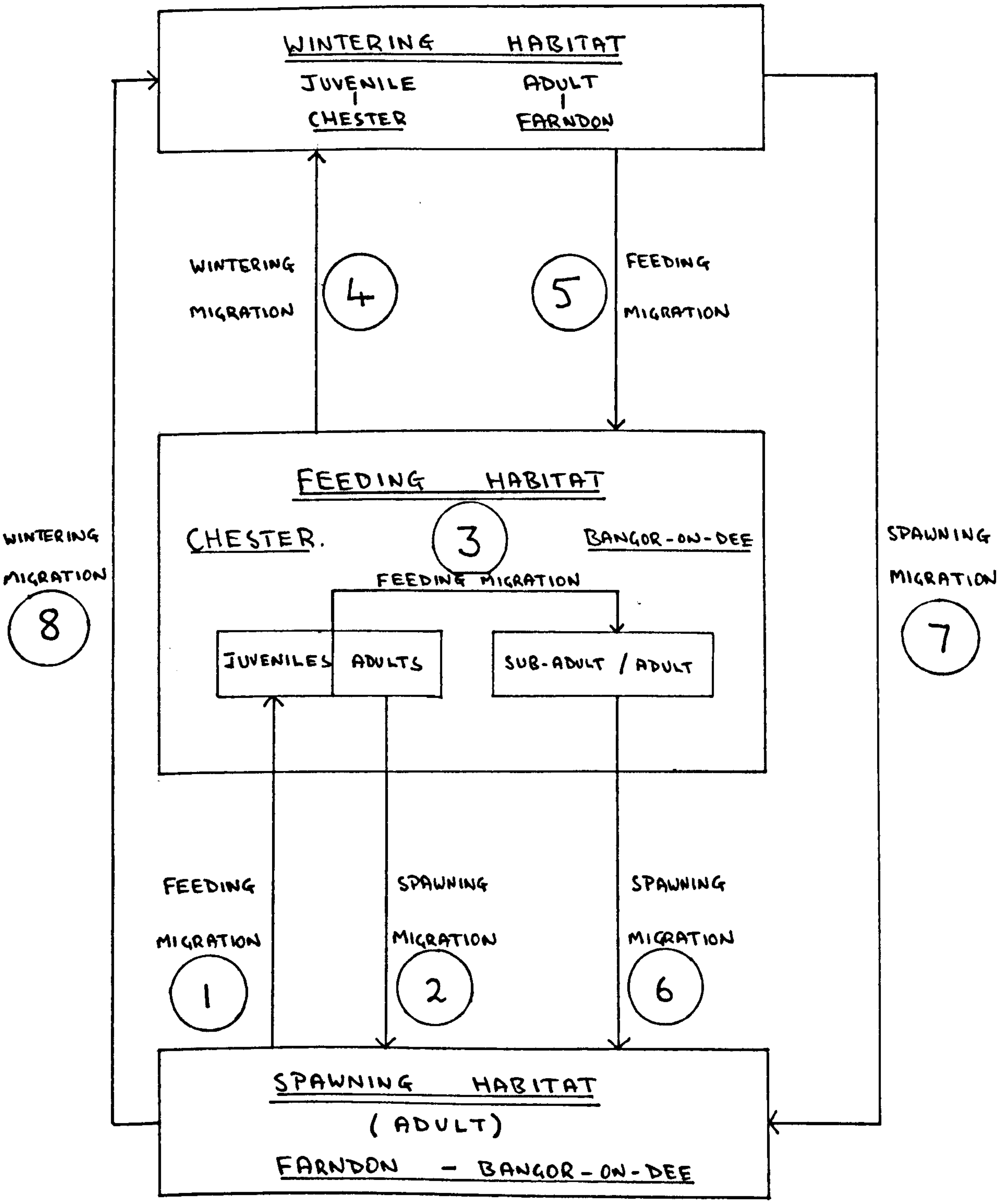
ii) It has been shown that in the winter, mature dace migrate from the summer feeding habitat at Chester to the winter feeding habitat near Farndon.

iii) In early spring the dace undertake a spawning migration to suitable habitat between Farndon and Bangor-on-Dee.

Northcote (1978) suggested that beneficial elements from the migrations could develop. These are summarised as follows:
From the spawning habitat the feeding migrations enhanced dispersion along the river catchment, decreased competition and maximized the

Migratory Pathways of Fish (After Northcote, 1978) Fig 7.2

Adapted for Dace of the Lower Dee



available food source. The more efficient utilisation of the food source increased growth and survival which produced more spawning stock with higher fecundity. Ultimate production rates of fry would therefore be expected to be higher.

The advantages of migratory pathways of this kind are particularly appropriate on river systems that are subject to fluctuations in flow regime, where fish habitat suitability is variable and where fish species competition is present. If the degree to which these phases of migration regulate production of dace on the Dee were fully understood, this knowledge may be usefully applied to manipulate the population size for best advantage. The present study has highlighted some of the periodicity of stock movements and particularly how these relate to anglers' catches.

7.3 Recommendations for Improvement to the Coarse Fish Populations of the Lower Dee.

Flow chart Fig 7.1 demonstrates the main factors that are affecting cyprinids in the lowland Dee. Specific boxes are edged in red, which are the suggested areas where realistic change could be pursued to bring about improvement to coarse fisheries. These will be considered in turn:

7.3.1 Regulation

On the Dee, the regulation scheme has allowed increased water abstractions to take place for public supply and from the outset has considered aspects that were deemed to be protective to environmental interests. Although the basic principles of transferring water down the catchment for abstraction is considered irreversible, the volumes and the way water is released needs to be reviewed, in the light of increased understanding of the damaging ecological consequences of its operation. Lowered water temperatures have been shown to create problems to the lower Dee coarse fishery and therefore methods to alleviate the detrimental conditions need to be examined in greater detail. No seasonal standards or target temperatures of release water are defined for the system to protect the environmental aspects downstream, as occur on some other regulated rivers (Cassidy, 1989). Temperature of the release water and variations that occur at the respective draw off levels in the reservoirs have also not been accurately determined despite there being 6.1m between draw off levels in Llyn Celyn and 10.7m in Llyn Brenig. The water volumes released are also principally designed to satisfy water supply requirements although special environmental releases are available and a minimum flow over Chester Weir is maintained to protect fish in the upper tideway.

With the realisation of problems associated with the coarse fishery a review of regulation methodology is required together with an evaluation of optimum flows for the system. The gradual improvement of water quality in the estuary may for instance allow modification to the dry weather flow regime during the summer to help raise water temperatures upstream of Chester Weir to benefit coarse fish. Until such a study is undertaken and the environmental consequences of released water are realised, proposals to significantly change the flow regime should be deferred.

1) <u>It is recommended that</u>:

i) That an assessment should be made of the temperature changes associated with release water from Llyn Celyn and Llyn Brenig and how the effects on the recipient rivers can best be minimized. Three areas of examination are suggested:

a) To establish the changes associated with the thermocline development and its position in the reservoir and also the temperature variations in release water as the reservoirs levels become lower, particularly the changes that occur between respective draw-off points.

b) By using continuous recorders at 11 points down the catchment, profiles of temperature changes associated with regulation within the river should be mapped for a range of release volumes and assess how they compare with natural flows.

The locations should be :
Llyn Celyn outlet works; Bala (Downstream of the sluice gates); Corwen (Upstream and downstream of the Dee/Alwen Junction); Manley Hall; Farndon; Ironbridge; Chester Weir and Shotton with two control tributaries that are unregulated eg Rivers Ceirw and Ceiriog.

Monitoring throughout a 12 month cycle should be undertaken according to standard regulation control conditions. By arrangement with abstractors, a two day trial recreating natural summer flows, should be pursued to establish temperature profiles down the catchment, which were typical of a time prior to regulation occurring.

c) The data from the continuous temperature recorder at Manley Hall be used more effectively by down loading and storing on a long term data base, rather than loosing the information after only a month, as at present. If the information is retained, it can be usefully related to the long term hydrological data. Similar consideration should be given to other parameters such as pH, suspended and dissolved solids which can also influence fisheries in a river system like the Dee.

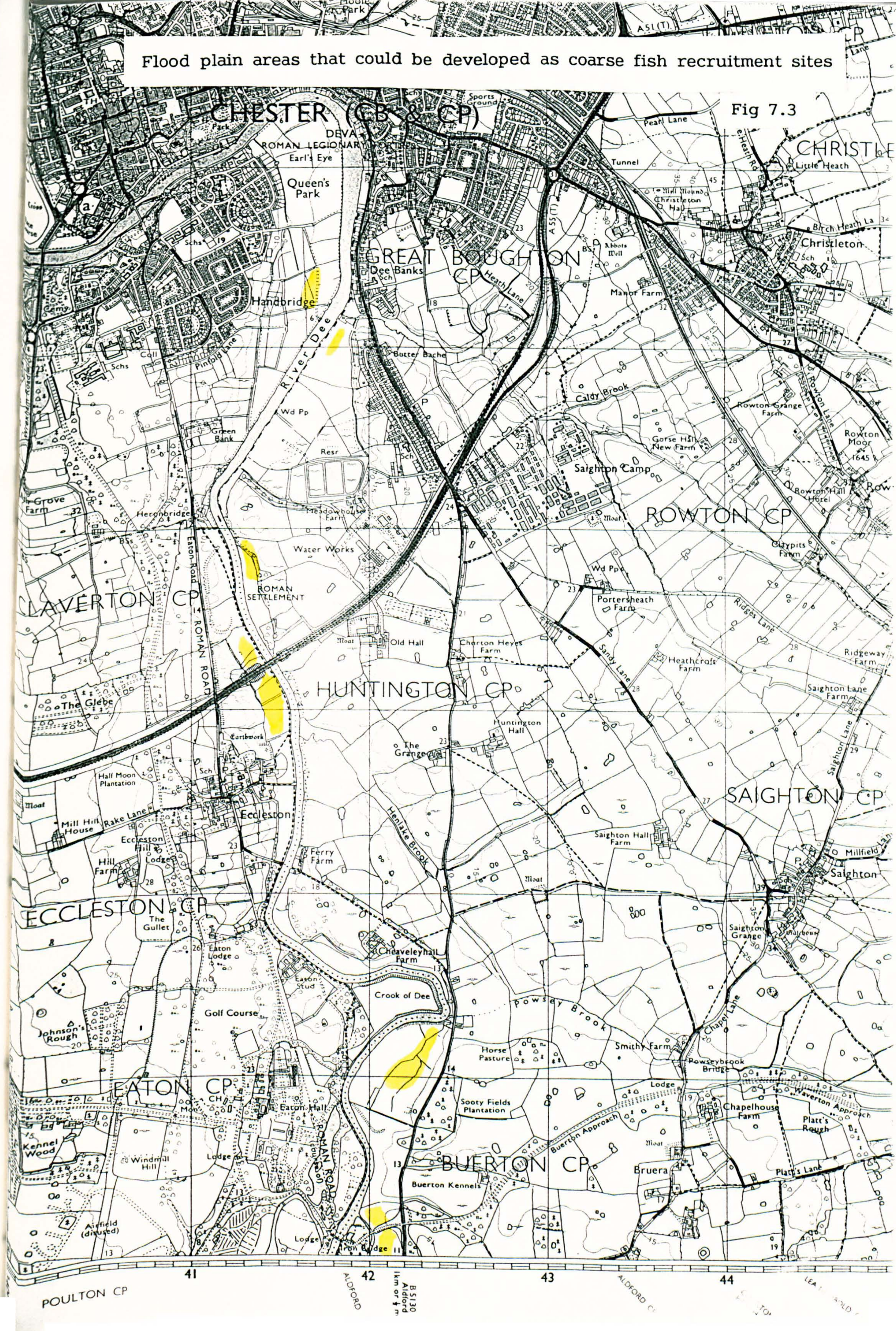
ii) The control rules for regulation should take account of the impact on coarse fish and angling and where possible be modified to bring about improvement to the fishery. To achieve this, an investigation should be undertaken to assess the impact of regulation releases on catchability by anglers.

7.3.2 Flood Banks and Utilisation of Flood Plain Areas

Many of the flood banks that have been constructed in the Cheshire Plain protect areas of human settlement or land of high agricultural value and therefore need continuing protection and maintenance. Equally there are other low lying areas, highlighted in Fig 7.3, that are frequently flooded in the winter and offer only low grade pasture when drying out in mid-summer which, if managed differently, could provide valuable wetland area. Evaluation and advancement of the most adaptable and cost effective areas should be undertaken to re-create shallow lakes or 'ox-bows' which interconnect with the river. Such sites would not only

Flood plain areas that could be developed as coarse fish recruitment sites

Fig 7.3



develop extensive fish spawning and rearing habitat that could be colonised naturally, but also, they would enhance the wildlife conservation value of the river corridor.

2) It is recommended that:

i) An evaluation of the listed flood plain areas in Fig 7.3 be undertaken to assess the feasibility of creating extensive on-stream cyprinid recruitment sites, which could also function as wildlife conservation areas.

ii) A trial area should be developed in the flood plain to re-create the principals of flood plain wetland. The site should be developed to allow minimum maintenance of operation but, it is important that the area should flood seasonally, to prevent an accumulation of silt deposits and also maintain a link with the river corridor. Much of the wetted area should be less than 1m but deeply excavated pools should be available for utilisation by larger fish, seeking sanctuary from the main river channel.

7.3.3 Tributary Improvements

Aldford and Pulford Brook are the only tributaries of sufficient size to be used by roach and bream on the lower Dee and also they are presently under-utilised as cyprinid recruitment and rearing areas. Barnabus (1971) indicated that Aldford Brook was used by both species for spawning, although water quality was a problem at that time. In the early 1970's a sluice was installed at Aldford, to reduce winter flooding upstream but, after completion, it prevented fish going more than the 1000m up the brook, from the main river. Frequent weed cutting also takes place within the brook as part of the land drainage maintenance programme. This can reduce the spawning potential for fish within a tributary (Pearson and Jones, 1978 and Swales, 1982).

Improved access into the tributary for fish and a reduction in the disturbance of vegetation from weed cutting could possibly expand the spawning requirements for roach and bream, although water quality and flow will continue to be a source of problem in the brook.

Pulford Brook also suffers from seasonal water quality problems and because of its bed slope is largely inaccessible to mature roach and bream from the main river at the present time. Like Aldford Brook it also has a rich macrophytic flora which is not fully utilised by spawning cyprinids.

3) It is recommended that:

Aldford Brook

i) The scope for opening up the sluice in the early spring and summer months be evaluated, with an aim to make available more tributary to spawning coarse fish and the resultant progeny.

ii) Water quality problems should be examined, to establish if further improvements can be made and, where appropriate, high pollution risk locations should be targeted for increased surveillance.

iii) Future abstraction licences on the brook should be refused until clear reasons for the diminishing flows recorded in recent years, are established. Steps should be taken to enhance flows to the tributary, particularly during the summer period, by modifying existing licences.

iv) Weed cutting methods should be examined to assess the scope for altering present land drainage working practices to retain aquatic vegetation, that can be utilised by spawning fish and juvenile fish.

Pulford Brook

i) Water quality problems should be reviewed to establish scope for improvement for coarse fish and, as with Aldford Brook, high pollution risk locations for increased surveillance should be targeted.

ii) The extent to which the flood banks could be adjusted on the lower brook should be examined, to assess the scope for making the channel wider and deeper, to allow increased access to roach and bream from the main river.

iii) Weed cutting methods be examined to assess the scope for maximizing the available spawning and recruitment habitat within the tributary in the same way as recommended for Aldford Brook.

7.3.4 On-stream Habitat Improvements

Four main areas of change have been established that could improve existing aquatic habitat in the available shallow margins. These are as follows:

a) Cattle Damage Reduction

Considerable damage to margins can take place following the intrusion by cattle and it has been shown that bankside fencing is highly effective in curbing this and allowing the development of a diverse marginal vegetation. In areas that are not severely affected by boat wash, expansion of aquatic plants into the river takes place to a limited extent and this develops beneficial microhabitats that fish can utilize. It has been shown that species succession takes place in the plant colonisation, which soon reduces species diversity and after 4-6 years willow can become dominant. Progressively this increases shading of the river and reduces the suitable aquatic habitat that is important to coarse fish.

4) It is recommended that:

i) Cattle access to the water's edge should be restricted, particularly at points where shallow margins exist, and then only allowed in areas where there are fenced 'cattle drinks'. Extensive fencing will be required to protect the aquatic plants that develop but, this will not only encourage marginal vegetation but will also consolidate banks that are subject to erosion and thereby possibly reduce the cost of flood defence maintenance work. A particularly appropriate length of river extends from Bangor-on-Dee to Farndon, where the river channel meanders and is subject to serious erosion at times of high flood flow.

Proposals to regulate cattle access will need to be discussed with local farmers and work advanced to an agreed procedure which must incorporate a provision for long term monitoring and maintenance. The involvement of volunteer groups should form an integral part of the construction phase of this work so as to reduce costs and maximize the extent of fencing achieved.

ii) In areas where aquatic and emegent weeds are of high priority as fish recruitment sites, experimentation should be undertaken to establish if cattle grazing can be used as a technique to prevent the dominance of certain large plants, and more particularly willow (Salix sp). This can be pursued by opening up fenced areas periodically, to allow cattle intrusion, in order to destroy the habitat created and restart the plant succession cycle again.

b) Reduction of Tree Shading

The extent of bankside trees is increasing along the study area and the canopy developed, shades marginal areas as well as expanding over large sections of the channel. The aesthetic landscape becomes stereotyped, with a consequent reduction in aquatic vegetation and loss of habitat for fish and other forms of wildlife.

5) It is recommended that:

i) Selective removal of bankside trees should take place in six, 250m sections between Ironbridge and Caldy, where there is presently a continuous tree line. Areas of shallow margins, where banks can be shaped to give a gradual slope, no steeper than 1:3, should be chosen, because more effective colonisation by aquatic vegetation can be achieved. After review of the sites development and the establishment of the maintenance requirement, further areas between Farndon and Ironbridge should be advanced.

ii) A study should be conducted to establish whether such cleared areas should be allowed to colonize naturally or active planting is necessary, to create margins and banksides with aquatic vegetation.

c) Improvements in boat activity on the river

It has been shown that considerable damage of the bankside margins occurs from wave wash as a consequence of recreational boating, including physical propellor damage of lily beds (Nuphar lutea). Chester is an important tourist centre and boating activity will continue to take place at a high intensity in mid-summer. It is important that present controls for boating (eg speed limits) are adhered to, but in the longer term an evaluation of the recreational byelaws and the types of craft using the river should be undertaken.

6) It is recommended that:

i) Present speed limits for recreational boats for the lower Dee should be strictly enforced to reduce bankside damage.

ii) A guidance leaflet should be prepared to explain the consequences of habitat and wildlife damage by indiscriminate activities of recreational boat usage. This should also include a code of conduct to help reduce the potential effects.

ii) A full evaluation of the impact of boats on the ecology of the lower Dee be undertaken with special consideration being given to the boat design requirements to minimize wave wash and reduce marginal habitat destruction.

d) Improvement of on-stream recruitment areas

The Heronbridge experimental site has indicated that the habitat at the water margins can be improved ecologically, to the potential benefit of both fish and other forms of wildlife. Larger population densities and species diversities of algae and invertebrates occur within vegetated areas compared to those that are unvegetated. An expansion of this programme should therefore be undertaken along the shoreline in places with wide littoral margins and shallow gradients and where flood flows have least effect. Sheltered bays and locations at the confluence of small tributaries with the river are preferable, even if limited excavation to maximize potential is necessary. Typha latifolia at the waters edge and Nuphar lutea within the water have been found to develop successfully, but other species such as Glyceria maxima and Sparganium erectum could also be considered.

In view of the anchorage limitations in the thick soft sediment along the margins of the river, a consolidatory material will be required. Tensar matting has been found to benefit the development of smaller marsh plants rather than larger species. Stone has been found to be effective for improving rooting conditions for Nuphar lutea in the deeper water. Soft substrates and continuous disturbance currently limit natural colonisation of aquatic species, so a programme of initial planting will likely be required.

Each site will need to be fenced on the landward side to keep out cattle. Anglers should be catered for by stiles for access and by small platforms, from which they can fish without damaging vegetation. On the waterside, boats should be prevented from entering the areas by a sequence of posts, but as attempts to reduce wave action are largely ineffectual on the Dee (Hodgson et.al., 1988), no permanent barrier is considered necessary on the riverside.

Holding areas for adult fish stocks within the main river corridor, have been found to be deficient because of the deep channel profile and the scouring potential during winter floods. Steps need to be taken to establish if habitat structures can be introduced to the main river corridor to allow fish stocks to obtain a small measure of protection during the periods of high flow velocities.

7) <u>It is recommended that</u>:

i) Bankside and marginal vegetation should be expanded at selected locations, which are presently clear of trees.
Priority should be given to the margin along the Earl's Eye at Chester (On the left bank, downstream of Caldy) where the bank profile could be shaped to a gradual slope and the water's edge planted with aquatic or marshland species. Plants should include <u>Typha latifolia</u> and <u>Phalaris arundinacea</u> and in the more protected areas <u>Glyceria maxima</u> should be encouraged. Cattle intrusion of the margins should be prevented and therefore, if the surrounding land continues to be grazed, steps should be taken to erect stockproof fencing.

ii) At other locations, different plant species should be used to fully establish the most successful species in areas of varying pressures. This would enable detailed designs to be prepared for practical management programmes for the enhancement of lowland river corridors. Where soft substrates are present they should be consolidated with stone, to aid plant stability, or with matting, where smaller marsh plant flora is required.

iii) All sites should be protected from cattle intrusion and where appropriate anglers' requirements must be accommodated.

iv) Monitoring and long term maintenance will be needed to ensure ecological balance but where willow develops, this should be curtailed by physical removal.

v) Consideration should be given to the installation of in-stream holding facilities for adult fish stocks. Fixed reefs offer the greatest potential, by providing protection to fish from high flow velocities but also they will likely develop as feeding areas for fish where anglers would likely have an increase in catches. Useful locations for installation will be beneath trees, particularly willow (<u>Salix sp</u>) where the branches closely overhang the water (Swales and O'Hara, 1980).

7.3.5 Off-stream Recruitment Areas

The Serpentine Lake scheme demonstrated specific problems which limited the success of achieving better growth rates of roach fry in this controlled environment, compared to natural development in the river. Inadequate temperatures, extensive macrophyte development and the difficulty in producing sustained growth of phytoplankton as food of fry, have all contributed to this lack of success. Cormorants also imposed difficulties by predating on brood stock for fry production, when introduced early to the lake.

Although problems have been encountered, the timing of the experiment coincided with two very warm summers (1989,1990), when conditions for fry production were probably good within the river. Therefore an assessment in colder years may be more worthwhile, as then poor recruitment on the Dee is more likely. If the good growth rates achieved from the Bretton Pool experiment by using an alternative feeding regime could be applied to the Serpentine, more favourable results might be achieved.

8) It is recommended that:

i) The Serpentine Lake scheme be continued to assess production and growth rates of roach fry especially in cool summers.
ii) Seasonal draining of the pools with periodic dredging be undertaken to reduce macrophyte development.

iii) Steps be taken to increase solar radiation to the water surface by tree removal, in order to raise summer water temperatures.

iv) The application of chemical fertilizers should be continued, to assist the development of plankton blooms for food of newly hatched fry, but manufactured fish foods should be used to help maintain consistent growth as the fry become larger.

7.3.6 Stocking

The study has revealed that mature roach and bream stocks of the lower Dee, are very low and under such circumstances anglers invariably suggest that stocking should take place. Several workers have, however, found that stocking of mature fish has limited success in increasing anglers' catches. For instance Axford (1974) concluded that the introduction of roach to the Hammerton fishery, on the River Nidd, did not lead to an improvement in angling catch rates, other than for a short initial period. Likewise Timmermans (1967), observed on Belgian watercourses, that even large quantities of stocked roach did not produce appreciable increases in capture rates by anglers. Summary conclusions on stocking of cyprinids into linear systems such as rivers, streams and canals in the United Kingdom are given in the EIFAC (1988) report. It is suggested that little or no impact is achieved on the overall fish biomass of receiving waters where stocking takes place. From this evidence, although stocking of a river system like the Dee would appear to have doubtful benefits, it is considered that when undertaken in combination with other aquatic habitat improvement measures, as suggested above, then faster progress with achieving increases in fish abundance is more likely.

9) It is recommended that:

Limited stocking should be undertaken initially, to boost recruitment success when habitat improvement works have been completed. Areas of introduction should include the Aldford and Pulford Brook section of river, so that fish can benefit from the available sanctuary area. It is important that initially, larger roach which have come from a riverine system with similar flow criteria to the Dee, should be obtained.

7.3.7 Development and implementation of a Management Plan

On account of the complex series of issues that are impacting on the coarse fish stocks of the lower Dee a novel and integrated approach will have to be advanced to bring about effective improvement. At the present time, as in the past, it is apparent that fisheries, water quality, water resources, conservation, flood defence, recreation and land management issues etc, are largely advanced independantly of each other, rather than by an integrated strategy of development. For speed of satisfying individual needs of the respective function, often inadequate analysis of the consequences of change is undertaken. When damaging consequences develop, as has been shown to have taken place with regulation in respect of coarse fish, under the present arrangement of management control, the fisheries budget of the National Rivers Authority will have to finance any planned programme of improvement. This arrangement is clearly unsatisfactory and because of shortage of funding will ultimately lead to limited change and slow improvement.

The advancement of catchment management plans as proposed by the National Rivers Authority are an important step forward in structuring necessary change for river systems. By this procedure, problem issues in respect of each function will be highlighted, on any particular river and these will be prioritised and targets set to bring about the neccessary change. It is however, more important that an integrated approach for solving problem issues is also pursued, which not only accommodates all relevant management functions but also other interested parties such as farmers, industrialists, angling associations, riparian owners, councils, volunteer groups etc who may have a vested interest and be keen to contribute to a structured scheme of improvement. This contribution need not necessarily be directly financial but constructive assistance eg setting land aside to create flood plain wetland or provision or installation of fencing along the river to exclude cattle. In what ever way possible, the planning and the development must be co-ordinated and also promoted to have wide input and endeavour to take account of the different interests. Collectively there is a greater chance of achieving the improvement objectives in a reasonable time scale and costs incurred can be minimized by the joint approach.

10) <u>It is recommended that</u>:

The River Dee Catchment Management Plan being advanced by the National Rivers Authority (Welsh Region) is used as a vehicle to bring about effective improvements to the coarse fishery and the ecological environment of the lower Dee. Special emphasis should be directed towards developing a wider involvement by user and other interests of the river in the implementation of aspects of the plan, so that structured improvements can be achieved, in as short a time scale as possible and at the lowest cost. Appropriate publicity should be used to encourage active participation.

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