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The Impact of an Alien Piscivore the Zander (Stizostedion lucioperca
(L)) on a Freshwater Fish Community.

Thesis submitted in accordance with the requirements of the
University of Liverpool for the Degree of Doctor in Philosophy by
Laurence Thomas Kell.

April 1985.

A B S T R A C T

The impact of an Alien Piscivore the Zander (Stizostedion lucioperca (L.)) on a Freshwater Fish Community.

The zander (Stizostedion lucioperca (L)), an alien piscivore, was introduced into the Great Ouse System of rivers in 1963; following this introduction a decline in the cyprinid populations (mainly roach Rutilus rutilus L. and common bream Abramis brama L.) was seen. The Anglian Water Authority in an attempt to bring about a recovery in the fish stocks implemented a cull of the two main piscivores pike and zander in the Middle Level Systems of the Cambridgeshire Fens. This study concentrated on the changes in the fish community following the cull.

By 1983 the total fish biomass had recovered from its previous low of 44.6 kg/ha in 1981 to a biomass of 195.1 kg/ha. This recovery occurred due to a succession of strong year-classes since 1979; the cull was shown to have influenced the patterns of recruitment and growth, along with environmental conditions.

Quantitative and Qualitative population sampling coupled with age and growth studies of zander, pike, roach and common bream enabled the response of the various year-classes to be investigated, so that the effect of management on the community could be gauged.

A comparative study of the feeding ecology of zander and pike, via stomach contents analysis, showed differences with implications for the fish community.

The zander predated predominantly on juvenile fish and by concentrating its predation pressure in this way under certain habitats may cause population declines. The way in which environment and management can influence the impact of zander in a habitat are discussed.

ACKNOWLEDGEMENTS

A work of this nature could not have been attempted without the help and co-operation of a large number of people and organisations; thanks must extend therefore to all those individuals whose help, often beyond what could reasonably be expected, and friendship made this study possible.

I would like to thank everybody in the Department of Zoology at the University of Liverpool where this study was carried out under the headships of Professor C.J.Duncan and Dr R.Pearson; in particular to my supervisor Dr. R.T.Leah and my colleagues in the Freshwater Group; H.G.Pearce, N.Weatherley, C.A.Saclauso, A.Brown and M.Diamond for their help with fieldwork and encouragement; A.Crabtree and L.Matthews who proved invaluable in the laboratory and especially to C.Aprahamian and P.M. Wakefield for their help during periods of often extensive fieldwork.

The Anglian Water Authority provided immense assistance without which it would not even have been possible to think about a study such as this. This help came in many forms and from many sources. In particular from Dr.R.S.J.Linfield, who helped supervise this study, for his support and encouragement. Thanks must also go to everybody at Cambridge Division Fisheries Department for their assistance in fieldwork and their every willingness to be of help, in particular C.Klee, P.Noble, J.Adams, J.McAngus and M.Stark. To B.Harbot and Richard Reeves of the Regional Research Team; everybody at the Fish Disease Unit and Headquarters at Huntingdon, in particular to Monica Gregory and to J.Short, H.Randall, J.Riggs, B.Bingham. H.Burgess and T.Thompson for the typing.

I would like to thank the Middle Level Commissioners for their help and permission to work on the Sixteen Foot Drain.

Sheffield Anglers kindly gave permission for sampling to be carried out on their waters.

The Anglian Water Authority, The Angling Foundation, The Sports Council and the Water Space Amenity Commission all helped by funding this project.

Thanks must also go to Peter Fuhrmann and Stephanie Byrne who helped with fieldwork in their own time.

Finally my thanks must extend to all those who put up with me while this thesis was being completed.

ABBREVIATIONS

Significance levels are indicated by the following symbols

n. s.	not significant
*	significant at the 95% level
**	significant at the 99% level
***	significant at the 99.9% level

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1.1 Introduction

The aim of this study was to describe the changes in the fish community of the Sixteen Foot Drain following the introduction of the zander (Stizostedion lucioperca (Linnaeus 1758)) and its subsequent management. A programme of work was agreed with the Anglian Water Authority (the body responsible for the water) at the onset and included four main areas. Sampling occurring from the beginning of 1981 until September 1983.

- 1) Regular quantitative and qualitative assessment of fish populations in the Sixteen Foot Drain, to study changes developing within the Fishery.
- 2) Analysis of predator prey relationships between the fish species, with particular emphasis on the role of Stizostedion lucioperca.
- 3) Assessment of the effects on the fish populations of predator removal carried out during 1979-81, and a particular study of the role played by the 1980-82 year classes of predators.
- 4) The description of the role of piscivores in the Middle Level fish community with particular reference to their management.

To develop a full understanding of the nature of piscivorous fish it is necessary to regard them as being part of a larger community; the component populations interacting with each other and with the various abiotic and biotic characteristics of a particular habitat.

The mechanisms that determine the status of the fish populations will be investigated after the ecology of the community has been described.

1.2 The zander

The zander, Stizostedion lucioperca (Linnaeus 1758), is a member of the family Percidae, originally found in Eastern and Central Europe. Its range has been extended considerably by both deliberate transplantations and natural dissemination, aided by the linking of water systems by man so that it can now be found throughout most of Europe (Deelder and Willemsen, 1964). In Europe it is commonly highly regarded as both a sport and food fish, being one of the most important commercial fishes ranked in value alongside salmonids and eels (Berg, 1965; Willemsen, 1983). The zander is also cultured in numerous countries to supplement stocks which are protected by the imposition of size limits.

It is a predatory species feeding mainly on any small fish that are available (ie. a piscivore) and is to be found mainly in lowland rivers and lakes, "preferring" turbid water with little macrophyte cover. It is most active at dawn and dusk, since it is adapted to hunting in low light conditions (Svardson & Molin, 1973) and at other times is usually found close to the bottom.

The zander was first introduced to Britain in 1878 (Lever, 1977) when 23 zander of about 1kg each were released into two lakes at Woburn. These fish which came from Schleswig-Holstein are the ancestors of those currently in British waters except for an isolated population introduced into a small lake at Mepal, Cambridgeshire in 1960.

See Wheeler and Maitland (1973), Lever (1977) and Fickling (1982) for a full account of the spread of the zander in Britain.

1.3 The zander in the Lower Great Ouse area

1.3.1 Colonisation

The zander was first introduced into an open river system in Britain in 1963, when the Fishery Officer of the Great Ouse River Board was responsible for releasing 97 (0+ or 1+) fish into the Relief Channel. This initial colonisation was first chronicled by Cawkwell and McAngus (1976) and subsequently updated by Linfield and Rickards (1979) and Klee (1981).

The zander had spread from the Relief Channel into the Tidal River Ouse by 1966 and then into the Hundred Foot River by 1967. By 1970 it had reach as far upstream as Huntingdon on the River Ouse. The first record in the Middle Level System was from the Main Drain in 1970 followed by captures in the Forty Foot in 1972 and the Sixteen Foot in 1973. The zander can now be found through out most of the lower Great Ouse area.

The Relief Channel has open connections to the Great Ouse system of rivers and drainage channels which has permitted the colonisation of numerous water courses. The spread of zander is still occurring not only within the Anglian region but beyond due to both natural dispersal and illegal introductions and has been reported from the Thames (Angling Mail, 1984) as well as being wide-spread in the Severn Catchment area (Hickley and North, 1983).

The zander population under went a dramatic increase in numbers following its initial stocking in the Relief Channel. Linfield and Rickards (1979) calculated that the original 97 fish stocked in 1963 had increased to over 20,000 by the 1966-1967 season. Coincidentally changes were also seen in the fish community. Klee (1981) proposed that a rapidly expanding zander population over-predated the prey populations resulting in a subsequent decline of its own stocks, so that by 1979 a much smaller zander population was present in the Great Ouse area. Such a pattern of events is often seen on the introduction of a new species, which often rapidly increase to the maximum population size that a colonised area will support before declining to a new stable level (Lever 1977). Just such a phenomenon was reported by Willemsen (1969), following the colonisation of the IJsselmeer by the zander in the Netherlands.

It has been suggested in the angling press that the scarcity of food due to the over predation of the prey stocks may have encouraged the spread of the zander throughout the Great Ouse system. A review of waters colonised by the zander (Klee, 1981) showed a correlation between the length of time the zander had been present and a reduction in overall stock levels. These waters were all influenced by the same environmental and management activities as those in which stocks were judged to be good but where the zander was absent.

A mechanism describing the decline was proposed by Klee (1981). The zander predated mainly on small fish (Biro, 1977; Popova and Sytina, 1977) and in the Anglian Region this will result in increased predation on the smaller roach and bream. In the mid 1970's while the zander population was expanding; several poor cyprinid year classes were produced due to environmental conditions (Linfield, 1981). This coupled

with increased predation resulted in weakened year classes. As the older fish died they would not be replaced and so a decline in anglers catches occurred.

The levels of zander and pike in some waters during 1979-1980 appeared to be higher than that which could be supported by the recorded prey stocks; this was probably due to the fact that an equilibrium had not then become established. It was feared, however, that the presence of a large predator biomass might have prevented or significantly delayed a return of the prey stocks to their previous levels (AWA, 1980). It was decided therefore that management action should be taken.

1.3.2 Fishery management preceding the project.

The Regional strategy for the management of the zander and the specific proposals for the Middle Level System were detailed in an AWA internal report in 1980 (AWA, 1980). Because of the potential of the zander to cause declines in fish stocks, it was decided that every effort should be made to prevent its spread. The removal of zander by fisheries staff was considered too inefficient and impractical, so it was recommended that anglers should be actively encouraged to remove all zander caught. This was to be done in all waters except the Ely Ouse and the Relief Channel, where it was thought that extensive cannibalism by zander might be an important factor in their population regulation. The removal of zander from these rivers could be counter-productive since it was feared that this might have promoted the survival of young zander (AWA, 1980).

In waters which had not undergone such a serious decline in the cyprinid fishery as the Ely Ouse and Relief Channel, it was hoped that a policy of zander removal would save the fishery from decline.

In the Middle Level system, however, it was proposed that more drastic action was needed to deal with the imbalance of predators and prey. By merely removing zander it would not be possible to restore a favourable balance between predators and prey, due to the large biomass of pike. Pike would also have to be removed.

A target stock level was proposed for a restored Middle Level fishery which would support a good quality fishery (Table 2). To achieve the "hypothetical balanced population" it was necessary to either cull the predators, stock with cyprinids or do a combination of both. It was decided to cull pike and zander and restock with cyprinids to help restore the fish stocks to a level which would be expected to support a good quality fishery (survey results from throughout the Anglian region suggested that a biomass of about 200 kg/ha would be required.)

The following recommendations for a regional policy for the management of zander were put forward in an internal report Water Authority report (AWA 1980).

- a) Anglers should be encouraged to kill and remove zander of all sizes from non-enclosed waters in the region except where a fisheries survey has indicated that such an action would be counter productive.
- b) An amendment to the fishery byelaws would be made to allow a) to be carried out.
- c) An attempt would be made to restore the predator prey balance in the Middle Level system during the 1980-1 and 1981-2 seasons by a combined exercise between the Authority and the regions anglers.

TABLE 1 Comparison between Middle Level Fishery biomasses (1980) and those of a "hypothetical good quality Fishery".

	Total Stock (Tonnes)		kg/ha		Hypothetical Normal levels (kg/ha) for good quality fishery
	Original	Revised	Original	Revised	
Prey Species	6.1	6.3	22	23	200-300
Pike	3.1	2.7	11	10	20- 60
Zander	.8	.6	3	2	NIL
Total	10.0	9.6	36	34	220-360

From A.W.A., 1980

This would entail an 80% cull of all piscivores in the system (culling as many zander as possible with the quota being completed by pike). This would be done in the 1980-1 season with restocking occurring in the 1981-2 season.

TABLE 2

Management targets for culling and restocking.

Quota for Cull of piscivores Kg	Stocking requirement	
	Kg = No @ 100g	= No @ 250g
3117	891	3562

- d) In culling pike the removal of young and small pike would be the most desirable; specimen sized individuals to be left. However if it proved necessary to meet the target larger fish would also be removed.
- e) As far as practical every effort would be made to contain zander within their existing distribution and no consents should be issued for introduction of the species into any waters within the region.

The quota for the Middle Level System broke down into 630kg for zander, which was met by January 1981 (although zander would be continued to be culled) and 2,478 kg for pike. The zander stock was an underestimate so that by February 1981 1,415 kg (984 fish) of zander and 2,971 kg (1,447 fish) of pike had been removed.

The removal of zander and pike was done mainly by anglers with their catches being recorded to monitor the cull.

Restocking of roach and bream occurred in April and May 1981 when 1,188 kg of fish were released at various points within the system and again in February 1982 when a further 187kg of fish were released (Linfield, 1982).

These fish came from drains similar to those of the Middle Level System in Lincolnshire and were distributed around the system resulting in an increase in biomass of 5 kg/ha/yr. These were unfortunately not marked on release and could not be identified subsequently.

1.4 The study site

1.4.1 The Middle Level System

The Middle Level of the fens derives its name from being the middle division of the Bedford Level which occupies the southern half of the great Fenland which includes the Isle of Ely, portions of Cambridgeshire, Northamptonshire, Norfolk and Lincolnshire. The Bedford Level was created by drainage in the 17th Century and divided into three parts for ease of working. The Middle Level (Figure 2) is bounded on the south-east and north-west by the straight artificial channels known respectively as the Old Bedford River and Moretons Leam. Its north-eastern boundary is along Well Creek and the bank called New Powdike, while its south western boundary lies along the edge of the Huntingdon uplands. Altogether this area contains 67,000 hectares of land, of which about 45,000 hectares are actual fenland (Darby, 1936).

TABLE 3

Middle Level drains in direct connection (ie. not separated by locks or other structures).

River	Width (M)	Length (Km)	Area (M ²)
Main Drain (1)	36	16.42	591,192
Sixteen Foot (2)	25	15.30	382,375
New Pophams Eau (3)	28	3.54	99,176
Forty Foot (to Horseways Lock)(4)	17	13.69	232,730
Twenty Foot (5)	25	16.10	402,500
Bevills Leam (6)	14	8.05	112,700
Whittlesey Dyke (from Ashline to Floods Ferry) (7)	15	8.86	132,825
Old Nene Marmont Priory - 20ft(8)	18	4.83	86,940
Twenty Foot Nightingales Corner(9)	14	27.85	389,900
Nightingales Corner-Bevills Leam (10)	15	4.83	72,450
New Cut (North West) (11)	14	3.86	54,040
Yaxley Lode (12)	10	2.74	27,370
Pig Water (13)	6	5.64	33,840
Monks Lode (14)	11	3.86	42,460
Great Raveley Drain (15)	13	4.19	54,418
New Dyke (16)	14	1.60	22,400
Old Pophams Eau (17)	13	3.52	45,760
TOTAL		144.88	2,783,076

From AWA, 1980

Number following river refers to coding on Figure 1.

Figure 1 The rivers of the Middle Level System. (Numbers refer to rivers coded in Table 3).

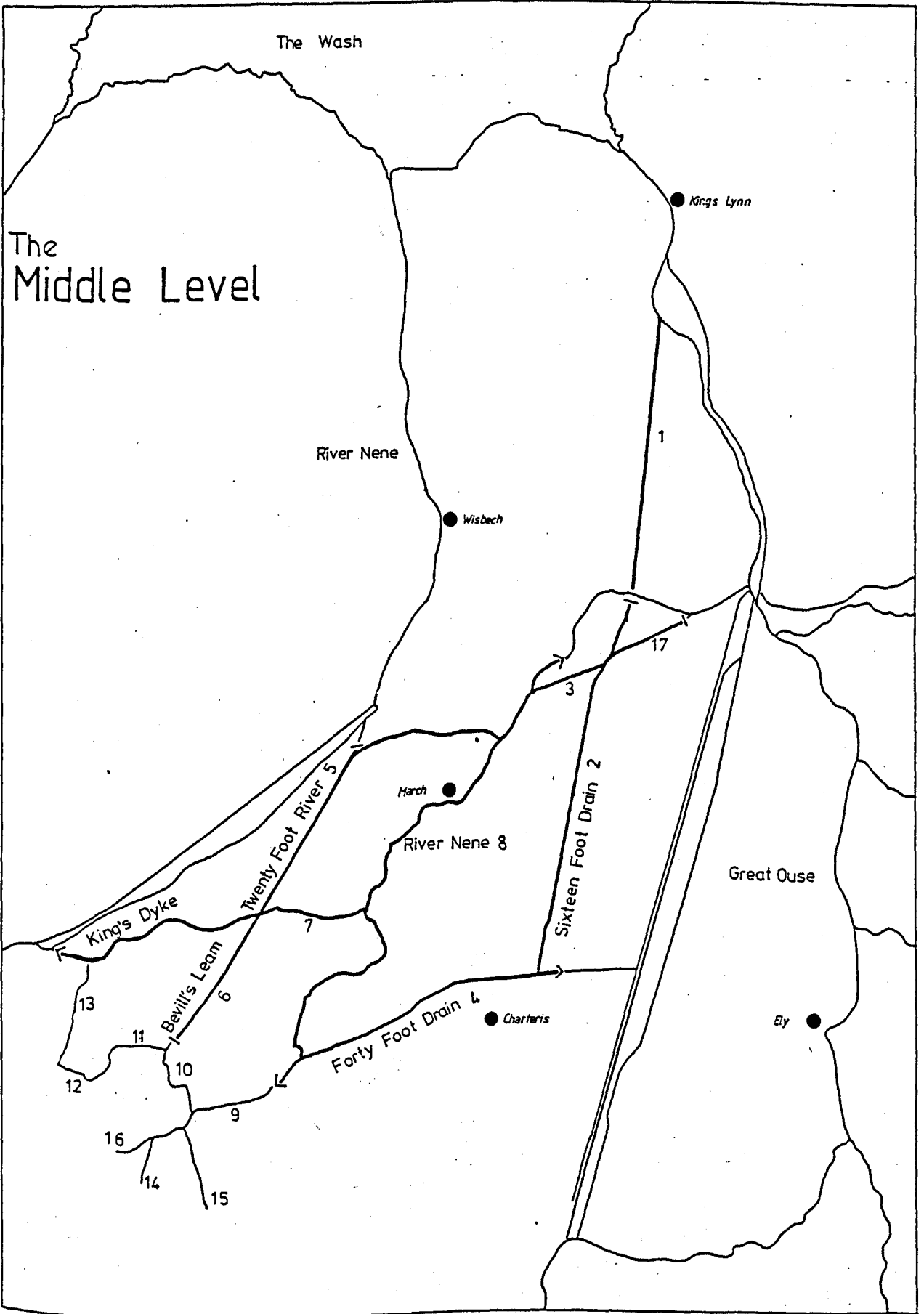
< Locks

| Sluices

~ Main Middle Level Rivers

~ Other rivers

Sampling sites on Sixteen Foot Drain are numbered at consecutive 250 mm intervals from south to north.



The drainage of the Middle Level is achieved by a network of improved rivers and artificial channels (Table 3 and Figure 1) which form an interconnected area of water of about 278 hectares. Since these rivers are all below sea level, water is pumped from the Main Drain at St Germans into the Great Ouse, the outfall of which reaches the Wash at Kings Lynn. Pumping occurs in response to rainfall and is mainly confined to periods of cheap off-peak electricity (i.e. midday or night time) is used to power the electric pumps. At times of heavy rainfall pumping will occur as required. The 4 pumps are capable of pumping on average 4,000 tons of water per minute over the worst tidal period (Middle Level Commissioners, 1983).

This can result in a drop of about 12 inches in the Sixteen Foot Drain in 2 hours. During the summer months pumping is much reduced, since the need then is to maintain the water table in the arable farm land. For long periods the system resembles a linear lake, with little or no flow and this is reflected in both the fauna and flora. Blooms of algae (Vaucharia spp) and stands of Lemna minor often develop in the summer.

The Sixteen Foot, the location of the study, in common with the other drains has a uniform trapizoidal cross-section reflecting its major function of water management. It varies in depth from about 2.5m to 3m at the centre of the channel (Figure A.1 and Table A.1, Appendix A) and is just over 20m wide, running for 16 kilometers in a roughly north-south direction with a total area of 32 hectares.

The Sixteen Foot is organically enriched by effluent from Ramsey Sewage Treatment works, and will also receive nitrate and phosphate inputs from leached fertilizer applications. Since drainage is from some of the most productive and intensively farmed land in England the drain is rich in nutrients.

1.4.2 The fishery

In the 1977 Edition of "Fishing in Anglia" (AWA, 1977) the Middle Level system was described as providing

" freshwater fisheries unsurpassed in England " and a description of the fishery given. "Bream are the predominant species and vast numbers are taken by anglers each season. These are matchmen's waters and catches of 20lb to 50lb of bream are commonly taken during the contests. Roach abound in large numbers but do not reach the size found in the natural rivers of the area. Rudd thrive especially well in the Fen drains and are found throughout the Middle Level area. 2lb and 3lb fish are reported from time to time. Perch are found on most drains, though they are not much fished for. Perch of 3lb and 4lb have been taken. Tench are quite common in the Fen waters where 4lb and 5lb specimens are taken regularly. Pike of great size lurk throughout the drains which are a mecca for pike fishing enthusiasts. Specimens ranging from 20lb and 30lb are taken".

This fishery was joined by the zander which was first recorded in the Middle Level Main Drain in 1970.

Fishing had been particularly good in the 1960's and early 1970's, but in common with most major waters in the Anglian region, fishing for roach and bream was poor in 1977 and 1978 (Klee, 1981). This was probably a result of poor spawning or fry survival in the early 1970's, particularly 1972-74 (Linfield, 1981).

TABLE 4 Water Quality data for selected determinands

Site	Determinands	Mean	n	Variance	Range	95%ile
Horseway's Corner	pH	7.57	14	1.904	4.3-10.2	-
	Temp °C	11.71	16	-	2.0-23.5	-
	DO% Sat Δ	92.3	16	1286.6	57-148	41.24-179.43
	BOD mg l ⁻¹	3.41	16	5.19	1.1-7.7	0.86-9.33
	Ammonia mg l ⁻¹	0.27	16	0.058	<0.05-0.6	0.03-1.03
Ancaster Farm	pH	8.08	4	0.009	8.0-8.2	-
	Temp °C	18.75	4	-	12.0-23.0	-
	DO% Sat Δ	94.3	4	564.6	61-112	56.66-147.68
	BOD mg l ⁻¹	4.15	4	5.95	1.8-7.4	1.23-10.41
	Ammonia mg l ⁻¹	0.22	4	0.022	<0.05-0.4	0.05-0.60
Cotton's Corner	pH	8.19	8	0.099	7.5-8.7	-
	Temp °C	12.40	7	-	4.0-19.5	-
	DO % Sat Δ	91.2	6	490.6	59-117	55.45-141.71
	BOD mg l ⁻¹	4.0	8	4.49	1.1-7.6	1.33-9.37
	Ammonia mg l ⁻¹	0.25	8	0.046	0.05-0.6	0.04-0.81

From Eckstein, 1983

But since the 1978 season, sport with roach in particular improved, as fish from strong year-classes, (i.e. 1975 and later) recruited to the fisheries. This improvement did not occur in the Middle Level System, nor in some other waters where zander were present such as the Relief Channel and Ely Ouse. (Klee, 1981).

1.4.3 Water Quality

The raw data obtained from regular monitoring of the Sixteen Foot Drain (Table A.3 and A.4, Appendix A) by the AWA and Ekstein (1983) was used by the later to investigate selected determinands. An organism has to survive the harshest conditions that occur during its life-time, so the use of mean values may be deceptive. In a discussion of the role of physio-chemical factors, the range will be of greater importance. Ekstein (1983) therefore used 95 % confidence intervals when discussing the effect of water quality (Table 4).

Oxygen levels are known to influence faunal diversity (Clare and Edwards, 1983) but Ekstein (1983) concluded that concentrations were unlikely to be an important factor during his period of study since saturated oxygen concentration never fell below 40% (ASV). Similarly Biological Oxygen Demand (BOD) was never high enough to show any adverse affects.

1.4.4 Invertebrates

A survey of the benthic macro-invertebrates of the Sixteen Foot Drain was conducted by Eckstein (1983) by taking grab samples from the main part of the channel and his findings will be summarised here (Table 5). Quantitative estimates of abundance and composition were made, in order to provide information on the invertebrate role in the productivity of such drains.

TABLE 5 Estimated mean densities and 95% confidence limits for population of macro invertebrates mean per square metre

Species	Horseway's Corner			Ancaster Farm			Cotton's Corner		
	x	C.L.	Dist \square	x	C.L.	dist \square	x	C.L.	dist \square
<u>Bithynia tentaculata</u>				24.7	0-50.1	R			
<u>Valvata piscinalis</u>							49.4	13.4-85.4	R
<u>Potamopyrgus jenkinsi</u>							44.4	10.3-78.6	R
<u>Anodonta cygnea</u>	19.7	0-42.5	R						
<u>Pisidium subtruncatum</u>	345.7	62.2-721.3	C	306.2	216.5-395.8	R	69.2	26.5-111.8	R
<u>Dreissena polymorpha</u>							49.4	85.4-13.4	R
<u>Corophium curvispinum</u>							98.8	0-120.9	C
<u>Sialis lutaria</u>	19.7	0-42.5	R						
<u>Chironomus 'thummi'group</u>	982.7	140-1852.9	C						
<u>Chironomus 'plumosus'group</u>				2829.6	1681.8-3771.1	C			
<u>Cryptochironomus spp</u>	261.7	16-405.3	C	296.3	72.0-501.8	C	212.4	9.3-287.1	C
<u>Polypedilum spp</u>	108.6	2.7-215.3	C				69.2	26.5-111.8	R
<u>Glyptotendipes spp</u>							627.1	63.1-868.4	C
<u>Microspectra spp</u>	395.1	67.6-661.8	C	207.4	16.9-332.4	C	128.3	9.8-198.2	C
<u>Procladius spp</u>	1940.6	1480.9-2345.8	C	1733.3	1266.7-2151.1	C	765.4	129.3-1215.1	C
<u>Tubifex tubifex</u>	3204.9	1658.7-4596.4	C	1832.1	259.6-3017.3	C	1955.5	374.7-3488.4	C
<u>Limnodrilus hoffmeisteri</u>	5432.0	3810.2-6868.4	C	3338.3	1669.8-4288.0	C	5919.9	3538.2-7837.3	C
<u>Limnodrilus cervix</u>	938.0	64.9-1552.0	C	207.4	3.6-302.7	C			
<u>Potamothenix hammoniensis</u>	587.6	22.2-829.3	C	627.1	43.1-936.9	C	414.8	17.8-580.4	C
<u>Potamothenix moldaviensis</u>				558.0	73.3-1067.6	C	839.5	106.7-1389.3	C
<u>Oligochaete+Chironomid m⁻²</u>	13851.2	7263.5-19327.2		11629.5	5086.8-16368.9	C	10932.1	4275.4-15976	

CL - Confidence Limits

dist \square

C = contagious

R = random

From Eckstein, 1983

Data were collected from three sites (Horseway's corner, Cottons Corner and Ancaster Farm) for which physico-chemical determinands were also available. (Table A.5, Appendix A shows the species of macro-invertebrates recorded from the Sixteen Foot Drain.)

Oligochaetes and chironomids were dominant at all sites (97.1%, 96% and 94% of total fauna at Horseways Corner, Ancaster Farm and Cotton's Corner respectively). The abundance of tubificids, however, is not necessarily indicative of organic pollution but more commonly of suitable soft substrates.

The bivalve Pisidium subtruncatum is abundant at Horseway's Corner, while other molluscs are also present in smaller numbers. Furthermore Sialis lutaria is more abundant at this site than at either of the other two sites.

Molluscs are again the most important group at Ancaster Farm, with P subtruncatum predominating.

Species diversity increases with distance down-stream. Cotton's Corner has an increased species richness, Ephemeroptera being present and several species of Trichoptera and Crustacea appearing.

Species with a tolerance to pollution decreased with distance up the drain whilst those with an intolerance to pollution increased. This suggests an improvement of water quality as one progresses down the Sixteen Foot, from the Forty Foot to the Middle Level Main Drain. However substrate might also be an important factor in influencing species distribution.

TABLE 6 Summary of biotic indices for the Sixteen Foot Drain

INDEX		Horseways Corner	Ancaster Farm	Cottons Corner
BMWP		30	31	36
ASPT		3.33	3.87	4.30
Chironomid	%Ii	21.4	17.6	19.3
Exuviae Score	%It	46.2	20.0	30.7
Margalef		3.12	2.94	5.35
Shannon	log ₂	2.86	2.95	2.87
Weaver	log _e	1.98	2.05	2.00
PIE		.79	.82	.74

1.4.5 Biotic Indices

Biotic indices are often used to provide qualitative estimates of water quality by looking at certain indicator species. These indices include BMWP scores (National Water Council 1980) modified to give Average Score Per Taxon (ASPT) values (Armitage et al, 1983), an assessment of the proportion of intolerant individuals (%Ii) and taxa (%It) of chironomid via pupal exuviae (Ruse and Wilson 1983) and diversity indices (eg Shannon Weaver score, Margalef index, PIE indices).

The values of these indices as calculated by Eckstein (1983) for the Sixteen Foot Drain are presented in Table 6. He concluded that factors other than water quality were probably responsible for the distribution of the invertebrate fauna; e.g. substrate and the variety and type of organic debris. He also concluded that the importance of the deep channel was likely to be under estimated by normal sampling methods which are largely limited to the margins. These deeper channel invertebrates also appeared to show decreased diversity compared with marginal sites.

1.4.6 Flora

Whilst macrophytes are important for their role in primary production, the physical and environmental heterogeneity that they provide can also influence the fish community. A survey of the flora of the Sixteen Foot Drain was therefore conducted on both a taxonomic and physionomic basis.

TABLE 7 Floristic data Survey of the flora of the Sixteen Foot Drain

SPECIES	May 1983			July 1983		
	% occurrence	% cover	% fringe	% occurrence	% cover	% fringe
<u>Nymphaea alba</u> L.				41.7	2.6	
<u>Nypfar lutea</u> (L.)	27.8	2.2		58.3	4.6	
<u>Rorippa-nasturtium aquaticum</u> agg.				5.6		
<u>Myriophyllum</u> sp.				47.2		
<u>Callitriche</u> sp.				2.8		
<u>Nymphoides peltata</u> (S.G.Gmel.) Kuntze				2.8		
<u>Alisma plantago - aquatica</u> L.				2.8		
<u>Sagittaria sagittifolia</u> L.				11.1		
<u>Botomus umbellatus</u> L.	5.6		2.1	13.9		1.5
<u>Elodea canadensis</u> L.				2.8		
<u>Potamogeton perfoliatus</u> L.				11.1		
<u>Potamogeton crispus</u> L.	2.3			2.8		
<u>Potamogeton pectinatus</u> L.				2.8		
<u>Juncus effusus</u> L.	2.8			2.8		
<u>Iris psuedoconus</u> L.				5.6		.3
<u>Lemna minor</u> L.	33.3			88.9		
<u>Sparginum erectum</u> L.	19.4		.6	13.9		2.3
<u>Typha latifolia</u> L.				2.8		.1
<u>Carex vesicaria</u> L.	2.8		1.4	5.6		
<u>Carex acutiformis</u>	5.6	9.4	19.4	3.1		
<u>Phyrogmites communis</u> Trin.	47.2	13.7	44.4	15.1		
<u>Glyceria maxima</u> (Hartm.) Holmberg	5.6	.5	22.2	1.2		
<u>Agrostis stolonifera</u> L.	41.7		11.2	40.0		12.0
<u>Cladophora</u> sp.	97.2	46.4	16.4	10.0	71.5	
<u>Enteromorpha</u> sp	11.1	.1	.1	30.6		

% occurrence = percentage of sites at which species was recorded

% cover = percentage of marginal area that each species was estimated to cover

% fringe = percentage of bankside that each species fringed

A brief summary of methods and results will be given here. Sites were chosen at random but structured so that all sections of the drain were covered. A survey site comprised 20m along each bank and 5m into the middle, where the floating plants were found; a grapnel was used to sample any plants out of reach. An estimate of percentage cover was made by eye for floating or submerged plants while an estimate of percentage of the site that they bordered was calculated for the emergent species confined to the margins.

The best time to survey the flora is in mid summer: most of the species present should be visible, since herbicide spraying to kill off the vegetation will not yet have taken place. The vegetation was surveyed in May 1983 to determine the availability of spawning substrate and later in the year to determine the nursery area available to the fry.

In May most of the floating macrophytes are not yet established (Table 7), the flora being dominated by emergent monocotyledous along the margins such as Botomus umbellatus, Sparganium erectum, Carex spp., Phragmites communis and Glyceria maxima. Mats of Cladophora sp. were common along the margins and these began to rise to the surface as the weather warmed up. In July the lilies Nymphaea alba and Nyphar lutea were seen in isolated patches and the flora becomes more well developed.

The aquatic macrophytes of the Middle Level System are subject to a programme of weed control. This involves up to 3 separate applications of herbicides per annum, if necessary followed by mechanical clearance. Two applications of Diquat are made annually to control submerged aquatics and Lemma minor and one application of Glyphosphate to control emergents. Control occurs in mid summer after spawning.

This results in the low percentage cover of floating macrophytes and the restriction of emergents to a narrow band along the bank. The flora in summer is dominated by blanket weed which is a mixture of Cladophora sp and Enteromorpha sp.

It has been shown that the management of drain vegetation can cause stands of Lemna minor to develop, which may deplete oxygen levels (Clare and Edwards, 1983) with harmful effects for the drain ecosystem. There is no evidence of this occurring in the Sixteen Foot Drain, although at times extensive stands of Lemna minor have developed and might prove to be a problem in the future especially if rotting vegetation as a result of herbicide spraying accumulates on the bottom of the drain.

Several possible effects of herbicides on aquatic communities (Brooker and Edwards, 1972, 1975; Newbold, 1975; Scotter et al 1974; Robson and Burrett, 1977; Marshall et al, 1978; Wade and Edwards, 1980; and Wade, 1981 for reviews) and their implications for fisheries have been identified and these are:-

- 1) Direct toxic action on fish and invertebrates (Tooby, 1976; Streit and Peter, 1978)
- 2) Indirect action on the fauna by the change in water quality, decrease in food or loss of substrate (Murphy et al, 1981)
- 3) Loss of structural diversity.

The first is unlikely to occur when approved herbicides are used correctly, whilst a decrease in faunal diversity has been linked to the second (Tyson, 1974; Hanbury et al, 1981). Data collected on

invertebrates and water quality, for the Sixteen Foot Drain, suggests that both are normal and no major fish kills have been reported. The loss of environmental structure probably has the greatest significance when considering zander predation, the marginal areas still supporting large numbers of pike.

The abundance of aquatic macrophytes is greatly reduced both by herbicide spraying and dredging, which results in a deep steep sided channel that is unsuitable for colonisation by most aquatic plants. The reduction in macrophytes means that phytoplankton blooms are more likely, increasing turbidity and further restricting macrophyte growth. Whilst mechanical control of macrophytes often increases species richness (Haslam, 1978), herbicides by eliminating many species will decrease it. Herbicides, turbidity and eutrophication all act to decrease species diversity so that drains such as the Sixteen Foot tend to be dominated by Agrostis stolonifera, Lemna minor and Enteromorpha sp. (Haslam, 1978).

If the channel were to be abandoned it would eventually be colonised as it silted up by many submerged and floating plants. The marginal emergents (especially Phragmites communis) would encroach on the main channel accelerating the serial succession to a terrestrial environment. This succession would not be complete since the fens are ultimately dependent on such drains for their drainage.

1.5 The ecology of drainage channels

Drainage channels are a heavily managed habitat and this has important consequence for their ecology. Dredging and control of aquatic macrophytes by herbicide spraying results in reduced species diversity for both fauna and flora. Marginal areas are reduced and so the deep

benthic habitat become very important when considering the productivity of such channels. Chironomids and tubificids are the dominant groups and this will have important consequences for nutrient cycling. Blooms of phytoplankton will also be common due to the lack of macrophytes, making these waters turbid during the summer months.

The specific ecology of the Sixteen Foot Drain and its importance for the Fish Community will be considered in Chapter 2.

CHAPTER 2.

THE ECOLOGY OF THE FISH COMMUNITY

2.1 Introduction

The success of individual species and hence ultimately the composition of the fish community is largely determined by the nature of a habitat and the particular niches that it provides. The important factors in determining habitat type are its physical structure, nutrient status and climatic conditions. Interactions between the members of the community will also be important in influencing its composition and stability; in this chapter the factors that determine the status of the fish community will be discussed.

2.2 The influence of physical characteristics

The role of physical structure in determining habitat type was first summarised by Carpenter (1928) and Huet (1949, 1954); they both proposed a classification of river types relating the fish community to the width and gradient of the river. The important factor is current flow (determined by gradient) since it is largely responsible for controlling sediment, flora, invertebrates, fauna and temperature and oxygen regimes. Fish species will also be directly influenced by current since species like the common bream will not be able to cope with fast flow rates.

Oxygen levels are likely to be less in slow flowing waters which are deep and wide due to the lack of turbulence and the presence of deep mud and emergent plants. Fish species present will therefore have to be tolerant of low oxygen levels.

The Middle Level System is typical of the bream zone of Huet's classification in that the rivers are deep with little or no flow (except during pumping). Peculiarities due to their function as drainage channels such as the destruction of aquatic macrophytes by herbicide spraying and the reduction of the marginal shallows by dredging means that they are very homogeneous with a uniformly deep cross-section dominated by the mid channel benthic habitat. They resemble shallow linear lowland lakes or ponds with a high allochthonous (or terrestrial input) making them eutrophic with a potentially high production.

The general absence of macrophytes and flow means that the establishment of a phytoplankton community is encouraged as are the development of stands of Lemna sp.)

The Middle Level System has some of the characteristics of both a slow flowing river and of a shallow lake. Having no flow for much of the summer a zooplankton community is more liable to become established than on a typical river. Its linear nature means that the high proportion of marginal or bankside habitat will also be important; management for drainage (macrophyte control and bank maintenance), however, has greatly reduced this habitat and so it lacks the heterogeneity of many rivers. Two main invertebrate communities can be identified; the macrobenthos and that associated with the vegetation (although the latter will be much reduced due to management activities). This alteration in the type of habitats available will in turn affect the fish community (Moss, 1980).

2.3 Nutrient status

The nutrient levels in a eutrophic water like the Sixteen Foot Drain will be expected to influence both the fish community and the observable characteristics of species present, since eutrophication enhances primary production and considerably influences abundance and species composition of plankton, benthos and through these ultimately fish (Willemsen, 1980).

As a water changes from an oligotrophic to an eutrophic nature feeding conditions tend to favour the planktonic and benthic feeding fish which respond by increases in abundance and growth rates. Changes are also seen in the plant community; macrophyte growth may become very dense in shallow waters unless kept clear by management or a cover of Lemna may develop over large areas causing insufficient light to penetrate for photosynthesis and so resulting in reduced O₂ levels. An increase in the phytoplankton community may cause an increase in turbidity which by reducing light penetration may act to inhibit macrophyte growth.

The increase in primary production associated with increased nutrient levels means that there will be a corresponding increase in the amount of decaying organic matter resulting in lowered O₂ levels at the bottom of the water. It will not normally be low enough to cause problems for the fish populations (Huisson, 1976), however, at the end of the summer when the aquatic vegetation dies back or else following weed control large amounts of decaying organic matter are produced fish mortalities may result, especially if temperatures are high producing low O₂ levels.

The response to eutrophication by the cyprinid community would be an increase in abundance of roach and common and silver bream at the expense of species such as chub and bleak which are more exacting in their oxygen and transparency conditions. Production of these populations would be high (Willemsen, 1980).

Vegetation is important in providing cover for pike since it is an ambush predator but also relies on clear water to locate prey. As the nutrient level in a water increase, feeding conditions will improve, especially since prey production will also increase, until turbidity produces a deterioration. This contrasts with the zander which is known to hunt in low light conditions (Popova & Sytina, 1977) and would be expected to replace the pike as the main piscivore in highly eutrophic water, especially if the macrophyte cover is reduced, either due to turbidity cutting off light or else as a result of management.

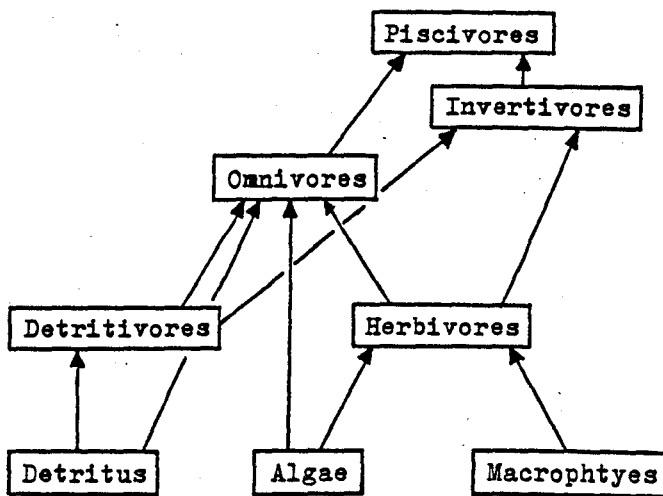
2.4 Energy flow and trophic interactions.

The sources of primary energy in the Middle Level Drains are aquatic macrophytes, filamentous algae, phytoplankton and detritus.

Waters with a high suspended solids load are an ideal habitat for lamellibranch molluscs such as Anodonta anatina; these would be expected to dominate both production and biomass but are too large to be exploited by the fish (Burgis and Dunn, 1978). Other components of the benthic fauna such as gastropods, tubificids, insect larvae and Asellus will be available as food but have about 1/10th the production of the filter feeders. The filter feeding molluscs will thus form an energy sink on the bottom of the river meaning that the primary energy is in a form that is not immediately available to the fish (Burgis and Dunn, 1978). Fish will be better able to utilise primary production when it is in the form of plankton or epiphytic filter feeders. Macrophytes are important for their structural rather than energetic role as they provide areas of shelter where epiphytic invertebrates such as cladocerans can exist.

The major species of fish found in the Middle Level System are roach, common and silver bream, ruffe, perch, tench, bleak, eels, pike and zander. All of these with the exception of pike and eel rely on zooplankton (chiefly cladocerans and copepods) when young. As roach grow their diet includes detritus, filamentous algae and benthic invertebrates. The latter food type, also being of importance to older common and silver bream, tench and ruffe, chironomid larvae being of major importance to ruffe and common bream. Bleak like rudd are primarily surface feeders taking aerial insects as well as other invertebrates. Perch and eels are both facultative piscivores. The eels' diet is generally very wide taking the entire range of bottom living organisms, the incidence of piscivory depending on local conditions.

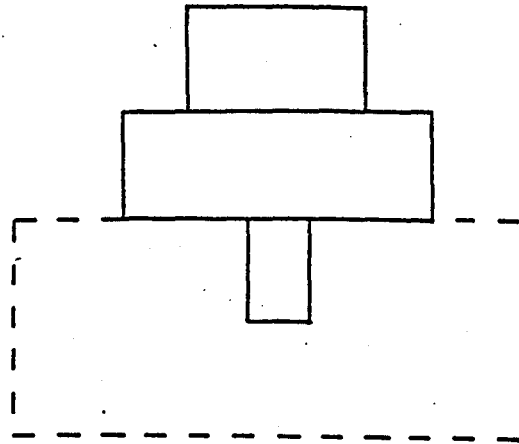
Figure 2 The trophic web of the Middle Level fish community



Macrophytes are of little direct energetic importance , major energy flow will be via detritus ; macrophytes will contribute to detritus , however . Fish species may change between one feeding mode and another.

Figure 3 The trophic pyramid in a riverine habitat (River Thames)

Carnivores	225 kJm^{-2}
Herbivores and detritivores	1050 kJm^{-2}
Primary producers	63 kJm^{-2}
Organic material (detritus)	(not to scale)



From Burgis and Dunn , 1978

In the Sixteen Foot a substantial proportion of the detritus will originate from decaying macrophytes , rather than from allochthonous sources as in the case of a typical river .

Perch predate on a range of free swimming organisms piscivory becoming increasingly important as they grow. The pike and zander are both almost totally piscivorous after the first year.

There are eight main classes of food types (figure 2); detritus, macrophytes, filamentous algae, phytoplankton, benthic and epiphytic filter feeders, benthic herbivorous and detritivores and terrestrial animals. The nature of the habitat will determine their relative importance and hence the way energy flows through the system and ultimately the nature of the fish community.

By far the largest component of energy input is in the form of detritus; benthic, planktonic and epiphytic invertebrates fixing this energy in a form that is available to the fish. The food web will result in a trophic pyramid with a small base unless detritus is included (Figure 3). Detritus whether fish feed on it directly or indirectly will be the major energy source of the fish populations. However, production is generally more efficient when based on an animal food source compared to plant or detrital ones (Burgiss and Dunn, 1978; Sillah, 1982) and so growth rates and levels of production may be below their optimum.

Decaying macrophytes within the Middle Level Drains will be an important component of the detritus since the actual marginal vegetation is much reduced by management. The macrophytes fix the high nutrient inputs from the land but only become available as an energy source as they decay, following either the autumnal die back or else weed control by man.

Lemna sp. will also contribute to the benthic detritus following herbicide spraying during the summer.

The importance of detritus in the Middle Level drains will influence the benthic invertebrate fauna, the major source of food to the fish community. The loss of macrophytes and the creation of a large deep water benthic habitat would be expected to improve the food available to older fish at the expense of 0+ fish. However, the absence of flow in the summer months allowing the build up of phytoplankton and hence zooplankton may compensate for this. The loss of macrophyte may reduce the spawning success, however, since all species except the zander and eels depend on vegetation to some degree for spawning; the zander preferring bare substances. This may mean that recruitment of zander is encouraged at the expense of other species.

2.5 Population dynamics

Data on population structure, diet, age and growth will need to be presented so that the population dynamics of the system can be explored. Whilst these factors are of interest in themselves it is the way in which they interact to determine the structure of the fish community that is the area of major interest in this study.

Their interactions will result in changes in the population dynamics of the component species within a fishery and ultimately the fisheries success. It is necessary therefore to know how variations in diet, age and growth can affect population structure and levels.

2.6 Recruitment and year-class strength

The success of a fishery depends on its ability to consistently provide an adequate number of fish of a desirable size of one or more species. Since populations are dynamic in nature, variations in species composition and abundance within a fishery are to be expected, although generally an equilibrium level will exist. This equilibrium will be established when recruitment of the younger age classes balances the losses due to mortality. The patterns of recruitment and mortality also determine the age structure of the population, variations being important in determining a population's sensitivity to perturbations (Garrod and Horwood, 1982).

Recruitment in fish populations commonly varies between years causing variations in year-class strengths and its occurrence has been well documented for

Roach. Mann, 1974; Diamond, 1983; Linfield, 1981;

Common bream Leemming, 1957; Nikolsky 1973; Backiel and Zawiska, 1968;
Goldspink, 1981; Jordan, 1983;

Zander Van Densen and Vijverberg, 1982;

Pike Kipling and Frost, 1970; Mann, 1976;

The level of recruitment is largely determined by the survival of the young stages (Hempel, 1965). Predation and/or starvation are the prime causes of this larval mortality, which means that the factors that influence competition and predation need to be investigated.

Mortality of older age groups is relatively constant and so variations in recruitment of 0+ fish are largely responsible for the variations observed in adult stocks (Le Cren, 1965).

The potential for recruitment has often been related to the abundance of mature spawners (Ricker, 1975) in marine fisheries where stock levels are variable due to the effects of exploitation. However, in lowland coarse fisheries absolute levels of recruitment are generally highly variable due to the modification of this relationship by other factors.

Variations are often seen in recruitment that are synchronous between waters of different types over wide geographic areas. This implies that factors controlled by climate have an important role to play. For a factor to be responsible for causing variations in recruitment it must be shown to vary itself. Factors that are generally constant between years such as the characteristics of spawning sites and nursery areas, management activities, community composition and population levels will influence the absolute level of recruitment but will not cause variations in year-class strength.

Roach:

The high survival of roach fry has been correlated with warmer summer temperatures.

Diamond (1984) noted the importance of trophic interactions in determining year-class strength.

The abundance of invertebrates (since these may be both the food of young roach and the predators of their larvae and eggs) is important in influencing recruitment. However in some years catastrophic mortalities due to disease or climate may be more important.

Common Bream

Strong year-classes have been linked to high water temperatures during July and August (Goldspink, 1981). Warm summers being thought to produce rapid growth through a reduction of competition due to improved food supply and better conditions of growth making individuals better able to escape predation.

This picture is further complicated when considering piscivores due to the importance of cannibalism.

Pike

Frost and Kipling (1970) showed that year-class strength was not correlated with the numbers of the parent stock, nor with the biomass of the mature female pike which laid the eggs from which the year-class derived. Rather significant correlations were shown with first year growth and the temperature regime pertaining during that first year of life. In particular it was the temperature regime existing in late summer to early autumn.

The important mechanism was thought to be cannibalism; growth in the first year determined survival to age II, since fish less than 200 mm in length were vulnerable to predation by earlier year-classes (Frost, 1954).

Zander

The year-class strength of zander is largely determined in the first year of life because the size to which 0+ zander grow determines their survival rates (and hence year-class strength) since large fish are better able to escape predation (Forney, 1976; Willemsen, 1977). The growth rate of zander depends on both the quality of the initial food

supply, (usually planktonic crustacea) and subsequent success in switching to a piscivorous diet. When environmental conditions are such that the initial food supply is good prey stocks will also benefit. Strong zander year-classes will therefore tend to synchronise with strong prey year-classes, especially since the high availability of alternative prey will tend to buffer the young zander against predation (van Densen and Vijverberg, 1982).

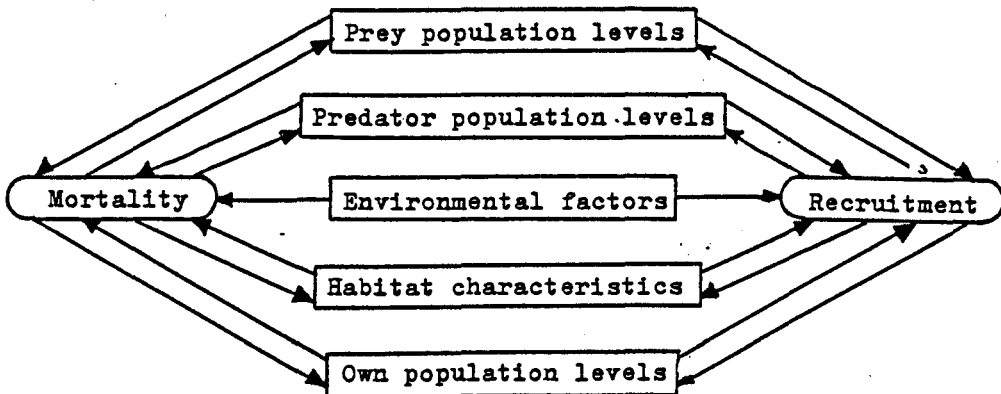
Cannibalism will vary in intensity, being greater in years of poor growth when prey stocks are low, this may cause zander year-class strength to vary with prey stock.

A populations standing crop is a function of the mortality and recruitment rates. Many factors influence these two rates (Figure 4) and through these population levels (Figures 5 and 6).

Predator and prey population dynamics vary due to the importance of cannibalism. Whilst competition can play a regulatory role by linking density to food supply, cannibalism being a more direct link between mortality and density is likely to be of profound importance in piscivore population dynamics (Nikolskii, 1953; Popova, 1965, 1971, 1975).

Variations in recruitment are important not only for their effect on standing crop but on the stability of a population. Species that experience variable recruitment would still persist if they were long lived; alternatively short lived species would need to not vary greatly in their spawning success (Murphy, 1968; Mann and Mills, 1979;). The nature of the environment will also influence the success of reproductive strategies.

Figure 4 Factors that influence rates of change (i.e. mortality and recruitment)



Rates of change

Rate influencing factor

A

B

Indicates that one property (A) has an influence on another property (B) , this influence may be either positive or negative

Figure 5 Factors that influence prey population levels

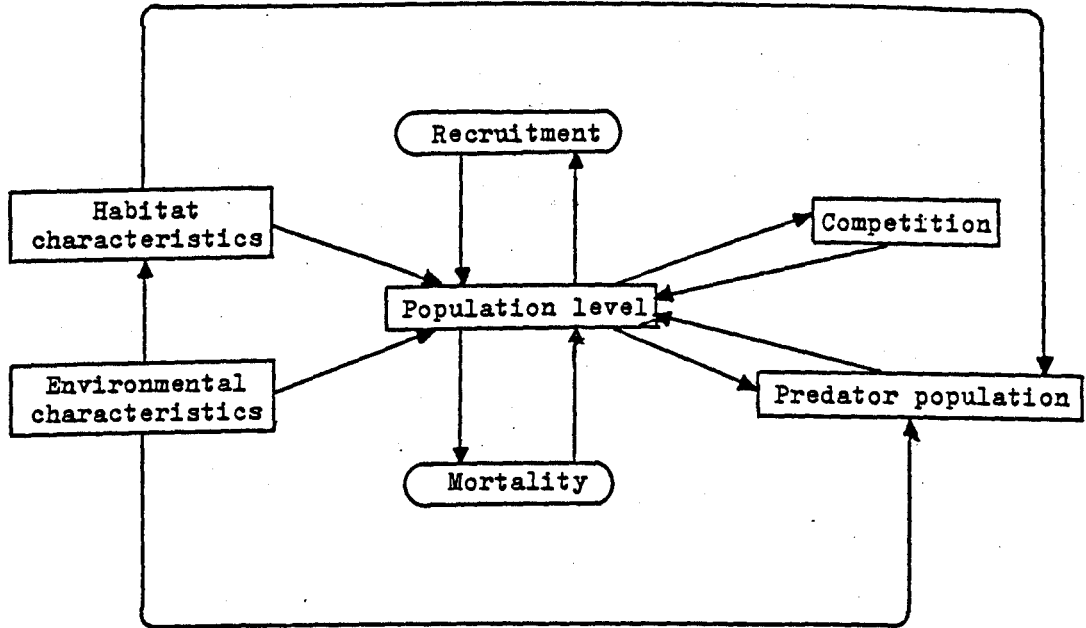
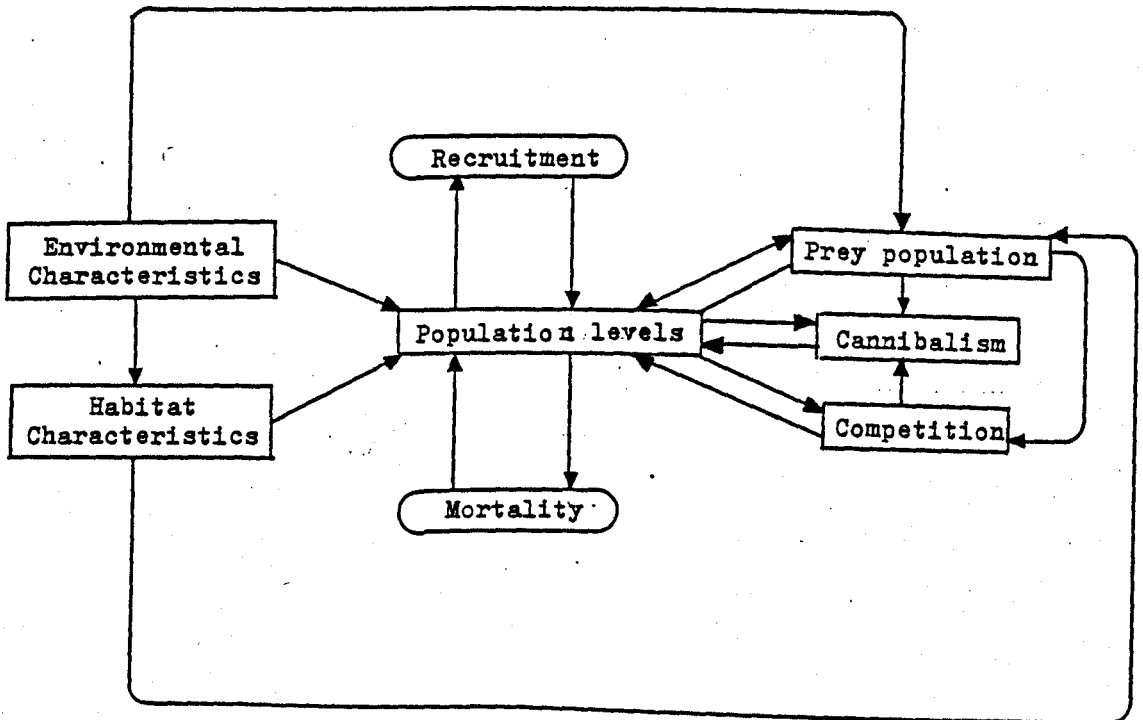


Figure 6 Factors that influence predator population levels



In a fluctuating environment effort should be put into reproduction to maintain recruitment levels; this means that age and size at first reproduction should be respectively lower and smaller, reproduction effort higher, size of young smaller and the number of young per brood higher than in constant environments, where the opposite trend should hold (Stearn, 1976).

Horwood and Shepard (1981) and Horwood (1982) analysed the response of fish populations to random perturbations and their findings have been summarised by Garrod and Horwood (1982).

A term known as the population sensitivity defined as the relative variance of the population per relative variance the recruitment i.e.

$$\text{Sensitivity} = \frac{\text{var (population)}}{\text{var (recruitment)}} \times \frac{(\text{equil. recruitment})^2}{(\text{equil. population})^2}$$

If the other terms are constant then it is found that sensitivity decreases stock (population) size increases. If the variance of recruitment is relatively greater than the variance of the stock then the stock will not drift far from its equilibrium and its sensitivity will be low. Conversely stocks with a low relative variance of recruitment are less responsive and therefore more sensitive to perturbations.

If populations change either in abundance or composition the species interactions will also vary which may bring about concurrent changes in the fish populations. This is the situation encountered in this study we are primarily concerned with the addition of an exotic piscivore and its influence on the fish community.

2.7 The influence of piscivores on the fish community.

Piscivores are capable of influencing both the quantitative and qualitative composition of their prey species and may act to regulate the abundance of both themselves and their prey (Popova, 1978).

The actual impact of a piscivore will depend on how predation is moderated by ecological factors. Under some conditions piscivores can show apparently little controlling effect on their prey stocks; in for example Windermere perch are more numerous than in Ullswater although pike are only present in the former (Le Cren, 1969). It is obviously not sufficient therefore to describe the role of a piscivore without including a detailed examination of how the particular ecological conditions existing within a habitat can influence its outcome.

The behaviour and life history characteristics of both piscivores and prey are their interaction with their habitat and environment, along with perturbations within the populations, will have important consequences for both stability and community structure. Changes due to piscivory may occur in species structure and/or size/age composition and these changes may produce either a new equilibrium or alternatively stable limit cycles, where population fluctuate around a mean.

2.8 Habitat structure

It is known that habitat structure can play a major role in determining the efficiency of a predator (Savina and Stein, 1982; Ware, 1972, 1973). Since the reduction in

".....structural complexity may remove prey refuges and so subject the remaining prey to high risk until they are decimated. The standing stock of prey would be reduced and the long term effect on fish productivity may be negative." (Cooper and Crowder; 1978).

Increased structural diversity would decrease the efficiency of predators and so limit their productivity and biomass.

A specific example is that of Zaret (1979) who followed the changes brought about by the introduction of Cichla ocellaris, a cichlid normally native to South America, to the fish communities of two different habitats. An important insight into the modification of predation by habitat can be given by looking at this example and so a summary will be included here.

In Gatun Lake a numerical reduction was seen of more than 99% in the total number of the twelve common native species and the local extermination of all but one. However, in the other habitat, the Charges River, no local exterminations occurred and a stable predator/prey balance appeared to have been established.

This difference in response appeared to be due to the nature of the two habitats. In the river there are only limited breeding sites which kept recruitment of the piscivore low. More important however are probably changes in water transparency in the river which resulted in decreased feeding activity by C. ocellaris, a visual predator, during the rainy season.

The results from the lake and the river shows that predators can alter species composition by eliminating those species maladapted to cope with a particular predator from the population unless other factors act to modify the efficiency of the predator in some way.

The feeding behaviours of the zander and pike will result in differences in their efficiency as piscivores, in a habitat like the Sixteen Foot Drain, and so one would expect different responses in the fish community.

The zander is an open water predator adapted to hunting in low light conditions often in turbid water, whilst the pike generally relies on cover to stalk or ambush prey for which it requires clear water to locate. The zander is ideally suited to a habitat like the Sixteen Foot Drain which is relatively deep and turbid with much reduced macrophyte cover. It is to be expected that there will be few refuges for prey and that the zander will be much more efficient than the pike in this situation.

In a more complex environment the availability of prey refuges would greatly reduce the zanders efficiency and so prevent it from over predating its prey stocks.

2.9 Community composition

The ecological characteristics of a particular species will determine its populations response to a piscivore and such interactions summed over the entire fish community will determine the species composition and their relative abundance. The impact of a predator will also depend

on the importance of competition in regulating the abundance of its prey species. A predator by limiting one population may improve the feeding condition of another allowing its expansion. Not all species will necessarily be limited by predation some may be limited by food or recruitment factors.

For a species to be vulnerable to predation it must be found in the same area as its predator for at least some part of its life span. Pike are associated with the vegetated margins (Grimm, 1981a) and so will have little direct effect on open water pelagic species (which is the area where the zander hunts) unless species move between habitat types.

Predators often also show preferences for a particular type of prey and this will lead to differences in vulnerability between species which may be reflected in the fish community.

The response of prey populations have often varied on the introduction of esocids to waters new to them. Beyerle and Williams (1968) and Coble (1973) showed that soft-rayed fish were preferred to spiny-rayed ones and hence the introduction of esocids would affect the former most.

Different populations of the same species often behave differently, Beyerle (1971) found that northern pike had little influence on population of blue gills whilst Doxtator (1967) and McCarraher (1957) found that on introducing northern pike their density was reduced.

In comparison Flicklinger and Clark (1978) found that the population of blue gills following such an introduction was drastically reduced although the numbers of carp and black crappies remained the same. The findings of Beyerle and Williams (1968) and Coble (1973) would not have predicted this.

It is apparent therefore that factors other than the qualitative composition of fish species present in a particular community are important in determining the outcome of any predator/prey interaction. The species present and how these are influenced by their environment will be of importance in determining the outcome of any such interaction.

Particularly:

- i) The nature of prey choice (size and species)
- ii) Variations in prey choice between age-groups of piscivore
- iii) The population structure of the piscivore and its variations
- iv) Recruitment of the piscivore
- v) Recruitment of the potential prey species
- vi) Environmental conditions (through their influence on i) to v) above)
- vii) Characteristics of the habitat

i) and ii) are largely fixed for a particular piscivore and so it will only be possible to manipulate iii), iv) v), vi), and vii) by management. The ways of doing so are either by culling, protection or destruction of spawning and/or nursery areas, introductions of new species and changes to habitat characteristics.

Where a predator switches between alternative prey, as their relative densities change, a piscivore may be less likely to over-predate (Southern, 1970).

2.10 The potential for zander to influence fish communities

The efficiency of predation by the zander will depend on the physical nature of the environment, since it is an open water predator that is specially adapted to hunting in low light conditions. The Middle Level System of drains, which are deep and generally turbid, are an ideal habitat therefore; their great homogeneity meaning that refuges for prey species will be few. This makes the opportunity for over predation by the zander on fish prey stocks to be real, although this depends partly on the recruitment potential of the zander and since it is an egg guarder with a high fecundity (135,000 eggs/kg, Fickling; 1982). 0+ zander feed on planktonic crustacea after hatching (during April in Britain) until they have grown sufficiently to switch to a piscivorous diet. If environmental conditions are such that growth is good the growth of their prey species will also benefit (since cyprinid fry also feed initially on zooplankton). Survival and hence year-class strength is known to be greatly influenced by 1st year-growth (Van Densen and Vijverberg, 1982) and so year-class strengths of zander and their prey will tend to be synchronised. The population structure and hence standing crop and predation pressure of the zander will be determined by the pattern of climatic conditions in the past. Since zander of all sizes predate mainly on 0+ and 1+ fish if conditions produce a series of weak year-classes over-predation of these may occur resulting in gaps in the prey fishes population structure.

The zander therefore has potential to influence fish communities but this ultimately depends on the nature of that community and how the biotic and abiotic factors interact. In assessing the role of the zander in any fish community it is necessary to identify the important factors and the way in which a particular habitat may modify them. In the following chapters the data that allows this to be done will be presented and their importance for both the Middle Level fisheries in particular and British fisheries in general will be discussed.

2.11 Conclusions

Differences exist between pike and zander that will determine their effect on the fish community. It is important therefore to identify these differences and how the nature of the Middle System ecosystem influences them.

Trophic interactions are not only important in determining the population dynamics of individual species but also in influencing community structure.

It is not always possible to obtain information directly on these interactions. However, data on stock levels and age structure can show what changes have occurred within the various populations and data on diet and growth rates can show how these have occurred.

The following chapters will attempt to describe the fish populations that are present in the Middle Level System (Chapter 3), the way in which these populations are able to influence each other (Chapter 4) and what changes these interactions have produced (Chapter 5). With this information it should be possible to determine the important processes that are operating within the fishery and hence explore the population dynamics of both the component populations of the fish community and of the community as a whole (in Chapter 6).

CHAPTER 3
POPULATION SAMPLING

3.1 Introduction

In order to describe the fish community, following the cull of zander and pike, it is necessary to sample the various fish populations to provide data on both their magnitudes and interactions. Two main methods were used; seine netting for the collection of quantitative data and otter trawling because of its efficiency in capturing fish. Two other methods, micromesh seining and an analysis of anglers catches were also used when appropriate.

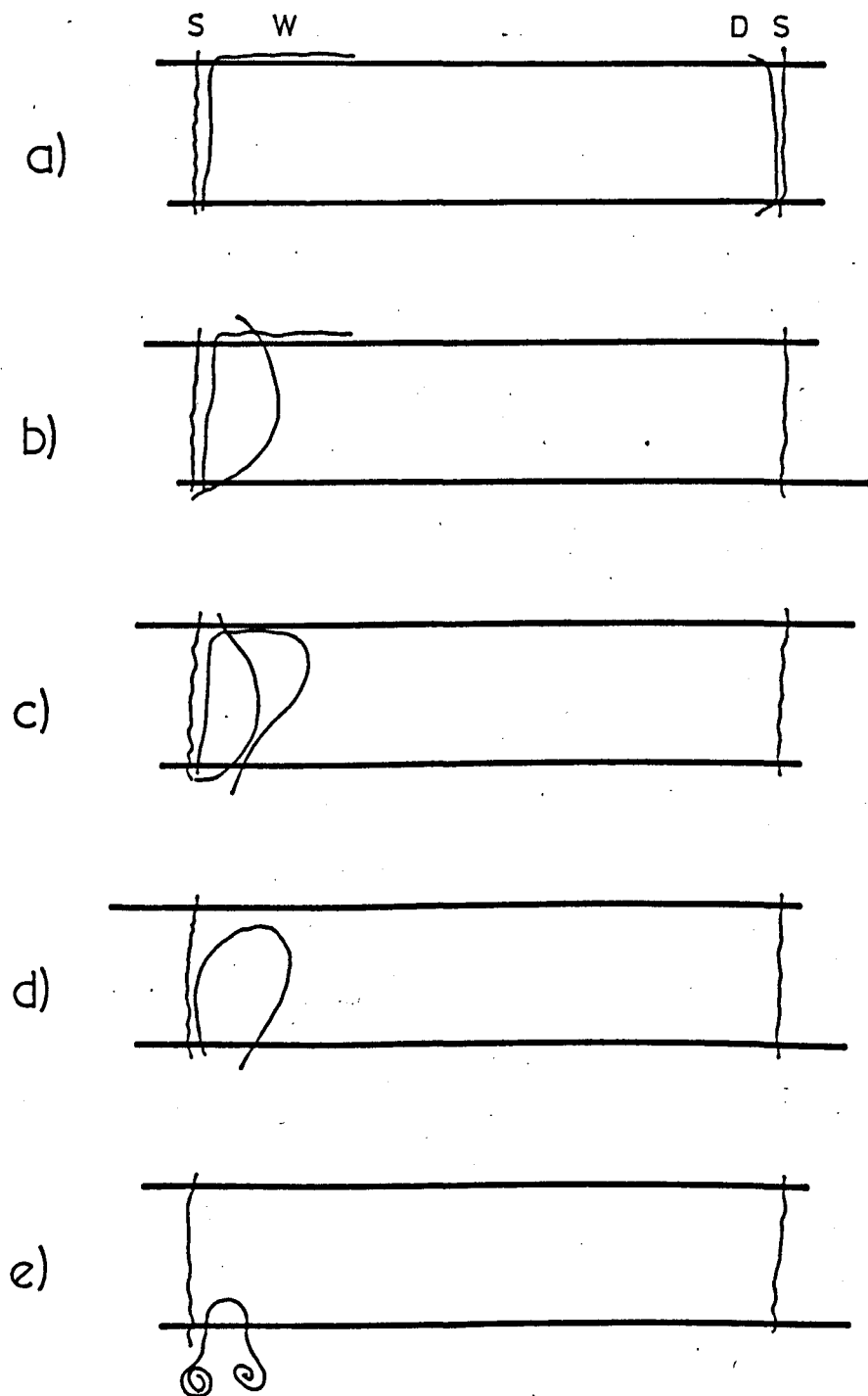
3.2 Methods

3.2.1 Seine netting

The Anglian Water Authority has been involved with the development of quantitative sampling techniques for the assessment of fish stocks since its formation. The rivers in the area, being slow flowing with maintained channels and banks are particularly suited to these techniques. One of the most important methods is the two-net method for netting along a section of a water course (Linfield, 1981a). This was the seine netting technique used in this study (Figure 7).

Figure 7 The "wrap round" seine netting technique.

- a) Stop (s), drag down (D) and wrap round (w) nets set.
- b) After hauling of drag down net.
- c) Setting of wrap round net.
- d) Removal of drag down net.
- e) Hauling of wrap round net.



A site is enclosed by laying stop nets from one bank to the other. The nets being laid simultaneously, to cause as little disturbance as possible to the fish at the sampling site. Two seine nets are then employed; a "drag down net" is laid parallel alongside one stop net, while the other an "encircling net" (which is more than twice the width of the river) is laid alongside the other stop net and along one bank.

The "drag down net" is used to concentrate the fish at one end of the site, where they can be captured by the "wrap round net". This technique has three advantages: it allows large areas to be netted; it permits mark recapture estimates (Petersen, 1886) as well as successive removal estimates (Seber and Le Cren 1967) to be made; and it allows the efficient capture of large numbers of fish.

The nets used were:

- a) stop nets 5m deep by 30m wide
- b) wrap round net 5m deep by 60m wide
- c) drag down net 5m deep by 45m wide

Mesh size was 1/2 inch knot to knot. It was important that the nets were deep and weighted so that they held bottom throughout the haul maintaining efficiency. (The dimensions of the drain (20 - 25m wide by 3m deep) were such that the nets hugged the channel contours). The nets were hauled from the banks, care being taken when pulling them past reed beds and other aquatic and terrestrial vegetation. The best time for netting was early in the year before aquatic plant growth made hauling difficult. The length of sites varied between 150m and 200m. Sites were selected at random but stratified, in order to cover representative sections of the river. 10 sites were covered in a complete survey, so

that in total about 10% of the entire area of the drain was sampled. In this way it was judged that a representative estimate of the population could be obtained.

Population sizes were estimated by the 2 catch method (Seber-LeCren, 1967). Mark - recapture (Petersen, 1886) was not carried out, since at the beginning of the study enough fish of a size suitable for marking could not be caught. The basis of the 2 catch method is the assumption of constant netting efficiency, which allows P (the probability of capture) to be estimated from the following equations.

$$\hat{P} = (C_1 - C_2)/C_1 \quad -(1)$$

C_1 = Total numbers in catch 1

C_2 = Total numbers in catch 2

An estimate of the total no of fish at each site can be estimated from

$$\hat{n} = C_1^2/(C_1 - C_2) \quad -(2)$$

C_1 and C_2 may be for either biomass or numbers caught, if no size selection is occurring, then $P_n = P_b$. However if small fish are being removed preferentially then $P_b \neq P_n$. Alternatively if large fish are being selected for (as in electro-fishing) then $P_b \neq P_n$. By calculating P_b and P_n size selectivity can be investigated.

P can also be calculated for each species separately, enabling selection for species to be adjusted.

Problems will occur if a systematic error is present, e.g. a habitat is missed, and this will be discussed later.

The mesh size of net used means that fish of $\frac{1}{2}$ 70mm were not sampled quantitatively.

3.2.2 Otter Trawling

Specially adapted versions of maritime trawls have become a popular sampling tool for inland water bodies, since they permit the efficient capture of fish from large areas. Often an estimation of standing stock can be derived from the mean catch by computing Catch Per Unit Effort (C.P.U.E) this is an index of abundance and can be used to monitor changes in a water body. Other indexes have also been used (Bannerot and Austin 1983), since the relationship between stocks and abundance is quite complex; C.P.U.E. also being a function of catchability, and this is known to vary with abundance, season, temperature, turbidity, size, age, species, hunger, time of day and the structure of the environment, (Nielsen, 1983). If sampling times, locations and methods are consistent, however, catchability is frequently assumed to be constant (Clady and Nielson, 1978) but this can not be relied upon. The influence of all these Factors on catchability can act to obscure the relationship between C.P.U.E. and true stock abundance. Furthermore, it is often difficult to use C.P.U.E. in comparisons between waters (with notable exceptions Quinn, Hoag and Southward, 1982). An important part of this work will be to compare the fish stocks in waters colonised by zander with those where the zander is absent. This will not be possible

with trawl data alone; however, since trawling permitted the efficient capture of fish it was used to collect material for other parts of this study.

The trawl used was an otter trawl .5m deep by 3m wide; chains were tied to the ground rope ensured that it fished on the bottom. The bag was made of 25mm mesh at the mouth, tapering down to micromesh at the cod end, where there was a trap to prevent escape of fish during hauling. The net did not have wings, the otter boards being attached by ropes to float and lead lines. A bridle fastened to each otter board was used for towing the nets.

The net was fished by a team of two from a 12ft boat, powered by a 15 hp outboard engine, at a speed of 2 knots. Sites were chosen along the length of the drain at random, by stratified random sampling, and were fixed by reference to bank side structures. This allowed the length of trawls to be measured. Trawl lengths ranged between 100m and 200m, and were kept short to minimise damage to the fish. A series of trawls take two days to perform.

3.2.3 Micromesh seining

Small seine nets have been used successfully to obtain samples of small or juvenile fish (Penczak and O'Hara, 1983), and are particularly useful for assessing distribution and species composition of fish. The nets used in this study were made from 2.5mm knotless netting material (Micromesh manufactured by C.J.Field Polynet Ltd) and were 14 m long and 4m deep.

To fish, a net was laid parallel to the bank 5m out, from the back of a small boat. It was then hauled into a semi-circle to the landing beach.

Such nets also proved particularly effective for catching pike of all sizes, due to their habit of lying up amongst the marginal vegetation.

3.2.4 Match Angling

Angler's catches or creel censuses are commonly used to monitor a fishery and have been described by many authors (e.g. Ricker, 1942; Axford, 1979;). The method has several advantages: most of the work is done by others; in assessing "the end product", fisheries biologists may be better able to interpretate survey data; and historical data can be collated (Pearce, 1983) to investigate trends that might otherwise be missed.

In this study a survey was conducted of the catches made by match anglers in the 1983 Great Ouse Championships, held on the Sixteen Foot Drain on the 25th June. The competition was held one week after a comprehensive seine and trawl survey, this enabled the relationship between stock levels and angler success to be investigated. It also provided information on the distribution of large common bream, which it was thought might possibly have been inefficiently sampled by the active sampling methods.

A questionnaire (Figure C.1 Appendix C) was distributed to anglers during the draw for pegs. This questionnaire explained the purpose of the survey and sought information on species composition, weight and numbers, as well as the size range of fish caught and was followed up by some subjective questions on the quality of the fishing.

Observers were present at the weigh-in to collect the returned forms, and to remind anglers to fill them in. Anglers who don't catch anything, "blanks", are often very important; Bannerot and Austin (1983) showed in an analysis of catch data, that transformation of the frequency of zero catches gave the best correlation with abundance. Blanks, however can be the result of different situations: the angler catches nothing and fishes to the end of the match (unlikely) or else he catches less than other anglers and leaves early. This means that when an angler fails to weigh-in fish might still have been caught at that peg, or else fishing effort will vary with catch rate. In both cases the result will be the underestimation of the catch rate. Close vigilance by observers is the answer in such situations.

3.2.5 Processing of the catch

All fish were sorted into species and measured to the nearest millimetre (fork length for all fish apart from eels, which were measured to total length). Fish were kept either in keep nets, or else in bins which were kept oxygenated by the use of an O₂ cylinder and diffusers. On occasions when large numbers of fish were caught and were likely to suffer before they could be processed, a sub sample would be taken and the remaining fish counted.

A variation on this, used for speed and convenience when trawling, was to use a prick board and permatrace paper. This enabled a permanent record of numbers and lengths to be made of each species, which could be worked up later.

Weights were taken by either bulk weighing all the fish after sorting into species utilizing the length weight relationship that had previously been calculated for each species, and the length frequency data.

Fish scales needed for age and growth studies were taken at this stage, and recorded against fish length. All fish were released as soon as processed outside of the stop nets.

3.3 Results

Since the data collected on the fish populations by quantitative seinings are to be used in the formulation of management strategies, it is important that it should provide as accurate assessment of fish stocks. Any selection for size or species will have to be allowed for in the conclusions drawn from these surveys.

3.3.1 Species Selection

By calculating P (the probability of capture in equation (1) above) separately for each species, preferential selection for species by seining has been allowed for. Biases will still exist if a systematic error is present. (Such an error may arise from non-random fish distributions or behaviour).

Large systematic errors will exist in the data obtained from the trawl, since it samples only the mid-channel benthic habitat and so fish found near the surface or in the margins will be under represented in trawl catches. The seine is designed to follow the contours of the channel over its entire depth and will be sampling all the habitats of the major fish species. Species less than 70mm will tend to be missed since they will be able to pass through the mesh. Such species are the three spined stickleback and spined loach, which are of only minor interest in this study. A problem arises when a population is distributed non-randomly; this will affect the validity of deriving a population estimate from the estimates made at each site.

Table 8 shows the mean capture efficiencies by species at each site, for both numbers and biomass. Capture efficiency is high for all species except for eels. (This is only to be expected since eels live on the bottom and are adept at crawling through the debris that may impede the passage of the seine). Pike are potentially another problem species, since they are largely confined to the margins where the vegetation may

TABLE 8 Capture efficiency (%) of seine netting (May, June 1983) based on biomass and numbers.

Species	Probability of capture (Pn) based on biomass			Probability of capture (Pn) based on numbers			Comparison between Pb and Pn	
	X	S	n	X	S	n	t-value	significance
Roach	87.0000	14.10674	7	84.7143	15.49962	7	0.2885	ns
Common Bream	77.7143	32.19583	7	94.667	8.01041	7	1.3120	ns
Silver Bream	89.0000	21.82506	7	90.8571	17.9298	7	0.1740	ns
Roach x Bream	98.4000	3.57771	5	87.3333	31.02687	6	0.7932	ns
Rudd	100.0000	0.00000	4	100.0000	0.00000	4	-	-
Bleak	94.0000	8.48528	2	94.0000	8.48528	2	-	-
Tench	95.0000	11.18034	5	86.6667	28.47923	5	0.6090	ns
Chub	100.0000	-	1	100.0000	-	1	-	-
Spined loach	100.0000	-	2	100.0000	0.00000	2	-	-
Perch	68.0000	30.80909	6	61.8333	27.43295	6	0.3662	ns
Ruffe	71.7143	18.30040	7	72.8571	20.44039	7	0.1102	ns
Gudgeon	100.0000	-	1	100.0000	-	1	-	-
Eels	73.0000	22.37558	4	53.2500	37.18759	4	0.9101	ns
Pike	64.8571	17.71467	7	71.3333	25.79664	6	0.5335	ns
Zander	91.6667	13.86603	6	94.8333	11.76328	5	0.4275	ns

impede the net, care needs to be taken in maintaining contact with the sides of to the channel.

Seine netting will provide an accurate picture of species composition with which to compare trawl catches, since it samples all the main habitats.

A chi-squared test was performed on the number of each species caught by trawling and seining (see Table 9), and a highly significant difference was found between catches. This would be due to trawling, tending to miss the pelagic surface species (e.g. bleak and rudd) and those associated with the marginal vegetation (ie. pike) and so being selective for benthic species such as ruffe.

Trawling is of limited use in the assessment of fish stocks, although it will be of value in collecting benthic species for study.

3.3.2 Size selection

Size selection was investigated by comparing the capture efficiency based on weight (P_b) to that based on number (P_n). If small fish are being selected for, then $P_n \neq P_b$. A t-test comparing P_b with P_n , for each species (see table 8) showed no significant difference between the two. Whilst fish below 70mm are being missed, the results will not have been affected since such fish are not included in the calculation of P_b or P_n .

TABLE 9 A comparison of composition of trawl catch to seine catch by a chi-squared analysis.

Species	Trawl catch (May 1983)		Seine catch (May, June 1983)		% species composition	
	Observed	Expected	Observed	Expected	Trawl	Seine
Roach	338	498.3	12778	12617.7	56.62	84.53
Common Bream	135	37.5	853	950.5	22.61	5.64
Silver Bream	18	12.3	384	386.7	3.02	2.54
Rudd		0.4	11	10.6		.07
Bleak		1.8	48	46.2		.32
Tench		0.9	24	23.1		.16
Roach x Bream	25	3.6	69	90.4	4.10	.46
Perch	11	6.6	163	167.4	1.84	1.08
Ruffe	57	18.3	424	9.55	9.55	2.80
Eels		9.2	243	233.8		1.61
Pike	6	3.7	90	92.4	1.01	0.60
Zander	7	1.4	30	35.6	1.17	0.20
Total	597		15117			

df = 11

Chi-squared = 576.702

Fish below 70mm, for all the major fish species, are immature and whilst these are an important part of the population it is not necessarily a disadvantage to exclude them from seine net catches. By including only mature fish, the mortality of which will be fairly constant, trends in the population will be easier to follow.

The size range of fish caught corresponds to the known size range of the various populations, and so it is safe to assume that the seine captures a representative range of fish present at each site.

A comparison of the age composition of the roach population found by seine netting and trawling in the summer of 1983 is shown (Tables 10 and 11). A chi-squared test showed that a significant difference existed when all fish from 0+ onwards were included. When the 0+ fish were omitted from the test the chi-squared value was not significant. It appears therefore that the trawl is better able to capture 0+ fish than the seine although it could capture even large common bream of over 4lbs.

3.3.3 Biomass Levels

C.P.U.E's are often used with non-quantitative data to investigate trends in stock levels over a period of time. It had been hoped that this would have been possible with the trawl data, but no relationship between catches and stock levels was apparent. The various factors that influence catchability will have acted to disguise this relationship. Estimates of biomass and density have therefore been calculated from seine netting alone.

TABLE 10 A comparison of trawl and seine roach catch age-composition by a chi-squared analysis

Age-Class	Trawl catch (May 1983)		Seine catch (May, June 1983)		TOTAL
	Observed	Expected	Observed	Expected	
0+	442	483.5	7490	7448.5	7932
1+	40	23.2	340	356.8	380
2+	74	58.5	886	901.5	960
3+	16	9.1	134	140.9	150
4+	5	3.5	53	54.5	58
>5+	6	5.1	78	78.9	84
Total	583		8981		9564

df = 5
 chi-squared = 27.546

0+ fish are the 1982 year-class.

TABLE 11 A comparison of trawl and seine roach catch age-composition by a chi-squared analysis

Age-Class	Trawl catch (May 1983)		Seine catch (May, June 1983)		TOTAL
	Observed	Expected	Observed	Expected	
1+	40	32.8	340	347.2	380
2+	74	82.9	886	877.1	960
3+	16	13.0	134	137.0	150
4+	5	5.0	53	53.0	58
>5+	6	7.3	78	76.7	84
Total	141		1491		1632

df = 4
 chi-squared = 3.787

1+ fish are the 1981 year-class

TABLE 12 Summary of Middle Level System seine surveys

	Middle Level Main Drain	Forty Foot Drain	Twenty Foot Drain etc	Sixteen Foot Drain	Sixteen Foot Drain	Yaxley Lode
	1979	1980	1981	1981	1983	1983
Total Biomass (kg/ha)	22.6	30.5	8.9	44.6	195.1	182.0
Zander Biomass (kg/ha)	2.6	0.5	0.03	0.2	4.7	16.0
Pike Biomass (kg/ha)	5.1	3.0	3.0	5.0	21.6	19.0
Non-piscivore Biomass (kg/ha)	14.8	27.0	5.9	39.4	168.8	147.0
Total Density (No/ha)	0.25	1030	40	980	4190	3800
Zander Density (no/ha)	.002	+	+	+	10	300
Pike Density (No/ha)	.001	10	+	10	30	10
Non-piscivore Density (No/ha)	.023	1020	40	970	4160	3500
Author	Klee, 1980a	Klee, 1980b	Klee, 1982	Present Study	Present Study	Noble, 1983

+ indicates density < 0.001

Data obtained by quantitative seine nettings , see section 3.2.1

Trawl and seine catches are summarised for biomass and density in Appendix C.

The changes in density and biomass within the Middle Level System between 1979 and 1983 are shown in Table 12. All these estimates were obtained by the two-net removal method. Stock levels were low for all the waters surveyed between 1979 and 1981. By 1983, however, there had been a fourfold increase in the biomass levels of the Sixteen Foot Drain. Yaxley Lode, another Middle Level drain, was also shown to hold good stocks when surveyed in that year. Similar biomass levels now exist in all the Middle Level System fisheries, as shown by the AWA's ongoing surveys (Noble, pers com.). Densities have also increased, which implies that the increase in biomass is due to recruitment to the fish population as well as the growth of the existing individuals.

3.3.4 Match catches

The match was fished on the first weekend of the 1983-1984 season and it is possible to compare the catches of the anglers with the survey results.

The anglers were fishing on the bottom trying to catch common bream since these would provide the match winning weights. In this they differ from the pleasure angler, who might be after a particular species or simply trying to consistently catch fish regardless of size, in which case he might tend to fish for roach.

TABLE 13 Summary of catches in the 1983 Great Ouse Championship

	Catch Recorded from Returns		Total Catch, species composition derived from returns		No of sites at which species caught	% species composition of catch	
	(Kg)	(No)	(Kg)	(No)		Wt	No
Common Bream	92.11	100	181.51	145	25	93.27	59.88
Eels	3.79	57	7.47	36	29	3.84	34.13
Roach	.13	5	.25	42	3	.13	2.99
Rudd	.30	1	.58	4	1	.30	.60
Trench	.40	1	.80	1	1	.41	.60
Pike	.20	1	.39	1	1	.20	.60
Zander	1.73	1	3.41	1	1	1.75	.60
Perch	.10	1	.19	1	1	.10	.60
TOTAL	98.76	167	194.61	231	51	100.00	100.00

TABLE 14 1983 Great Ouse Championship, summary of match data

Distance between pegs	40m
No of pegs	150
No of pegs fished	120
No of anglers weighing in	74
No of returns received	51
Area fished	15 ha
Total weight caught	194.61 kg
Biomass of fish caught	12.97 kg/ha
Biomass of common bream caught	12.10 kg/ha
Estimated biomass of fish present	124.64
Estimated biomass of common bream present	37.42 kg/ha
Mean weight caught per man	1.62 kg
Mean No caught per man	1.93
Mean Weight caught per man catching	2.63 kg
Mean No caught per man catching	3.12

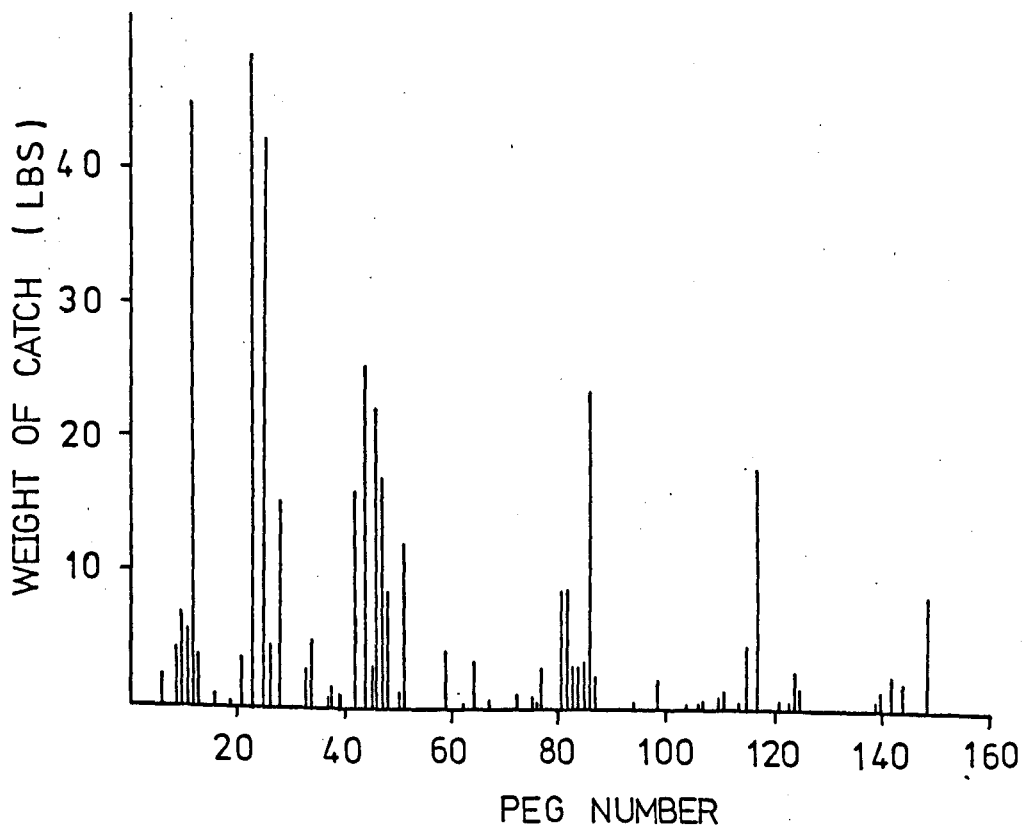
Common bream dominated catches (see Table 13), followed by eels and roach. Other fish caught were rudd, tench, pike, zander and perch. The results show the importance of a few large individuals to a fishery; the winning weights appear impressive but disguise the fact that many anglers were not catching. It appears that the relatively few large fish, which may greatly influence the success of a fishery are subject to quite heavy fishing pressure, a third of the population being caught during the match.

The catch plotted against peg number (see Figure 8) shows the existence of 3 or 4 shoals in a length of about 6 kilometres. The range of a shoal in a match was about 500m, or 8% of the area of the drain. This shows the difficulty of locating shoals and has implications for seine surveys as well as the angler. The more tightly concentrated fish are in shoals the more intensive must be the sampling effort to gain an estimate of similar accuracy to that of a more evenly distributed population. Since common bream are such an important component of the biomass, survey techniques must be able to sample them. 10% of the total area of the Sixteen Foot was sampled in a seine survey.

3.4 Discussion

The biomass levels recorded for the Sixteen Foot Drain have increased by a factor of four between 1981 and 1983. The levels are now comparable with other Anglian waters where fishing is judged to be satisfactory. Linfield 1981 quoted a figure of 200 kg/ha^{-1} as the level where anglers experience good catches, drawing on the experience of the Anglian Water Authority. Anglers were generally satisfied with fisheries where surveys had shown such biomass levels.

Figure 8 Distribution of catches during the 1983 Great Ouse Championships.



A survey of biomass levels from a range of lowland coarse fisheries is shown in Table 15, and it would appear that a figure of around 200 kg/ha is the norm.

The population is dominated by roach (93 kg/ha), eels (42 kg/ha), pike (21 kg/ha), common bream (16 kg/ha) and tench (11 kg/ha). Zander biomass is still very much reduced at 5 kg/ha. The age structure of each of these populations will be important in explaining the dynamic processes occurring in the fishery. Density has also increased and suggests the recovery is due to improved recruitment.

The recovery in biomass levels will be due mainly to increased recruitment and this can best be understood by examining year-class strength, this will be done in Chapter 5.

The cull of pike and zander was implemented because it was feared that in the late 1970's recruitment and mortality were being adversely affected by the presence of the zander. Things had deteriorated so badly that by 1979 - 1980 the predators pike and zander were accounting for 50% of the total biomass (Klee, 1981). It would be expected that this would result in heavy mortality on the prey populations, possibly establishing a new equilibrium population at a much lower level than previously.

TABLE 15 Summary of fish biomasses in selected lowland waters

Locality	Biomass (kg/ha)	Authority
Lakes and Reservoirs in the USA	228-340	Carlander, 1955
Pools in the Labe Region, Czech.	157-1006	Oliva, 1957
Lake Zemzuchojce, Russia	60	Rudenko, 1966
Lake Demenec, Russia	228	Rudenko, 1971
Danube arm Zofin, Czech.	276-292	Holcik and Bastl, 1973
Zaskalska Reservoir, Czech.	200	Svatora, 1981
Rybinsk Reservoir, Russia	170	Gordejev et al 1974
Klicava Reservoir, Czech.	184	Pivnicka, 1982
Sixteen Foot Drain (1983)	195	Present study

TABLE 16 Summary of pike biomasses from selected lowland waters

Locality	Biomass (kg/ha)	Author
River Frome	68.6	Mann, 1980
River Stour	45.8	Mann, 1980
River Vistula	1.82-2.42	Backiel, 1971
River Nene	115	Hart and Pitcher, 1973
River Oulujoki	7.2	Lind and Kaukoranta, 1975
River Pilica	9.26	Penczak, Zalewski and Molinski, 1976
Lake Windermere	6.05	Kipling and Frost, 1970
Lake Demenets	9.3	Rudenko, 1970
Lake Warniak	22.3	Ciepielewski, 1973
Jan Verhoefgracht	10.1	Grimm, 1981 a
Fortgracht	53.4	Grimm, 1981 a
Kleine Wielan	50.1	Grimm, 1981 a
Parkeerterreinsloot	12.0	Grimm, 1981 a
Sixteen Foot Drain(1983)	21.6	Present study

TABLE 17 Summary of zander biomasses from selected lowland waters

Locality	Biomass (Kg Ha ⁻¹)	Author
River Vistula	1.1-1.4	Bakiel, 1971
Klicave Reservoir	2	Pivnicka, 1982
Tjeukemeer	14	Van Zalinge, 1970
Relief Channel	14 - 49	Fickling, 1981
Sixteen Foot Drain (1983)	4.7	Present study

Pike and zander now account for 13.5% of the total biomass; this is similar to that recorded in other Anglian Waters where fish populations are satisfactory (Klee, 1981). Popova (1967) in a review of East European predator fisheries also give this as the usual ratio.

The zander biomass (47 kg/ha) Table 17 is low since it is still being contained by culling, whilst that of the pike (21.6 kg/ha) Table 16 is similar to that found in waters not yet colonised by the zander. Some authors state that zander can influence the abundance of pike (see Chapter 4) especially in habitats that are becoming more eutrophic, and so it is possible that the pike population is being protected to some degree by the continued culling of zander.

When considering predator to prey ratios using standing crop it must be realised that we are really dealing with a dynamic situation. The annual ration of a predator population will depend on the size structure of the population as well as its biomass.

The important factors in the predator-prey relationships of the zander and the pike in the Sixteen Foot Drain will be discussed more fully in Chapters 4 and 6.

3.5 Conclusions

The biomass levels in the Sixteen Foot Drain have recovered from their low in the late 1970's (44.6 kg/ha) to a level (183.1 kg/ha) that is comparable to Anglian Waters where zander are absent. Stocks are now good and there is no evidence of a predator-prey imbalance, both pike and zander biomasses are presently at levels commonly recorded elsewhere.

The zander is probably being kept at an artificially low level of biomass since it is still being culled .

This recovery has also occurred throughout the Middle Level system and the role played by recruitment will be discussed in Chapter 5.

CHAPTER 4

THE TROPHIC INTERACTIONS
OF THE FISH COMMUNITY4.1 Introduction

Within a community, interactions occur between species which influence the abundance, structure and stability of the component populations. These interactions are normally the result of predation or competition and so studies of population dynamics often need to include an analysis of food habits. Such studies are of two types: the investigation of prey selection, and the calculation of consumption rates. Both are needed to determine the magnitude of the species interactions.

Following its introduction, the zander was incriminated in the decline of the resident fish populations which had previously co-existed with the pike. This implies that there may be important differences in the nature of predation exerted by the two piscivores, and that the mode of predation exhibited by the zander may have been responsible for adversely affecting the fishery. It was decided therefore to investigate the diets of both the pike and zander. The principal areas of interest were the size and species composition of prey, and how this varied with predator size. Annual rations were also calculated, and these data will be used in Chapter 6 to investigate trends within the fishery.

4.2 Methods

The detailed methods that permitted the study of the diets of pike and zander as well as the other major species are contained in Appendix D. This includes practical methods for the estimation of diet consumption and prey length and statistical tests. In this chapter it is the nature of the interactions within the fish community that are of major interest rather than a study of the appropriate methods which have already been discussed by numerous authors.

All the fish in this study were obtained during the sampling programme outlined in chapter 3.

4.3 Results

4.3.1 Zander

The most important prey item by weight was the roach (Table 18) for all age classes of zander. Other species consumed were common bream, silver bream, perch and ruffe. Non-fish prey items were only important for 0+ zander, copepods and cladocerans predominated, with chironomid larvae and pupae, dipteran pupae and larvae, Ephemeroptera and bivalve molluscs also occurring. This non-piscivorous feeding mode was exhibited by the young of the year only in the first few months of life, as they grow they switch to a piscivorous diet. (The size of 0+ zander feeding on invertebrates was generally less than 40 mm).

An analysis of the diet by numbers (Table 19) over-emphasises the non-piscivorous part of the diet.

4.3.2 Pike

Roach was the most important prey by weight (Table 20) but a greater range of prey items were encountered in pike stomachs than in those of zander. Other species found were common bream, perch, ruffe, spined loach, 3 spined stickleback, eel, pike and zander, with the occasional small mammal. The non-piscivorous part of the diet was small, largely exhibited by 0+ fish. The main invertebrate prey were chironomid larvae and pupae, odonata and isopods. In an analysis by numbers, the invertebrate component was over emphasised (Table 21).

TABLE 18 Diet of zander by age-class (% wt)

	0+		1+		2+ & 3+		4+& over		Combined	
	%wt	Rank	%wt	Rank	%wt	Rank	%wt	Rank	%wt	Rank
Roach	64.62	1	67.76	1	78.42	1	46.34	1	63.71	1
Common Bream	3.71	4	16.05	2	11.66	2			7.15	4
Silver Bream	10.57	3	11.96	3	3.51	4	35.80	2	17.20	2
Perch	1.30	6	3.94	4	.57	5			.93	6
Ruffe	.37	7			5.72	3	17.87	3	8.68	3
Non-fish	17.28	2			.12	6			2.04	5
Unid.fish	2.15	5	.30	5					.29	7
No of empty stomachs	50		29		13		8		100	
No of stomachs	156		47		30		34		267	

TABLE 19 Diet of zander by age class (%No)

	0+		1+		2+ & 3+		4+& over		Combined	
	%No	Rank	% No	Rank	% No	Rank	% No	Rank	% No	Rank
Roach	10.54	2	56.00	1	81.82	1	46.15	1	18.55	2
Common Bream	.15	6	12.00	3	1.52	5			.64	6
Silver Bream	.29	4	12.00	3	3.03	4	15.38	3	1.14	4
Perch	.29	4	4.00	5	1.52	5			.51	7
Ruffe	.15	6			4.55	3	38.46	2	1.14	4
Non fish	87.43	1			7.58	2			76.50	1
Unid. Fish	1.17	3	16.00	2					1.52	3
No of empty stomachs	50		29		13		8		100	
No of stomachs	156		47		30		34		267	

TABLE 20 Diet of pike by age-class (%wt)

	0+		1+		2+ & 3+		4+& over		Combined	
	%wt	Rank	%wt	Rank	%wt	Rank	%wt	Rank	%wt	Rank
Roach	95.14	1	57.22	1	81.12	1	51.39	1	57.67	1
Common Bream	2.62	3	7.90	3	.38	6	2.62	5	2.26	6
Perch			28.75	2	1.71	5	.27	7	1.10	7
Ruffe			.95	8	10.57	2	1.45	6	3.21	4
Sp.Loach			.68	7	.06	8	.04	8	.06	10
3 Spined Stickleback			.95	8	.14	7			.05	11
Eel							13.98	3	10.87	3
Pike					3.46	4	26.67	2	21.41	2
Zander					25.8	3			.50	8
Mammals							3.58	4	2.78	5
Non Fish	3.12	2	3.54	4	.01	9			.10	9
No of empty stomachs		7		11		30		10		58
No of stomachs		27		36		79		45		187

TABLE 21 Diet of pike by age-class (%No)

	0+		1+		2+ & 3+		4+& over		Combined	
	% No	Rank	% No	Rank	% No	Rank	% No	Rank	% No	Rank
Roach	53.70	1	24.07	2	75.32	1	75.76	1	61.62	1
C. Bream			3.70	4	1.30	7	5.05	3	2.82	5
Perch	1.85	3	7.41	3	2.60	4	4.04	4	3.87	4
Ruffe			1.85	5	7.79	2	7.07	2	4.93	3
Sp.Loach			1.85	5	1.30	7	1.01	7	1.06	7
3 Spined Stickleback			1.85	5	3.90	3			1.41	6
Eel							3.03	5	1.06	7
Pike					1.30	7	1.01	7	.70	10
Zander					2.60	4			.70	10
Mammals					1.30	7	2.02	6	.70	10
Non-fish	42.6	2	59.26	1	2.60	4			8.80	2
Unid. Fish	1.85	3					1.01	7	1.06	7
No of stomachs		7		11		30		10		58
No of stomachs		27		36		79		45		187

Pike took a wider range of prey types than the zander which fed mainly on shoaling fish. This difference is probably due to the pike being an opportunist; small mammals as well as eels, spined loach and sticklebacks being predated. Cannibalism was recorded only in pike which also predated on the zander. As zander grew their range of prey items decreased this contrasts with the pike where it increased.

4.3.3 Tests of significance

In the tests of significance the invertebrate component of the diet will be ignored since we are mainly concerned with the effect that the piscivores have on the fish community. (An analysis on the raw data, using numbers, was performed since the size of the prey items were generally of the same order of magnitude).

The data were tested to show selection by pike and zander of the major prey species : roach, common bream, silver bream, perch and ruffe (Table 22). A zero value indicates no selection; values up to +1 indicate positive selection and values down to -1 indicate negative selection. The chi-squared value indicating the degree of significance to be attached to the result. (see Appendix for an explanation of methods).

Zander were shown to be taking prey in the proportion in which they were available, except for common bream. The reason for the negative selection of common bream is the large average size of fish in this population, most individuals being safe from predation. Pike were shown to positively select ruffe and perch and negatively select roach (Table 22).

TABLE 22 Preference of piscivores

PREY SPECIES	ZANDER				PIKE			
	V	$\frac{X^2}{y}$	C	X^2	V	$\frac{X^2}{y}$	C	X^2
Roach	-0.006	0.431	-0.007	0.585	-0.019	4.161*	-0.020	4.131
Common Bream	-0.017	3.629	-0.019	4.251*	-0.015	2.608	-0.016	1.7558
Silver Bream	0.017	3.479	0.015	2.691	-	-	-	-
Perch	0.011	1.589	.008	.847	.046	24.841***	0.043	2.9058***
Ruffe	0.012	1.811	.010	1.278	.023	6.556*	0.022	5.6913*

1df

Chi-squared 0.05 = 3.841

Chi-squared 0.01 = 6.635

Chi-squared 0.001 = 10.828

Values of V and C range from -1 to +1 , no selection corresponds to avalue of 0
 -1 and +1 correspond to maximum negative and positive selection respectively

TABLE 23 Comparison between zander and pike diets (G-statistic see Appendix E)

	Zander	Pike	Ni	Gi
Roach	175	146	321	.2536
Common Bream	8	5	13	.1687
Silver Bream	11	4	15	1.9446
Ruffe	14	9	23	.2314
Nj	208	164	372	
Gj	1.0229	1.5753		2.5982

$$X^2_{.05}[6] = 12.592 \quad X^2_{.01}[6] = 16.812 \quad X^2_{.001}[6] = 22.458$$

TABLE 24 Diet of different age groups of zander (G - statistic)

	0+	1+	2+0 3+	Ni	Gi
Roach	72	14	54	140	1.5612
Common Bream	1	3	1	5	5.9202
Silver Bream	2	3	2	7	3.7080
Perch	2	1	1	4	.4959
Nj	77	21	58	156	
Gj	1.9727	8.8303	.8823		11.6853

$$X^2_{.05}[6] = 12.592 \quad X^2_{.01}[6] = 16.812 \quad X^2_{.001}[6] = 22.458$$

TABLE 25 Diet of different age groups of pike (G - statistic)

	1+	2+&3+	4+&over	Ni	Gi
Roach	13	58	75	146	.9286
Common Bream	2	1	5	8	3.0035
Perch	4	2	4	10	5.6658
Ruffe	1	6	7	14	.3404
Nj	20	67	91	178	
Gj	6.4033	3.0790	.4560		9.9383

$$X^2_{.05}[6] = 12.592 \quad X^2_{.01}[6] = 16.812 \quad X^2_{.001}[6] = 22.458$$

Tests for differences in choice of the major prey species for both pike and zander (see Tables 23,24,25) showed no significant difference between age groups of piscivore or between piscivores. However as already stated the range of prey is different for both species. Analysis of seasonal and yearly variations in the composition of diet, (Tables E.1 to E.8, Appendix E) was complicated by the low numbers of fish present each year. This necessitated pooling of data. However, due to the changing population structure of the pike and zander after the cull, trends between size classes of predators tended to disguise those between seasons and years.

It is sufficient to say however, that in all months, throughout the period of the study pike and zander fed predominantly on fish, mainly roach. This supports the pooling of the diet data for the three years of the study in the analysis (Tables E.1 to E.8, Appendix E).

The size range of the age-classes of pike and zander sampled are shown in Figures E.1 and E.2.

4.3.4 Relationship between predator and prey size (for pike and zander)

The relationship of prey to predator size is shown by Figures 9 and 10. The fork length of the piscivore is compared to the fork length of roach in the form of a scatter diagram, and the size range of prey taken by each age-class of predator is displayed as a kite diagram. The only prey species plotted is roach, since this is the most important prey item; there being insufficient data for other species. However, the size ranges of other species eaten was similar to that of roach.

Figure 9 Size of roach predated by zander, 1980-84

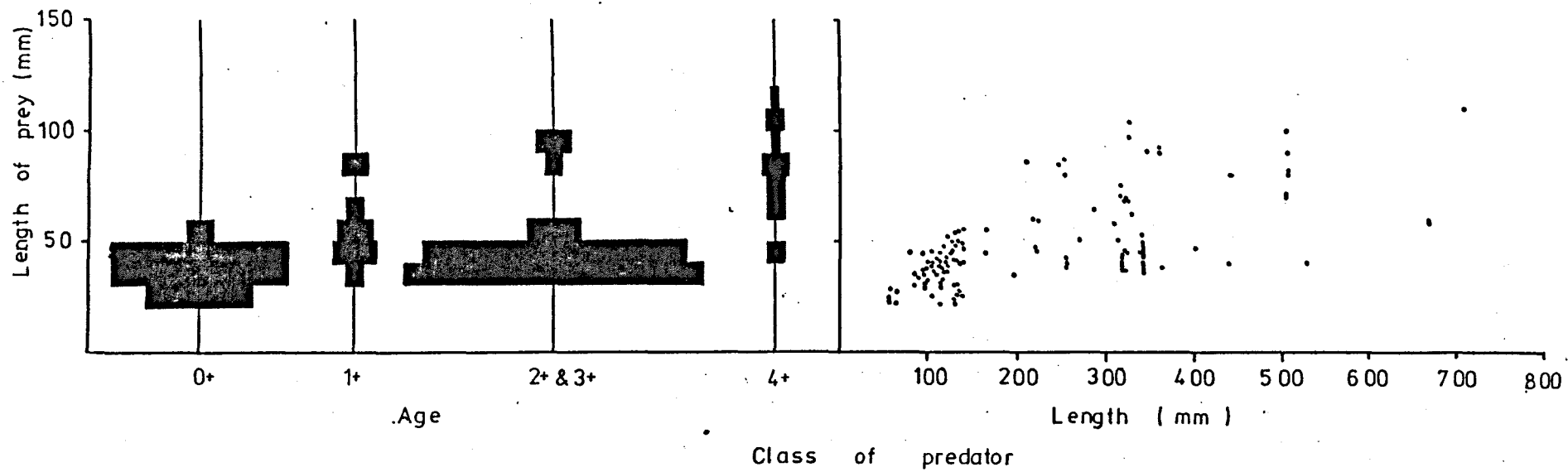


Figure 10 Size of roach predated by pike, 1980-84.

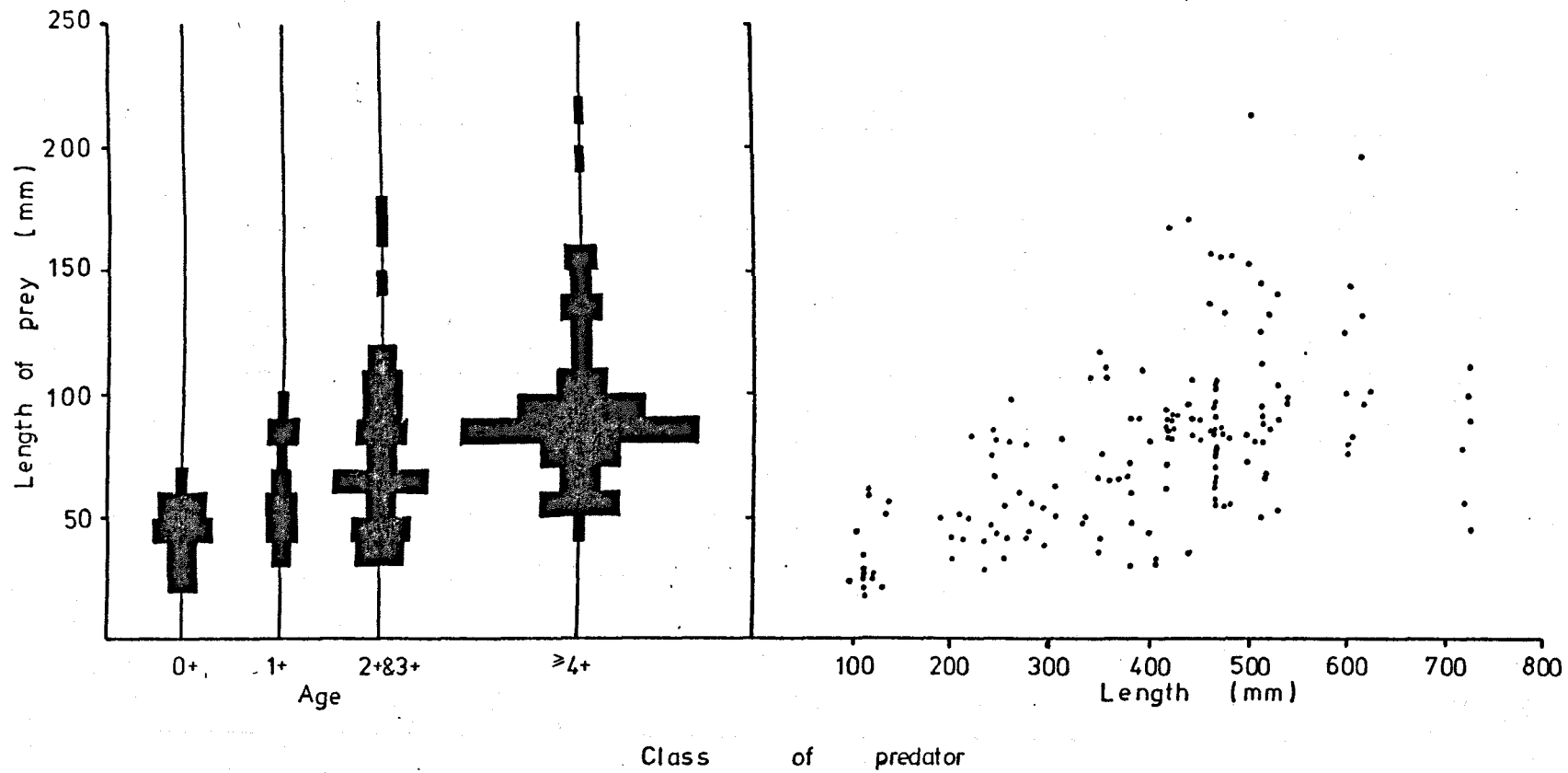


TABLE 26 Selective predation of roach age classes by zander

Age-class of zander	0+		1+		2+	
	% No.	% Wt	% No.	% Wt	% No.	% Wt
0+	100	100				
1+, 2+ & 3+	87.9	61.6	12.1	38.5		
>, 4+	13.0	2.2	56.5	43.1	30.4	54.76

TABLE 27 Selective predation of roach age-classes by pike

Age Class of Pike	0+		1+		2+		3+		>4+	
	% No	% Wt	% No	% Wt	% No	% Wt	% No	% Wt	% No	% Wt
0+	94.44	78.87	5.56	21.13						
1+	53.33	20.07	46.67	79.93						
2+ & 3+	30.43	3.61	47.83	25.80	15.22	19.40			6.52	51.20
>4+	11.54	0.79	57.69	18.01	8.97	6.62	7.69	10.50	14.10	64.08

It can be seen that the zander population predated on fish predominantly smaller than 80 mm. Even fish 4 years of age and older still predated on this size of prey. No prey fish greater than 110 mm (i.e. fish older than 2+) were found in any sized zander. Even as large roach became more common in the later years of the study, predation was concentrated on the small fish.

A similar graph for pike Figure 10 shows that whilst small pike are restricted to small prey items, as they grow the range of prey sizes increases, so that most of the roach population will be vulnerable to predation by pike older than 3. Large pike were taking large prey in all of the years of the study, although these were scarcer in the early years of the study. This may suggest a preference for large prey.

These conclusions about selective size predation of pike and zander may hold true for other species of prey, although it is to be expected that the morphology of the particular prey fish will also be of importance. Deeper bodied fish (e.g. common bream), or those with protective spines (e.g. ruffe), may be afforded some protection against predation at a smaller size than roach.

4.3.5 Consumption of Pike and Zander

Using the methods of obtaining annual predator consumption from field data described by Popova (1967), the annual consumption of prey fish by pike and zander was 254% and 273% of their body weight respectively.

The consumption of predators and their effect on their prey populations will be discussed in depth in Chapter 6.

4.4 Discussion

4.4.1 Comparison between diets of major piscivores

The zander is to be found in lakes and larger rivers, where it hunts in areas of open turbid water. Its feeding mode was summarised by Popova and Sytina (1977).

"The zander is an ambush pursuit predator that feeds at low light intensities or at night. It is always found with a complex of other species and becomes a fish predator within a few months of hatching. When zander become predatory the main food is immature and young schooling fishes up to 200 mm long, which inhabit open water. Zander often eat large numbers of their own kind when other food fish are scarce".

The pike, in comparison whilst still being found in lakes and rivers, is associated primarily with the vegetated margins which provide cover, allowing the pike to attack its prey at great speed over a short distance. It also takes a very wide range of prey size (up to 30% of its own body weight Schols; 1933). Pike are known to be cannibalistic and this may act to give an even spaced pike population (Pitcher, 1980).

Popova (1967) compared the diets of zander and pike and confirmed those observations, saying that the zander fed on small pelagic shoaling fish, whilst the pike feed on the larger fish that were found in the marginal vegetation. Despite these differences, prey choice appeared to be governed solely by availability.

That prey choice is determined largely by availability is confirmed by a review of the literature.

The main prey species of the zander are cyprinids, coregonids, perch and smelt, with smelt being the preferred prey if present (Deelder and Willemsen, 1964; Wiktor, 1962; Rundberg, 1977). It is stated by Deelder and Willamsen (1964) that all the small fish that occur in a water will be utilized as prey. To date only three studies of the diet of the zander have been conducted in England (Linfield and Rickards, 1979; Fickling, 1982; Hickley and North, 1983). Fickling (1982) included the Middle Level system in his study and found that the major prey item was roach, followed by common bream, perch, silver bream, and ruffe, roach being the most abundant species in the environment. These findings are similar to those of the present study. In the other water studied by Fickling (1982) (Coombe Abbey Lake, the Relief Channel, The Oxford Canal and Burwell Lode) roach were again numerically dominant in both zander stomachs and the environment. He also noted the presence of 0+ zander as a prey item for Relief Channel Zander.

The feeding of young zander has received much study and it has important consequences for growth rate; growth rate affecting survival and year-class strength (see section 2.6).

Zander up to a size of about 50 to 100 mm (Nagiec 1977) are known to feed on zooplankton. When they switched to a piscivorous diet depends on the availability of prey fish. The way in which the diet changes in the zanders first months of life was summarised by Deelder and Willemsen, 1964 (Table 28).

Variations on this scheme are frequent and will depend on availability of prey. Where zander are not able to undergo the transition from preying on zooplankton to fish, they will continue to feed on plankton and will exhibit a reduced growth rate.

These observations are consistent with the findings of this study. 0+ zander initially fed mainly on zooplankton (copepoda and cladoceran) changing to fish (chiefly roach) in mid Summer.

Table 28 Food of Young Zander

Approximate length of zander (mm)	Most important Food Organisms
6 - 9	Nauplius - larvae and Copepodites
10 - 20	Copepoda (Eurytemora and Cyclops)
20 - 30	Copepoda and juvenile Neomysis
≥50	Smelt or other suitable fish prey

(After Deelder and Willemsen, 1964.)

Some 0+ zander were found in the later months (August, September) which were much smaller than others of the same cohort. On examination, they were found to be the only individuals feeding solely on zooplankton, presumably having failed to make a transition to preying on fish. A possible explanation for this failure can be put forward. Since 0+ zander can only predate fry 50% less than their own body length, if the

initial food supply of the zander is poor, or environmental conditions (mainly temperature) are unfavourable, growth rate will be slow. This would lead to the possibility that some zander will be too small to predate on fry, and so a polymodal length frequency will be seen for 0+ zander. In years of favourable environmental conditions and ample food supply, the ratio of the abundance of the bimodal growth forms of zander will increase in favour of the faster growing individuals. This in turn will increase the survival rate of the 0+ zander, since they will be better able to escape predation (Forney, 1976; Willemsen, 1977).

Like zander, the composition of the diet of the pike appears to be largely determined by the availability of suitable prey species, and is mainly composed of fish (Healy, 1956; Seaburg and Moyle; 1964; Hunt, 1965; Lawler, 1965; Neuhaus, 1934; Heffer, 1944; Steffens, 1960; Frost, 1954; and Mann 1982). The prey species listed by Frost (1954) and Mann (1982) comprised nearly the entire fish fauna at each site. Perch were the dominant species, both in Windermere and in pike stomachs, (Frost, 1954), but in the River Frome pike were feeding mainly on roach which were the dominant species.

A wider range of prey species was taken by the pike than by the zander. Species that were absent in the diet of the zander were eels, stone loach, 3 spined sticklebacks, pike and zander. This implies that whilst, availability determines choice for the major species the mechanisms governing diet choice may be more complex than at first thought. Models describing the type of predation exhibited by pike and zander will be discussed.

4.4.2 Models describing prey selection

The pike generally "lies in wait" for suitable prey, so the likelihood of any individual prey item being predated will depend on the frequency with which it encounters a pike. The zander, however "tends" to forage actively, and so will presumably be able to increase the encounter and hence predation rates, at low prey densities.

Three models to describe prey-selection were proposed by Ricker (1952).

- A. Predators of any given abundance take a fixed number of the prey species during the time they are in contact, enough to satiate them. The surplus prey escapes.
- B. Predators at any given abundance take a fixed fraction of prey species present, as though there were captures at random encounter.
- C. Predators take all the individuals of the prey species that are present in excess of a certain minimum number. This minimum may be determined in different ways: a) There may be only a limited number of secure habitable places in the environment, so that some prey are forced to live in exposed situations where capture is inevitable. The number of such secure niches may be partly governed by territorial behaviour of the prey. b) The maximum "safe" density of prey may be the one at which predators no longer find it sufficiently rewarding to forage for them, and move to other feeding grounds or switch to an alternative prey species.

The three models will tend to intergrade but it is useful to take account of their differences.

Each of these models can be described by a functional response (Holling, 1959, 1965) where the intensity of predation is some function of prey density (Figure 4A). The nature of the function of pike and zander was examined by plotting the percentage of piscivore stomachs containing fish prey against year (there having been an upward trend in fish density between 1980 and 1984).

From figure 4B it can be seen that the intensity of zander predation has remained the same whilst that of pike predation has increased following the increase in prey density.

It is likely that pike predation is of the B type, where the number of prey eaten is proportional to their abundance. The pike is an ambush predator, so the encounter rate will be a function of the density of prey and the availability of cover. This model was also used by Mann (1982) to describe River Frome pike predating on dace.

Individual zander are known to forage over wide areas (Gourbier, 1977; and Fickling, 1982), predating on shoaling fish. Its response to a decrease prey availability will presumably be an increase in searching behaviour, until it locates new prey. At low prey densities it will therefore presumably be able to increase encounter rates and thereby maintain consumption of prey. Zander predation will tend therefore towards type A. The main characteristic of such a situation is that the number of prey eaten depends on the abundance of predators. This will result in an increase in abundance of the predator, (unless recruitment is limited in some way and so large scale reduction of the prey will

Figure 4.A Functional Responses

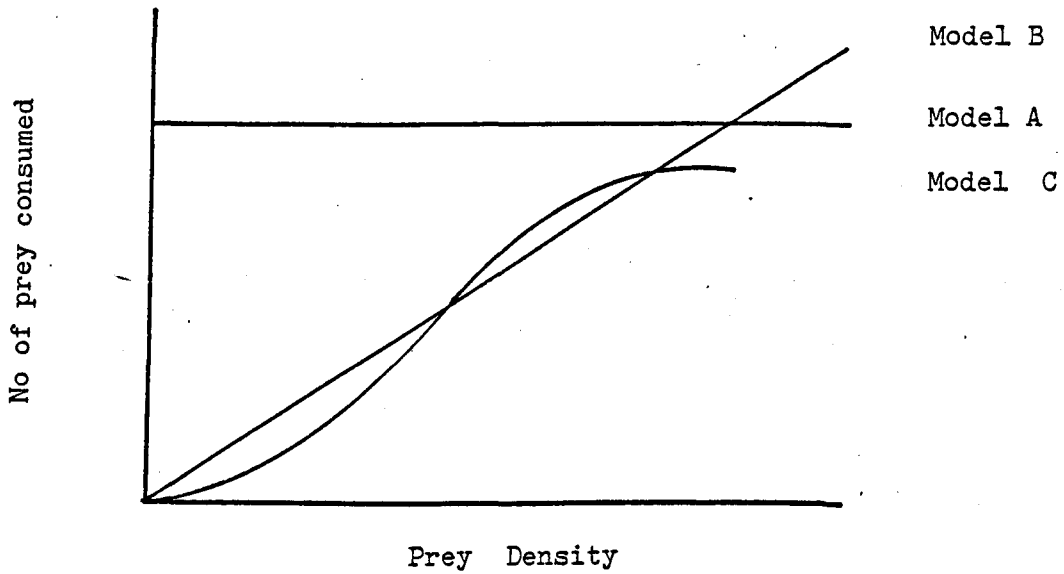
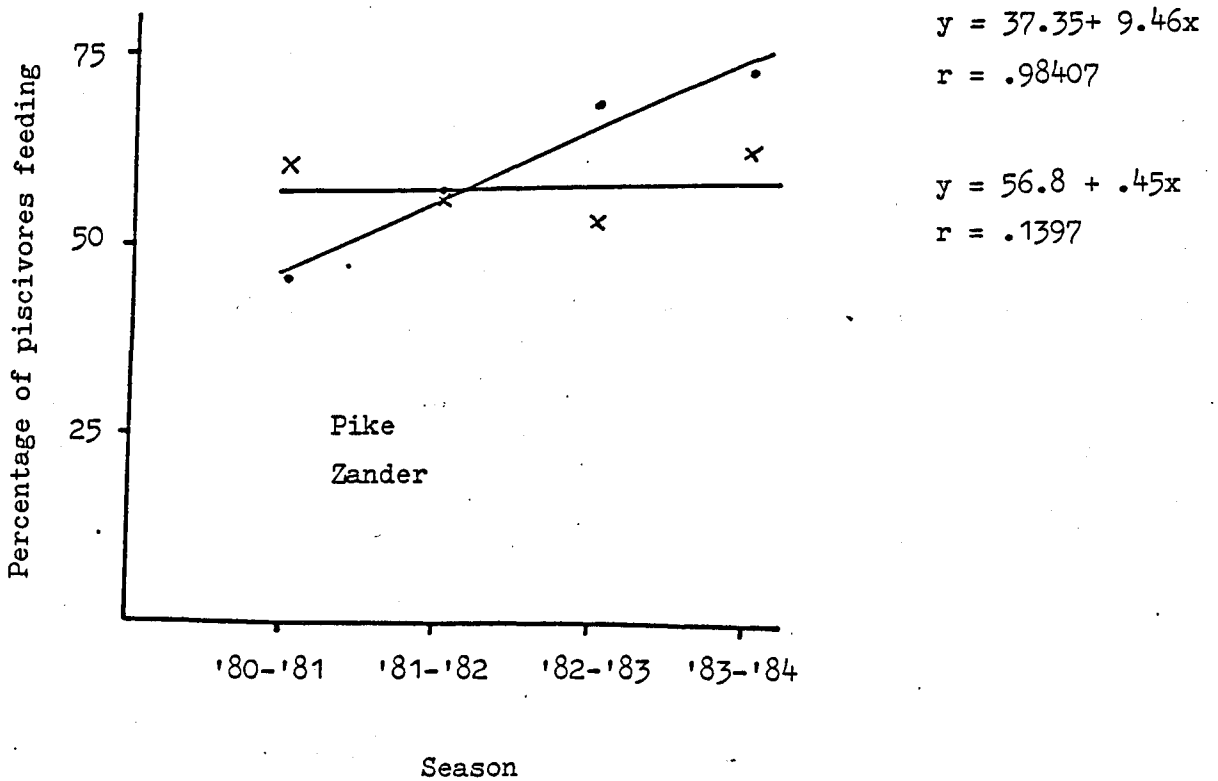


Figure 4.B Percentage of piscivores feeding on fish in each season of the study



result. It would be expected that as the prey population declines, that the type of predation would change to type B or C. In any environment, there are likely to be a limited number of refuges for prey, which will prevent over exploitation of the stock. Alternatively at certain densities a predator will switch to other more profitable prey, predator then being of the C type.

In habitats which are homogenous, prey refuges are likely to be few, which will mean that the population will have to decline markedly before predation switches from type A to type C, and the population dynamics stabilize. Also, if the indigenous fish fauna is impoverished, the opportunity to switch between prey types may be limited.

Other factors (i.e. recruitment, productivity, density - dependent regulation of the predator and prey populations, environmental) will also be of importance and will be discussed later. It would be reasonable to assume that in a habitat which is relatively deep, turbid, slow flowing, with little weed cover, of low structural diversity and with a relatively simple fish fauna that the zander would be a very efficient predator. (It would only switch from type A to type B or C predation at low prey densities).

Intraspecific predation by pike will be of type C; the carrying capacity of any particular water being determined by habitat structure - largely fixed (Grimm, 1981) and so any pike over a certain density will tend to be more likely to be predated. Since intraspecific predation is obviously density-dependent, this will tend to result in the stabilization of pike populations.

The intensity of intraspecific predation by the zander in comparison is influenced by both the relative abundance and 0+ growth rate of zander and its prey species. As 0+ zander grow they will be less likely to be predated (ie. a size refuge exists) or where alternative prey exert a buffering effect the incidence of intraspecific predation will be reduced (see section 2.6); cannibalism tending towards type C predation.

4.4.3 Choice of prey size

Another difference between zander and pike predation is in the choice of prey size. Zander predate mainly on immature fish whilst pike predate on larger, and a greater size range, of prey. This preference of zander for small prey was shown by Fickling (1982) in laboratory experiments.

These findings are in agreement with Popova (1967) who states that zander prey preferentially on the immature or smaller individuals in the prey stock. The zander is restricted by morphological and behavioural (ie. mouth size, Fickling, 1982) characteristics to predating on small fish throughout its life span.

The result of this is that zander predation is concentrated on 0+ fish, with some predation on 1+ individuals as the zander grows. However prey fish greater than 100mm will be relatively free from zander predation.

Strong zander year-classes tend to be synchronous with strong prey year-classes (Van Densen and Vijverberg, 1982) if subsequent prey year classes are weak they will be predated heavily by zander. This may further weaken these year-classes. Such a phenomenon has been observed in Dutch lakes following strong zander-year classes (Willemsen pers com) and was the mechanism for the decline in the Middle Level stocks proposed by Klee (1981). It might be that the zander is adapted to feed on species with sustained recruitment.

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4.4.4 Cannibalism

Cannibalism is a commonly reported phenomenon in predator populations and may act as a density-dependent mechanism regulating population size. It is not always easy to observe since each predator in a population need only consume one conspecific per year for the entire population to be eliminated; even low levels of cannibalism can still produce large effects in a population.

In this study cannibalism was recorded for pike but not for zander. It has, however, been commonly recorded by other authors (Steffens, 1960; Woynarovich, 1961; Biro and Elek, 1969; Willemsen 1977; Fickling, 1982). Intraspecific predation appears to be important during years when the underyearlings are very abundant. Dikansky (1974) found that in 1964 and 1968, when year-class strengths were strong in the Kurshyn Meres, 0+ zander constituted 15.4% and 17.7% respectively (by frequency of occurrence) of the food of adult fish. An even higher figure of 30% was given by Biro and Elek (1969) for Lake Balaton. Willemsen (1977) when comparing the incidence of cannibalism in the IJsselmeer and Velumeer, found that in the former where prey fish were very abundant it was low at .14% while in the latter where prey fish are much rarer it was over 4% in years of high abundance of zander. Cannibalism may be important in helping determine year-class strength, in situations where prey fish are scarce and young of the same kind are abundant, therefore.

Cannibalism by pike is well documented and was shown in this study (Frost (1954), Lawler (1965), Willemsen (1967), Banks (1970), Munro (1957) and Mann (1982)). Mann (1982) calculated that the biomass lost to mortality of pike up to age 2 years in the River Frome, was 10 kg/ha /yr , which when compared to the estimated consumption of pike by other pike of 7.96 kg/ha /yr, suggests that a substantial amount of mortality of young pike after the fry stage is a result of cannibalism. These findings support the conclusions of Kipling and Frost (1970), that cannibalism by pike could be important in determining year-class strength, predation being particularly heavy in cool summers when growth is slow. Grimm (1981a) found that the biomass of pike ≥ 41 cm, especially 0+ pike, depended on the abundance of larger individuals. It is interesting to note that the very largest pike were not a major factor in controlling the abundance of small pike, due to differences in habitat preference (Grimm 1981b). Grimm's mechanism controlling cannibalism was the availability of cover, in years of high predator abundance the encounter rate between individuals and hence predation would increase. In turn, this may result in density dependent regulation of the population.

Zander has a greater potential for recruitment than the pike (135,000 eggs/kg Fickling, 1982 compared to 28,000 eggs/kg Frost and Kipling, 1969) although the actual level achieved is highly variable (Deelder and Willemsen, 1964) and so whilst cannibalism may result in some self-regulation for the zander (Popova and Sytina (1977) Nagiec (1977) and Forney (1971)) its effect is less than for the pike, and so strong year-classes may dominate biomass levels. The result of these differences will be that biomass levels (and hence consumption) of the zander population will tend to vary, depending on recruitment.

This variability in year-class strength and biomass, may introduce a time lag in the mechanism governing the ratio of predator to prey abundance for the zander, and so tend to destabilize fish populations under certain circumstances. The pike, having a more stable population structure, should not tend to destabilize fish populations in the same way.

If the habitat is such that zander recruitment is good, large effects in the prey stocks may result.

4.4.5 Competition between pike and zander

Since the pike and zander are both piscivores the introduction of the latter may result in an alteration in the abundance and/or type of prey available to the pike.

Deelder and Willemsen (1964) stated that since zander

"prefer to live in open water-spaces to prey upon small fishes, they have no serious interspecific competition since predators following this pattern are not numerous. The perch could be the most serious competitor of the pike-perch (zander). The eel and the sheat fish (Silurus glanis) should be considered as minor competitors".

Whilst there have been reports of pike being ousted by the zander (Dahl, 1962; Nikols'skii, 1957; Woker, 1953) or the walleye (Johnson, 1949) Deelder and Willemsen (1964) thought that it was "... at least dubious if such a diminishment of a pike stock must be ascribed solely to the pike-perch and not to a possible eutrophication of the water area concerned".

Willemsen (1980) reviewed the fishery aspects of eutrophication and discussed how these might affect the density of pike and zander. The pike hunts by sight needing clear water to enable it to locate prey and vegetation to provide cover. These conditions are met during the earlier phases of eutrophication a process which is also characterised by increasing numbers of prey fish. This will result in an increase in the pike stock as well. The optimum conditions for pike are attained in a mesotrophic - eutrophic environment at transparencies above 1 m and with an abundance of prey fish (Casselman, 1978) . Such a water would give an annual production of pike of about 20 kg Ha⁻¹. As eutrophication progresses prey capture becomes more difficult and the pike stock decreases as noted for many Dutch lakes in the last 10 to 20 years.

The zander being adapted to low light conditions however prefers turbid waters and so will be favoured by eutrophication.

The creation of bodies of open water with little macrophyte cover also favours the zander; on the damming of a river to create a reservoir the populations of pike often decrease and those of Stizostedion spp. increase (Nikolskii, 1957; Elrod and Hassler 1969).

When a habitat is suitable for the zander it is likely that it may have some impact on the pike population. However, Agnedal (1969) chronicled the decline of the pike population following the introduction of zander to Lake Erken, where zander reproduction was poor. As the zander population declined due to natural mortality and exploitation, the pike population recovered.

The assessment of competition has often been carried out by calculating overlap indices (see Wallace, 1981 for a review). These indices all describe whether the predators are feeding on the same prey items. Competition will only occur however, if the resource that is being utilized is in limited supply.

The Sixteen Foot Drain populations of zander and pike are both feeding mainly on roach although the type of predation exhibited has some important differences. This may mean that in some waters zander will feed preferentially on small pelagic shoaling fish species (such as smelt), whilst pike will feed on phytophyllus species composed of numerous age-classes (such as roach), although when a water is dominated by one major food item this will generally be taken by both species.

Is the prey available to zander and pike in the Sixteen Foot Drain limited? If zander can cause declines in the prey populations, this will result in less forage fish being available. It would be expected under these conditions that the predator populations would undergo a decline and so competition would be occurring. In waters where a range of habitats and refuges for the prey species exist, biomass levels may never become low enough for competition to occur. If the zander causes declines such as those seen in the Middle Level System the pike population must be adversely affected.

A better understanding will be obtained when predation rates, biomass levels and mortality rates are discussed in Chapter 6.

4.5 Diet of roach, common bream, ruffe, perch and eels

4.5.1 Results

Diet data has been ranked in order of importance. For each of three measures, % Occurrence, % Volume and Relative Importance (RI). % Occurrence may over emphasise common food items which are not important overall whilst % volume may over emphasise bulky items of low energy value. RI combines both % Occurrence and % Volume into one measure, although in any discussion of diet it is advisable to have more than one measure so that any biases can be allowed for.

Roach:

The major difference between the months, (Table 29 and 30) for which roach stomachs were sampled, was the appearance of cladocerans and copepods in July; this would correspond to the increase in the populations of zooplankton.

Filamentous algae was 'the most important component of the diet followed by molluscs, detritus, oligochaetes and chironomid larvae. Also featuring in the diet were crustaceans and insect larvae (mainly Sialis sp).

Common Bream:

Zooplankton was the most important prey items followed by molluscs aquatic insect larvae and chironomid larvae, filamentous algae and detritus were not as important for common bream as they were for roach

TABLE 29 Diet of roach, June 1983

Classes of diet items ranked in order of importance					
% Occurrence		% Volume		Relative Importance (RI)	
Filamentous algae	61.21	Filamentous algae	52.51	Filamentous algae	3214.14
Molluscs	41.48	Molluscs	18.79	Molluscs	777.53
Detritus	39.66	Detritus	17.49	Detritus	693.65
Oligochaetes	11.21	Isopods	2.85	Oligochaetes	19.73
Chironomid larvae	6.90	Chironomid larvae	2.37	Chironomid larvae	16.35
Isopods	5.17	Oligochaetes	1.76	Isopods	14.73
Aquatic insect larvae	4.31	Aquatic insect adults	1.58	Aquatic insect adults	5.45
Aquatic insect adults	3.45	Aquatic insects larvae	1.11	Aquatic insects larvae	4.78
Ostracods	3.45	Terrestrial Vegetation	1.01	Copepods	.86
Copepods	1.75	Copepods	.50	Aerial Insects	.03
Amphipods	.86	Aerial insects	.03	Terrestrial Vegetation	.01
Aerial insects	.86	Amphipods	+	Amphipods	+
Terrestrial Vegetation	.01	Ostracods	+	Ostracods	+

No of stomachs =

mean size of fish =

TABLE 30 Diet of roach, July 1983

Classes of diet items ranked in order of importance					
% Occurrence		% Volume		Relative Importance (RI)	
Filamentous algae	64.58	Filamentous algae	52.50	Filamentous algae	3390.45
Detritus	35.42	Molluscs	16.43	Detritus	453.73
Molluscs	27.08	Detritus	12.81	Molluscs	444.92
Copepods	18.75	Copepods	6.15	Copepods	115.31
Oligochaetes	11.11	Oligochaetes	3.02	Oligochaetes	33.55
Aquatic insect larvae	6.25	Aquatic insect adults	2.74	Aquatic insect adults	17.13
Aquatic insect adults	6.25	Aquatic insect larvae	1.71	Aquatic insect larvae	10.69
Cladocerans	6.25	Cladocerans	1.27	Cladocerans	7.94
Chironomid larvae	3.47	Aerial insects	1.15	Aerial insects	3.20
Aerial insects	2.78	Isopods	1.03	Chironomid larvae	2.64
Isopods	2.08	Chironomid larvae	.76	Isopods	2.14
Amphipods	1.39	Amphipods	.24	Amphipods	.33
Ostracods	1.39	Ostracods	.20	Ostracods	.28
Mites	1.39	Mites	+	Mites	+

No of stomachs =

mean size of fish =

TABLE 31 Diet of common bream, July 1983

Classes of diet items ranked in order of importance					
% Occurrence		% Volume		Relative Importance (RI)	
Copepods	66.07	Copepods	50.86	Copepods	3360.32
Cladoceraus	39.29	Cladoceraus	24.40	Cladoceraus	958.68
Ostracods	16.07	Ostraceds	8.54	Ostraceds	137.24
Aquatic insect larvae	16.07	Molluscs	6.38	Mollusc	56.97
Molluscs	8.93	Aquatic insect larvae	3.29	Aquatic insect larvae	52.87
Chironomid larvae	7.14	Chironomid larvae	2.57	Chironomid larvae	18.35
Detritus	7.14	Detritus	1.65	Detritus	11.78
Aquatic insect adults	3.57	Aquatic insect adults	1.03	Aquatic insect adults	3.68
Isopods	3.57	Filamentous algae	.04	Filamentous algae	.07
Oligochaetes	1.79	Isopods	.41	Isopods	1.46
Filamentous algae	1.79	Oligochaetes	.82	Oligochaetes	1.47
No of stomachs =			mean size of fish =		

TABLE 32 Diet of ruffe, June 1983

Classes of diet items, ranked in order of importance					
% Occurrence		% Volume		Relative Importance (RI)	
Chironomid larvae	82.98	Chironomid larvae	29.26	Chironomid larvae	2428.21
Aquatic insect larvae	57.45	Aquatic insect larvae	22.21	Aquatic insect larvae	1276.05
Ostracods	46.81	Aerial insects	13.07	Ostracods	365.47
Isopods	23.40	Isopods	9.99	Isopods	233.84
Amphipods	19.15	Ostracods	7.81	Aerial insects	111.23
Aquatic insect adults	17.02	Detritus	4.89	Detritus	83.21
Detritus	17.02	Aquatic insects adults	4.53	Aquatic insect adults	77.10
Molluscs	14.89	Amphipods	4.03	Amphipods	77.10
Aerial insects	8.51	Fish eggs	1.44	Molluscs	14.34
Copepods	6.38	Molluscs	.97	Copepods	3.67
Cladocerans	2.13	Oligochaetes	.86	Fish eggs	3.06
Oligochaetes	2.13	Copepods	.53	Oligochaetes	1.84
Ephemeroptera	2.13	Cladocerans	.22	Cladocerans	.46
Fish eggs	2.13	Odonata	.15	Odonata	.30
Odonata	2.13	Ephemeroptera	+	Ephemeroptera	+
No of stomachs =			mean size of fish =		

TABLE 33 Diet of ruffe, July 1983

Classes of diet items, ranked in order of importance					
% Occurrence		% Volume		Relative Importance (RI)	
Chironomid larvae	84.21	Chironomid larvae	64.48	Chironomid larvae	4272.81
Ostracods	60.53	Aquatic insect larvae	10.52	Aerial insect larvae	359.74
Isopods	39.47	Isopods	8.16	Ostracods	326.33
Aquatic insect larvae	34.21	Aquatic insects adults	7.89	Isopods	322.16
Detritus	18.42	Ostracods	5.39	Aquatic insects adults	124.54
Aquatic insect adults	15.79	Detritus	1.91	Detritus	35.20
Aerial insects	13.16	Ephemeroptera	.55	Ephemeroptera	5.83
Molluscs	7.89	Aerial insects	.41	Aerial insects	5.47
Ephemeroptera	10.53	Molluscs	.41	Molluscs	3.24
Copepods	2.63	Copepods	.28	Copepods	.73
Mites	2.63	Mites	+	Mites	+

No of stomachs =

size of fish =

TABLE 34 Diet of perch, June 1983

Classes of diet items, ranked in order of importance					
% Occurrence		% Volume		Relative Importance (RI)	
Chironomid larvae	46.15	Chironomid larvae	21.62	Chironomid larvae	997.46
Copepods	30.77	Amphipods	19.96	Isopods	368.47
Isopods	26.92	Isopods	13.69	Aquatic insect larvae	312.98
Aquatic insect larvae	23.08	Aquatic insect larvae	13.56	Copepods	309.05
Aquatic insect adult	19.23	Copepods	10.04	Amphipods	306.91
Amphipods	15.38	Aquatic insect adults	6.34	Aquatic insect adults	122.24
Filamentous algae	7.69	Cladocerans	4.24	Detritus	32.59
Detritus	7.69	Molluscs	4.24	Molluscs	16.32
Molluscs	3.85	Detritus	4.24	Cladoceros	16.32
Cladoceros	3.85	Filamentous algae	1.23	Filamentous alge	9.45
Terrestrial Vegetation	3.85	Terrestrial Vegetation	.85	Terrestrial Vegetation	3.27

No of stomachs =

size of fish =

TABLE 35 Diet of eels, June 1983

Classes of diet items, ranked in order of importance					
% Occurrence		% Volume		Relative Importance (RI)	
Detritus	38.79	Fish	23.65	Fish	591.37
Chironomid larvae	32.76	Terrestrial		Molluscs	488.98
		Vegetation	16.13		
Molluscs	31.90	Molluscs	15.33	Detritus	420.08
Isopods	30.17	Detritus	10.83	Isopods	292.62
Filamentous algae	26.72	Isopods	9.70	Chironomid larvae	227.40
Fish	25.00	Chironomid larvae	6.94	Filamentous algae	158.66
Aquatic insect larvae	12.07	Filamentous algae	5.94	Terrestrial veg.	41.77
Aquatic insect adults	8.62	Aquatic insect larvae	2.98	Aquatic insect larvae	35.98
Amphipods	6.90	Aquatic insect adults	2.08	Aquatic insect adults	17.93
Ephemeroptera	6.03	Chironomid pupae	1.63	Chironomid pupae	4.21
Aerial insects	2.59	Aerial insects	1.00	Ephemeroptera	4.15
Chironomid pupae	2.59	Fish eggs	.96	Amphipods	3.59
Terrestrial		Bird	.96	Aerial insects	2.60
Vegetation	2.59				
Odonata	1.72	Ephemeroptera	.69	Bird	.96
Bird	1.00	Amphipods	.52	Fish eggs	.83
Ostracods	.86	Odonata	.38	Odonata	.65
Mites	.86	Mites	.29	Mites	.25
Fish eggs	.86	Cladocerans	+	Cladocerans	+
Cladocerans	.86	Ostracods	+	Ostracods	+

No of stomachs =

mean size of fish =

(Table 31). Zooplankton was probably important due to the month (July) and the relatively small size of the common bream studied. It was not thought that the killing of large common bream was justifiable since a few large individuals can be of such importance to a fishery.

Ruffe:

Zooplankton becomes more important in July than June otherwise there is little variation in the diets (Table 32 and 33). Chironomid larvae, feature strongly followed by insects and crustaceans, but quite a wide range of prey is taken, including interestingly fish eggs.

Perch:

Chironomid larvae were the most important prey item (Table 34), with crustaceans both zooplankton and macro-invertebrates featuring. No piscivorous individuals were found, this is due to the small size of perch present. Ulcerated fish were common and so it is likely that mortality is high, due to perch ulcer disease. The perch biomass was not high and is unlikely to be competing with pike or zander.

Eels:

Eels took the widest range of prey of any fish in this study (Table 35). They fed mainly on macro-invertebrates with the larger individuals preying on fish. The larger individuals did not feed exclusively on fish (unlike pike and zander) taking a range of prey.

4.5.2 Discussion

The roach normally shows good growth and high biomass when suitable molluscs are available (Kempe, 1962). That filamentous algae is such an important item in the diet suggests that the choice of diet is limited, this would explain poorer growth rates for Fenland roach than the average (see Chapter 5). If the food available to the roach is poor but plentiful then little competition will exist between individuals and one would not expect to see widely varying growth rates with changes in population density.

Common bream populations show good growth and high biomass when chironomids are plentiful (Goldspink, 1978). The invertebrate data (Chapter 1) shows the populations to be dominated by chironomids and oligochaetes. This relative unimportance of chironomid larvae in the diet is probably due to the small size of common bream used in the diet study.

It might be expected that ruffe and perch would be competitors of 0+ zander (Willemsen, 1977). If ruffe and perch populations decline as a result of eutrophication whilst zander populations increase (Willemsen, 1980) then the decrease in interspecific competition for 0+ zander may possibly enhance the recruitment of zander.

Eels consumed the largest prey range of any fish in this study. Fish were taken by the largest eels although these individuals would also take other prey items (unlike pike and zander). This is important since the eel not being an obligatory piscivore will switch to other prey when suitable prey fish become scarce and so the type of over-predation

described for zander will not occur. Fish eggs were found and this confirms personal observations. During June 1983 bleak were seen to be spawning on gravel at the junction of the Sixteen and Forty Foot Drains in the presence of eels. Small eels were seen to be rooting amongst the gravel which when examined was found to be covered with spawn, but otherwise no other animal matter was found. Larger eels were also observed and these were attacking and devouring the spawning bleak. It is likely that eels will predate on other spawning fish and their eggs, which are not so easily observed (Diamond and Brown, 1983). The large biomass of eels in the Sixteen Foot Drain (Section 3) may mean that high mortality of egg results, with important consequences for recruitment. Fish eggs will not necessarily be readily identifiable, as a prey item, since they are so easily digestible and only available for a short period of time. The importance for recruitment may be missed.

4.6 Trophic interactions and the fish community

4.6.1 Importance of prey size

Swingle (1950) showed that by stocking small ponds with various ratios of piscivores and prey that a balance could be achieved so that stunting of the prey population due to overcrowding could be prevented. Johnson (1949) proposed that the important relationship between predators and prey was the ratio of the biomass of the piscivore to the biomass of the size class of prey available to it. This is important because piscivores generally predate on a restricted size class of prey generally the smaller individuals, although this may change as the predator grows (Popova, 1967). The biomass of larger prey individuals

is only important, in this context therefore, in their role to provide recruits to the size group that the piscivore predated upon. A simple ratio of predator to prey biomass like Swingle's ratio will only adequately describe the "balance" of a fish community if it also describes the trophic relationship. It would be expected that the ratios showing a "balance community" would be different for zander and pike since the zander predated on a much smaller size range (and hence fraction) of prey. A ratio of available prey to piscivore biomass being more appropriate (as formulated by Johnson, 1949). This of course ignores the importance of the production of each size class of the prey species.

The recruitment of 0+ piscivore and prey species depends on climatic factors providing good feeding conditions and often results in the synchronisation of their year-class strengths (see section 2.6). If a strong year-class of a piscivore that predated mainly an 0+ prey becomes established the heaviest predation pressure will tend to fall on the following prey year-classes as the strong piscivore year-class starts to dominate its population. If environmental conditions mean that subsequent prey year-classes are weak then over-predation may occur. It is the ratio of biomass of piscivore to the available prey rather than the ratio of piscivore biomass to total prey biomass that is important therefore. In chapter 6 an attempt will be made to show the levels of zander biomass and the population structures that may cause problems under certain conditions of prey recruitment and stock structure.

This illustrates the importance of considering the temporal dimension, and how variations in populations may influence the stability of a system as much as the mean levels of the population parameters.

4.6.2 Production of prey

A low standing crop of a prey species will be able to support a relatively high piscivore biomass if the prey shows a high annual production rate. Variations in productivity due to variable recruitment and the productivity of the various size-classes of prey will also have an influence on the level of piscivore biomass that they can support.

The total level of production of a population is the sum of the production of each age-class. A predator that predated only on the young stages would have a different effect from one that predated either on the most abundant age-class or on all age-classes. In the former case it is obvious that by concentrating predation on a limited size range that a gap in the prey age structure could be produced, this would be especially likely for a long lived species with variable recruitment and or low productivity.

4.7 Conclusions

There are important differences between the types of predation shown by pike and zander. The predation pressure exerted by pike will be dependent largely on the density of prey whilst that exerted by zander will be dependent on its own density. The models of Ricker (1952) were used to describe these differences. Zander also differs from the pike in that it predaes mainly on the immature stock and so is more likely to produce weak prey year-classes. The Zander will be an efficient predator in the Sixteen Foot Drain and so over-predation may occur.

As eutrophication progresses habitats are liable to change to the zander's advantage and it is possible that any reduction in prey stocks by the zander might adversely affect the pike population.

Cannibalism will tend to stabilize pike populations since its intensity is controlled by the availability of cover (a constant largely determined by habitat structure). Whilst cannibalism also acts as a density-dependent mechanism for zander it is largely determined by the relative density of 0+ zander and 0+ prey fish. This will be determined by environmental conditions and so one would expect fluctuations in year-class strengths and hence population levels of zander.

The diet of roach, common bream, perch, ruffe and eels has also been discussed.

CHAPTER 5

TEMPORAL CHANGES IN THE FISH COMMUNITY

5.1 Introduction

The ability to determine the age of fish is of great value to fishery biologists. Not only is age important in providing information on onset of maturity and life span, but it is an important parameter in the calculation of growth, production and mortality.

This work is primarily concerned with the changes in the fish stocks following the introduction of an exotic piscivore, and their subsequent management. The study of a dynamic system of this type necessitates the ageing of fish so that the component population can be broken down in to age classes, whereby the factors influencing the fish community can be identified.

Growth rates are of interest, since it is known that year-class strength (and hence population structure) is often linked to the growth rate of 0+ fish variations in growth rates may also provide evidence as to the effect of varying ecological conditions. The importance of these variations for the fish stocks being shown by an examination of year-class strength.

5.2 Growth Patterns

5.2.1 Methods

Techniques for age determination have long been established, the first account is from 1759 (Hederstrom, 1959). They have been extensively reviewed by Rounsefell and Everhart (1953) and Bagenal and Tesch (1978). There are three main techniques, which are summarised below.

- a) The interpretation of growth checks on hard parts of the fish, which are the result of periods of slow or no growth (Bilton, 1974 and Simkiss, 1974). These are generally seasonal in nature and are known as annuli.
- b) The Petersen method, by which cohorts are distinguishable within a length/frequency histogram.
- c) The identification of individual fish by marks, so that their growth history is known.

Only the first two are of direct interest in this work, which was primarily an extensive field study.

The following species were aged: zander, pike, roach and common bream.

Numerous hard structures have been used for age and growth studies and include scales, opercular bones, otoliths, dorsal fin spines, pelvic fins, pectoral fins, branchiostegal rays, vertebrae, teeth, metapterygoids and cleithral bones.

Scales were used for cyprinids, since whenever possible it would be preferable that they be returned alive; scales, cleithral and opercular bones for pike; and opercular and scales for zander.

Campbell and Babaluk (1979) had noted that scales tended to underestimate the age of the walleyes (Stizostedion vitreum, vitreum Mitchell). However, this was only an important factor for those fish over 9 years old. Since all the fish populations studied were characterised during the first year by a lack of older fish most of the ageing to begin with was of younger fish. These were relatively easy to age so that as the study progressed and older fish became a more significant component of the population, experience had been built up from previous seasons, which greatly facilitated the interpretation of the older structures.

The validity of any method of age determination depends on the checks being annual in occurrence. This has been shown to be so by Nagiec (1961) and Fickling (1982) for zander; Frost and Kipling (1959) for pike; Williams (1955), Mann (1978) for roach; and Gajdusek (1981) and Goldspink (1978) for common bream.

Annuli formation was shown to occur in early summer for all of these species and a birthday of the 1st June was assigned to roach and common bream and of 1st May for zander and pike.

5.2.2 Growth curves.

The growth of year-classes, from the time of the colonisation of the Middle Level system by the zander up to the recovery of the fishery in the early 1980's is presented, for roach, common bream, zander and pike. All of this data was obtained from back calculation using scales.

Data from different years (see Appendix F) was combined, after allowing for the Rose-Lee phenomenon, into growth curves (Figures 11,12,13 and 14) for each species.

5.2.3 Comparisons with other populations

Standard growth curves have been prepared by Hickley and Dexter (1979) for roach and common bream and Hickley and Sutton (1984) for pike. These standards are calculated from data that are representative of the range of habitats within a geographical area and this means that difference will largely be due to habitat rather than climate.

Growth is largely determined by both food supply and temperature regime whilst temperature may produce a variation in growth rates between years. It would be expected that a pattern of poor or good growth would be due to feeding conditions.

Common bream growth is good (Figure 15) whilst both pike (Figure 16) and roach (Figure 17) growth is below average. Interestingly the growth of 0+ roach has a tendency to be above average.

Figure 13 Back calculated growth of the 1974 to 1981 year-classes of zander.

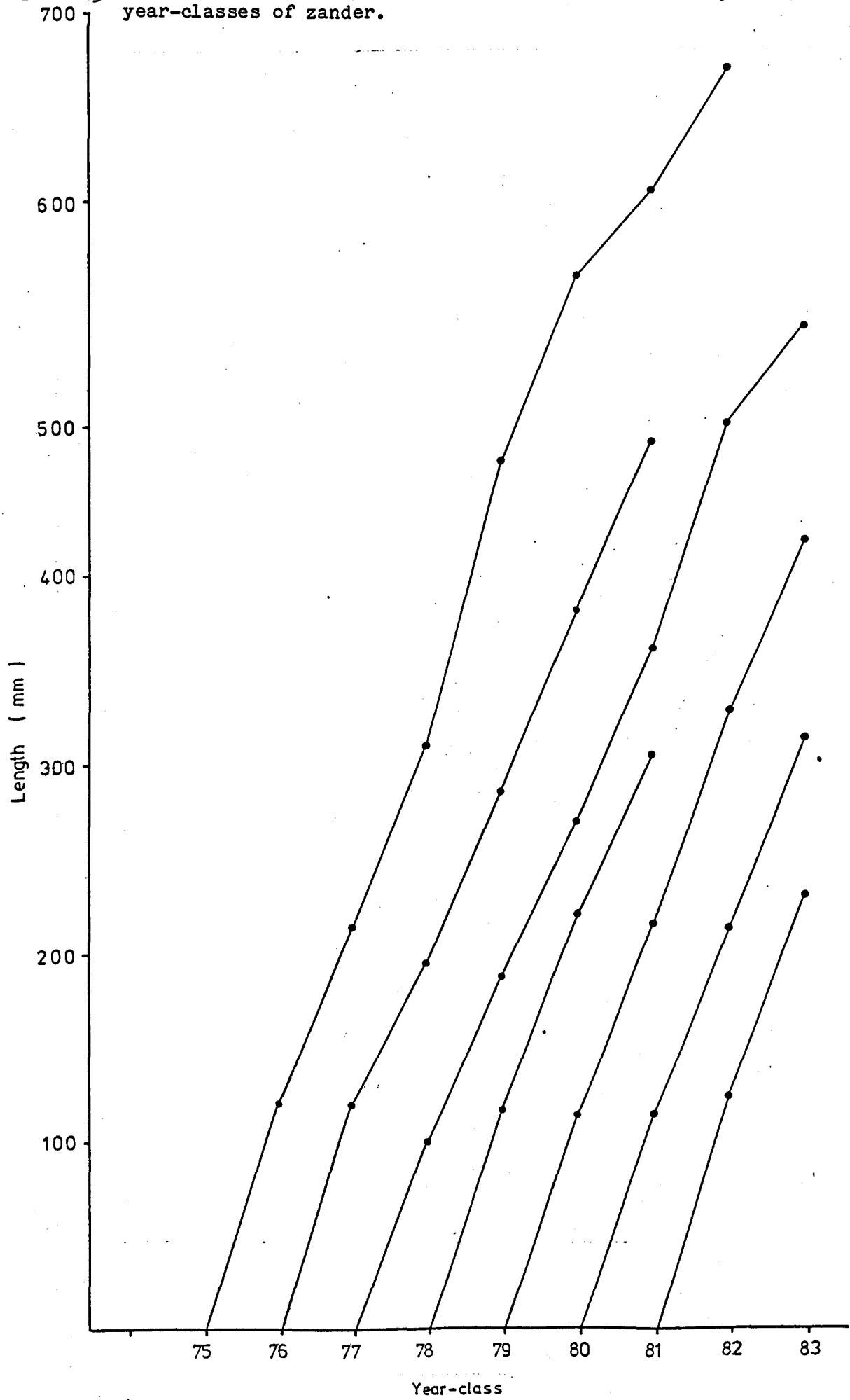


Figure 14 Back calculated growth of the 1976 to 1982 year-classes of pike.

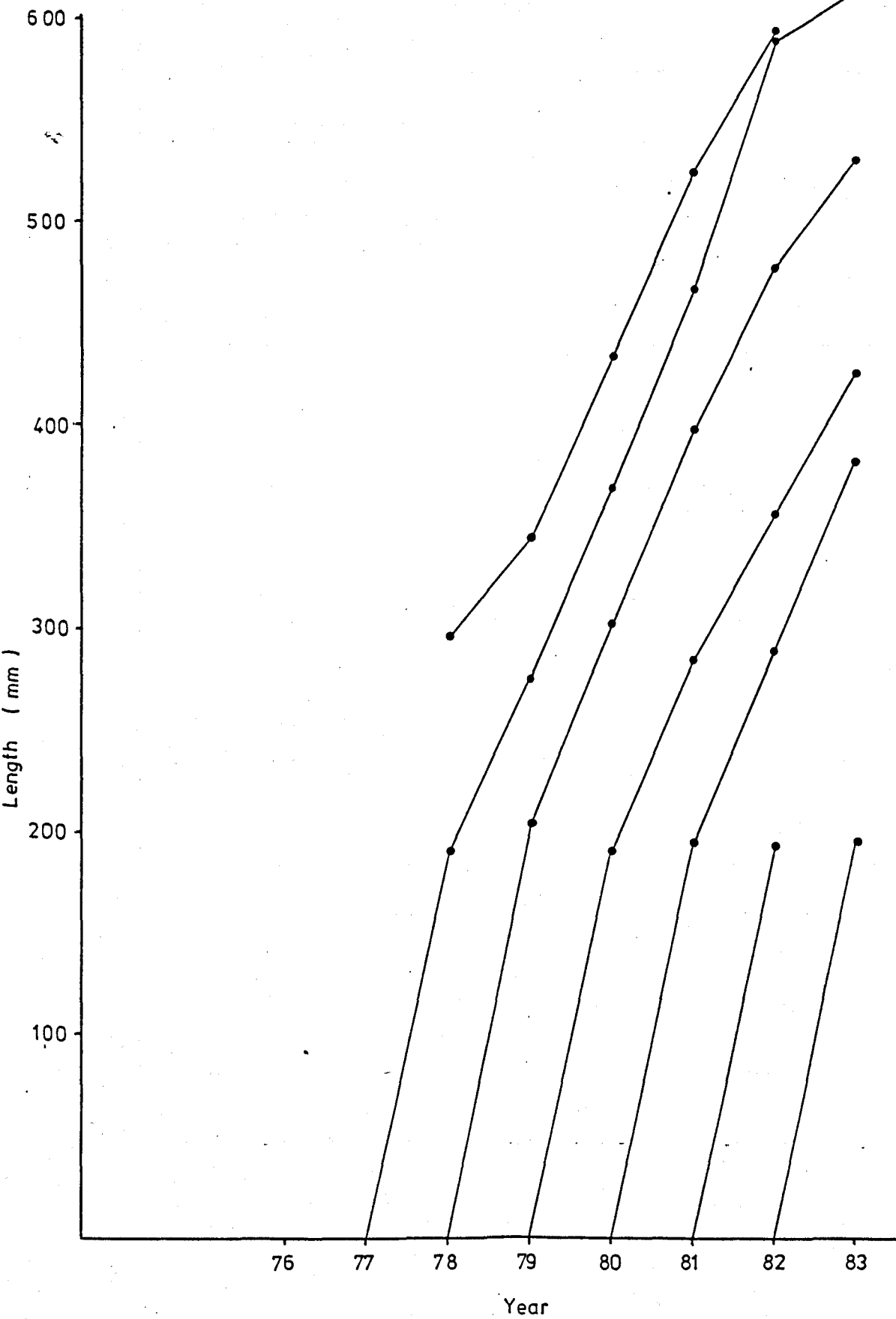
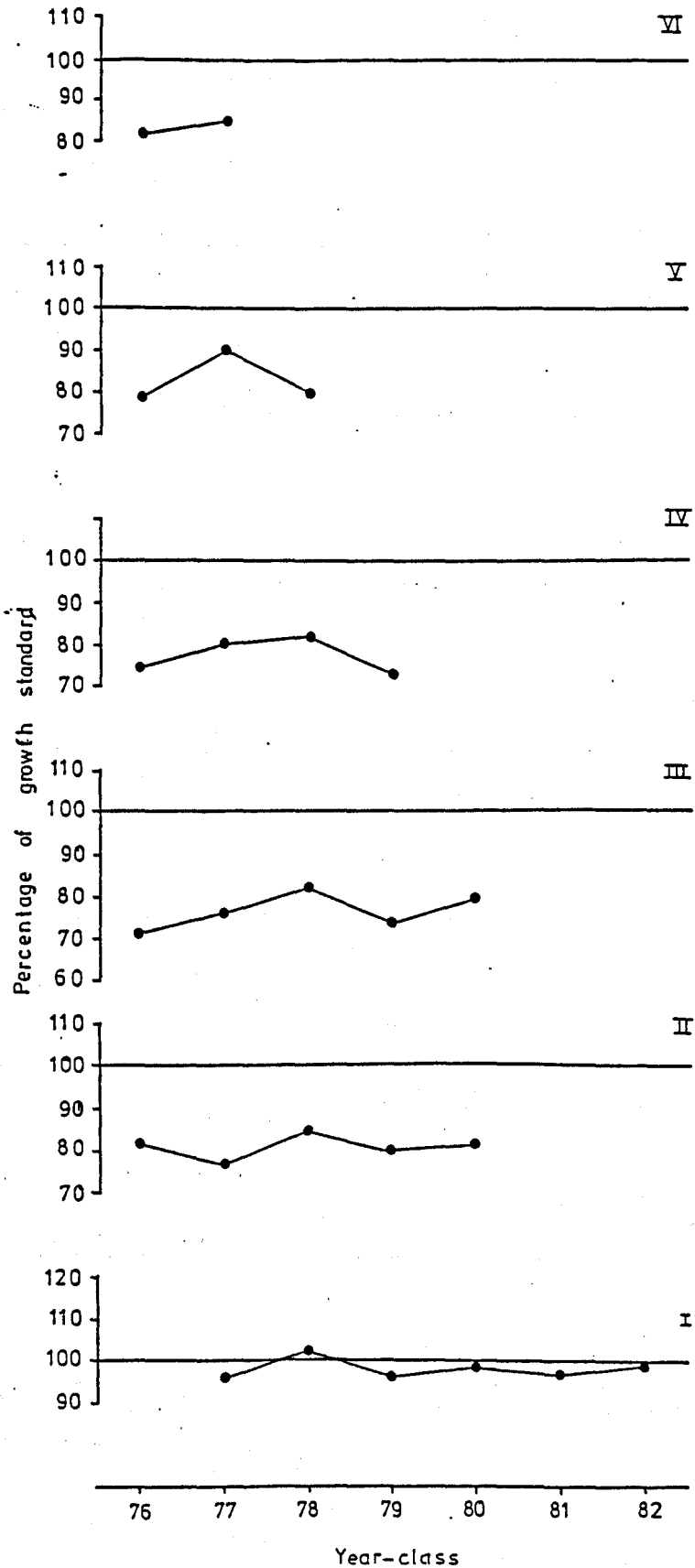


Figure 16 The comparison of the growth of pike with the growth standard of Hickley and Sutton (1984).



It is not possible to compare zander growth using a standard growth curve, since not enough representative data exists from this country. A comparison has therefore been performed with various British (Table 36) and European (Table 37) populations. Growth is comparable to that observed in the Oxford Canal and the Relief Channel but less than that of the Middle Level Main Drain and Combe Abbey Lake populations.

The growth of zander in the Sixteen Foot Drain is at the bottom of the recorded range. This is probably due to feeding conditions and climate.

Growth rates recorded by fishery surveys conducted by the AWA are summarised for roach (Table 38), common bream (Table 39) and pike (Table 40). All these rivers are similar to those of the Middle Level system, being slow flowing and highly eutrophic, the only exception is the River Welland which is a more typical river and there roach have faster growth rates than the Middle Level populations.

Roach, common bream and pike growth rates are similar throughout the Anglian region and it would appear that the growth of fish in the Middle Level is unexceptional.

5.2.4 Variations in growth rates

Comparisons between the growth rates of roach, common bream, pike and zander year classes were performed by the calculation of an index and a statistical analysis.

TABLE 36 Growth of zander in Britain

Location	Author	Length (mm)							
		I	II	III	IV	V	VI	VII	VIII
Relief Channel	Fickling, 1982	107	223	349	463	537	603	653	
Middle Level Main Drain	Fickling, 1982	149	294	436	544	603	646	663	
Combe Abbey Lake	Fickling, 1982	109	231	363	488				
Relief and Cut off Channels	Linfield & Rickards, 1979			280	310	360	400	510	560
Ely Ouse	Klee, 1980	133	147	-	328	498			
Oxford Canal	Hickly and North, 1983	100	200	310	360	440	520	600	
Sixteen Foot Drain	Present study	124	215	291	403	511	619	640	690

TABLE 37 Growth of Continental Zander

Location	Country	Author	Length (cm)					
			I	II	III	IV	V	VI
Lake Ijssel	Netherlands	Willemsen, 1969	15	30	42	50	57	63
Lauwersmeer	Netherlands	Willemsen, 1969	11	26	39	48		
Tjeukemeer	Netherlands	Van Zalinge, 1970	13	28	40	45		
Upper Ob	USSR	Solovov, 1971	17	35	50	63	72	
Lake Balkhash	USSR	Solovov, 1971	24	42	55	61	67	
Lake Mermere	Turkey	Aksiray, 1960	23	31	47	58		
Lower Vistula	Poland	Nagiec, 1964	17	29	45	58	68	77
Malaren	Sweden	Suardson & Molin	11	20	29	34	39	45
Sixteen Foot Drain			12	21	29	40	51	62

TABLE 38 Comparisons with AWA growth data, roach

River	Author	Length (mm)									
		I	II	III	IV	V	VI	VII	VIII	VIII	
Witham	Coles, 1978	46	72	114	142	166	199	208	227		
Ancholm	Coles, 1980c	41	66	96	112	154	175	193	215		
Witham + Fosdyke	Coles, 1979b	44	72	99	128	150	174	207	212		
South Forty Foot	Coles, 1980b	41	73	102	131	161	182	209	254		
West Fen Drain	Coles, 1981a	45	83	110	136	221					
Hobhole Drain	Coles, 1981a	44	89	135	174	228					
Lud	Coles, 1982b	46	73	115	151	174	207	242	259		
Steeping	Coles, 1982a	40	71	99	124	153	174	213	235		
Grantham Canal	Coles, 1983	47	91	102	137	192	225	254	270		
Lower Cam	Klee, 1978a	65	95	118	146	173	195				
Great Ouse	Klee, 1978b	23	61	97	116	150	160	180			
Old West	Klee, 1978d	45	79	121	142	155					
Lark	Klee, 1979d	33	65	126	160	177	211	228	264		
Ely Ouse	Klee, 1979d	41	75	101	148	197	213	216	231	239	
Relief Channel	Klee, 1979b	43	98								
Middle Level Main Drain	Klee, 1980	58	92	123	145	163	176	194	208	228	
Sixteen Foot	Present Study	55	86	111	134	157	181	203	216		

TABLE 39 Comparison with AWA growth data, common bream

River	Author	Length (mm)											
		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Witham	Coles, 1981c	57	87	121	150	192	232	260	304	330	377	387	396
South Forty Foot	Coles, 1980b	51	86	126	175	221	263	300	365	391	400	412	
Witham & Fosssdyke	Coles, 1979b	42	71	104	140	173	212	261	299	317	342	355	
Sibsey Trader	Coles, 1981b	50	70	113	161	200	275	325	358	403	437		
Steeping	Coles, 1982a	40	67	92	125	181	227						
Moretons Leam	Noble, 1981		92	128	186	242	281						
South Holland Drain	Noble, 1982b	60	-	175	228	285	320	395					
Welland & Deeping													
Drains	Noble, 1982a	76	139	-	234	279	329	406	453				
Lark	Klee, 1979d	63	117										
Ivel	Klee, 1979a	73	140	188	177	-	215	262	288				
Great Ouse	Klee, 1978b		142	195	-	-	-	359	374	401	405	423	433
Yaxley Lode	Noble, 1983	82	144	203	245	-	-	353	372	384	415	-	-
Sixteen Foot Drain	Present Study	60	103	154	201	245	284	319	348	374	401		

TABLE 40 Comparison with AWA growth data, pike

River	Author	Length (mm)											
		I	II	III	IV	V	VI	VII	VIII	IX	X		
Sibsey Trader	Coles, 1981b	218	364	467	601								
Witham	Coles, 1981c	168	266	353	455	527							
Steeping	Coles, 1982a	182	246	314	382	451	541						
West Fen and Hobhole													
Drain	Coles, 1981a	182	239	351	429	491	579	664	752	800	847		
South Forty Foot	Coles, 1980b	160	251	330	413	495	581	636	695	723			
Witham + Fosssdyke	Coles, 1979b	168	266	353	455	527							
Nene	Noble, 1980a	201		450	540	601							
Welland	Noble, 1980b	102	245	393	489	565							
Sixteen Foot	Present Study	195	287	368	450	547	570						

The index was that proposed by Kempe (1962) and is calculated by finding the average length at each age I, II, III etc, weighted accordingly to the number of fish in each year-class and using this as a standard. Kempe (1962) excluded fish aged I and II from his calculations since the size of fish of these ages did not correlate strongly with the length at later ages. In this study only size at age I was not as strongly correlated with that of older fish (Table F13, Appendix F) and so the index has been calculated using fish at age II and older.

The growth of each year-class in each growth year was then calculated as a percentage of this standard (Tables 41, 42, 43 and 44).

The mean growth rate for all age-classes in a growth year could also be calculated using the mean of the percentages for each age group.

Above average growth was shown by the 1977, 1978, 1979, and 1976 year-classes of roach. (Table, 41); the 1979, 1980, 1977, 1978, 1976, 1975 and 1974 year-classes of common bream (Table, 42) and the 1981, 1979 and 1980 year-classes of zander (Table 43). The pattern for pike was obscured however by a shortage of data (Table 44) and no conclusions can be drawn.

Length at any particular age and growth in any particular season can be compared by performing an analysis of variance (Tables 45, 46, 47 and 48). Any significant differences can then be shown by the Tukey-Kramer method (Sokal and Rohlf, 1969). Summaries are only presented for positive results (Tables 49, 50, 51 and 52); full details of the analysis is given in Appendix G.

TABLE 41

Relative growth of roach (Kempe's Method)

Year class	Index of growth	Season	Index of growth
1981	91	82-83	91
1980	95	81-82	97
1979	103	80-81	108
1978	103	79-80	104
1977	105	78-79	97
1976	102	77-78	86
1975	99	76-77	96
1974	85	75-76	73
1973	84		

100 = average growth

TABLE 42 Relative growth of Common Bream (Kempe's Method)

Year class	Index of growth	Season	Index of growth
1980	115	81-80	118
1979	121	80-79	111
1978	105	79-78	95
1977	114	78-77	94
1976	100	77-76	96
1975	100	76-75	96
1974	100	75-74	98
1973	96	74-73	95
1972	90	73-72	94
1971	99	72-71	83
1970	91	71-70	107

100 = average growth

TABLE 43 Relative growth of zander (Kempe's method)

Year class	Index of growth	Season	Index of growth
1981	107	82-81	104
1980	100	81-80	105
1979	105	80-79	100
1978	99	79-78	98
1977	95	78-77	92
1976	93	77-76	88
1975	96	76-75	93

100 = average growth

TABLE 44 Relative growth of pike (Kempe's method)

Year class	Index of growth	Season	Index of growth
1980	100	82-83	104
1979	95	81-82	92
1978	106	80-81	101
1977	101	79-80	98
1976	111	78-79	125

100 = average growth

TABLE 45 Summary of analysis of variance for differences in mean lengths of roach year-classes

Source of Measurement	Variation in length of year classes (Fs) at age						
	I	II	III	IV	V	VI	VII
1+	6.895 ***						
2+	3.774 *	2.726 *					
3+	.707 ns	1.219 ns	3.305 *				
4+	2.052 ns	1.742 ns	1.792 ns	1.425 ns			
5+	.319 ns	.383 ns	1.729 ns	6.297 **	8.264 ***		
6+	3.981 *	.836 ns	.971 ns	5.553 **	12.396 ***	6.729 **	
7+	.191 ns	6.266 *	1.168 ns	.008 ns	.093 ns	.374 ns	2.179 ns
8+	4.271 ***	.459 ns	1.818 ns	.757 ns	.365 ns	.018 ns	.489 ns
All	7.671 ***	3.592 ***	9.107 ***	6.045 ***	8.652 ***	6.784 ***	5.638 **

TABLE 46 Summary of analysis of variance for differences in mean lengths of common bream year classes

Common Bream		
Source of measurements	Variations in length of year classes (Fs)	
I	3.0678	***
II	4.0088	***
III	2.6772	**
IV	1.5517	ns
V	2.0528	ns
VI	3.0927	*
VII	3.0989	*
VIII	1.1957	ns
IX	1.9992	ns

TABLE 47 Summary of analysis of variance for differences in mean lengths of zander year classes.

Zander		
Source of measurements	Variations in length of year classes (Fs)	
I	3.2673	**
II	2.5734	*
III	2.1901	ns

TABLE 48 Summary of analysis of variance for differences in mean lengths of pike year classes

Pike		
Source of measurements	Variations in length of year classes (Fs)	
I	1.9910	ns
II	2.9823	*
III	3.2508	*
IV	.6567	ns
V	1.1529	ns

TABLE 49 Summary of comparisons between lengths of roach year-classes at different ages (Tukey-Kramer method)

Age	Year-class
I	1981 > 1977 1980 > 1975, 1976, 1977, 1978, 1979 1982 > 1975, 1976, 1977, 1978, 1979, 1981
II	1979 > 1981
III	1977 > 1975 1979 > 1973, 1974, 1975, 1976 1978 > 1973, 1974, 1975, 1976
IV	1976 > 1973, 1974 1978 > 1973, 1974 1977 > 1973, 1974
V	1975 > 1973 1976 > 1973, 1974 1977 > 1973, 1974
VI	1975 > 1974 1976 > 1974
VII	1975 > 1974

TABLE 50 Summary of comparisons between lengths of bream year-classes at different ages (tTukey-Kramer method)

Age	Year-class
I	1980 > 1981 1970 > 1972, 1975, 1981, 1977, 1979, 1974, 1976, 1973
II	1974 > 1975
III	1975 > 1979 1978 > 1979 1976 > 1979
VII	1973 > 1975 1970 > 1975

TABLE 51 Summary of comparisons between lengths of zander year-classes at different ages (Tukey-Kramer method)

Age	Year-class
I	1981 > 1977, 1979
II	1979 > 1974 1978 > 1974 1981 > 1974

TABLE 52 Summary of comparisons between growth in a season for various age groups of roach (Tukey-Kramer method)

Age group	Season
I-II	81-82 > 80-81, 79-80 82-83 > 80-81, 79-80, 78-79
II-III	81-82 > 80-81 82-83 > 80-81 76-77 > 80-81 78-79 > 80-81, 79-80, 81-82, 82-83 77-78 > 80-81, 79-80, 81-82, 82-83 75-76 > 80-81, 79-80, 81-82
III-IV	79-80 > 77-78, 78-79, 76-77 75-76 > 77-78, 78-79, 76-77 80-81 > 77-78, 78-79, 76-77
I-V	78-79 > 80-81, 77-78 > 80-81 82-83 > 80-81, 81-82, 79-80, 78-79
V-VI	81-82 > 80-81 79-80 > 80-81

TABLE 53 Summary of comparisons between growth in a season for various age groups of bream (Tukey-Kramer method)

Age group	Season
I-II	74-75 > 81-82 72-73 > 81-82
II-III	76-77 > 81-82 77-78 > 81-82
V-VI	78-79 > 80-81

Significantly better 0+ growth was shown by the 1982, 1980 and 1981 year-classes of roach (see Table 49). This pattern of better growth for the later year-classes was confirmed when data were compared from fish of the same age, so avoiding any biases due to the Rose-Lee phenomenon.

1970 was a particularly poor growing year-class for 0+ common bream (Table 50), whilst in 1981 0+ zander (Table 51) showed significantly better growth than either the 1977 or 1979 year-classes.

The data are only extensive enough to explore variations in length of different year-classes at the same age for roach (Table 49), a general trend is apparent in that the later year-classes show better growth; this is a similar finding to the analysis by Kempe's method.

Variations in growth between years were also examined and the seasons with better than average growth (as shown by the Kempe' analysis) were shown to be 1980-81, 1979-80, for roach (Table 41), 1981-82, 1980-81 and 1971-70 for common bream (Table 42) 1981-82, 1982-83 and 1980-80 for zander (Table 43) and 1978-79, 1982-83 and 1980-81 for pike (Table 44). A consistent trend of good growth in the later seasons is apparent and this is supported by the analysis of variance analysis of growth for these species (Tables 52 and 53).

5.2.5 Discussion

The major influences on growth rates are temperature and feeding conditions, these factors determine both the average growth rate of a population and its variation between years. The feeding conditions will depend on the availability of suitable food and the density of potential competitors. Some years will have better potential for growth than

others and it will be expected in this study that growth will also have been affected by the variations in density of the various fish populations. Growth in turn may influence survival and hence year-class strength and biomass levels.

Roach growth is poorer than that found in many other British waters. However, it is similar to that found throughout the Anglian region and so it would appear that the feeding conditions for the fish populations of the Sixteen Foot Drain are normal for the region. Roach biomass and growth rates are greatest when there is an abundance of suitable molluscs (Kempe 1962). Since roach were found to be feeding predominantly on filamentous algae and detritus (see Chapter 4) it is likely that the food supply is less than ideal. The data on macro-invertebrate abundance (Chapter 1) would support this as chironomids and tubificids were the major species present. This would explain the relatively poor growth rates observed for roach.

Common bream growth in common with populations throughout Anglia is good and is probably due to the abundance of macro benthos and chironomids in particular (see Section 1.4.4).

It is known that the growth rate in common bream is positively correlated with the standing crop biomass of invertebrates in mud (Marciak, 1972; Cazemier, 1975). The good growth rates of common bream compared to the below average growth rates of roach is a reflection of the management of the Sixteen Foot Drain for land drainage. This results in reduced shallow water macrophute cover and an increase in the deep water benthic habitat, so that the macro benthos will be the most important secondary producers available to the fish populations.

The growth of pike in the Sixteen Foot is similar to that of other populations in the region but is lower than the standard growth rate. For a visual predator like pike the availability of prey will be determined not only by prey density but by the turbidity of the water and the presence of cover. It would be expected in the turbid drains of the Middle Level that prey would be harder to catch and so growth rates would be relatively slow (see Willemsen, 1980).

The growth of zander varies with temperature and food availability (Willemsen, 1983) and so varies widely over its range. The optimum temperature for growth amounts to approximately 28°C (Willemsen, 1978) and so British growth rates will not be amongst the highest. The highest growth rates come from Central Asia (Solonov, 1975) and the lowest from Sweden (Svardson and Molin, 1971), corresponding to the climatic extremes of the zander's distribution.

Climatic conditions in Britain are similar to those in the Netherlands where growth rates are generally better, this was attributed to the abundance of suitable prey fish (mainly cyprinids, smelt and ruffe) in Dutch waters (Willemsen 1983).

The growth rates of the Sixteen Foot Drain zander populations are very similar to other British populations, although the Middle Level populations contained both fast growing and slow growing fish, which Fickling (1982) attributed to variations in both predator and prey abundance.

The changes in abundance of the major fish species should be largely responsible for the variations in growth rates between year-classes. Roach and common bream year-classes exhibited good growth when biomass

levels were low in the late 1970's. The growth rates of zander improved later at the beginning of the 80's when presumably cyprinid recruitment and hence food supply improved. Fickling (1982) showed a similar phenomenon in the Middle Level; zander were fast growing before 1977 when prey were abundant but as the prey populations declined so did zander growth rates.

The inverse relationship between growth rate and density (Walter, 1934; Le Cren, 1965) is thought to break down at high levels of abundance (Backiel and Le Cren 1967), i.e. when a population approaches its carrying capacity.

An analysis of growth rates of different year classes may in future be able to help determine the carrying capacity of the Sixteen Foot Drain and show whether the populations are limited by recruitment rather than food supply. This would have important consequences for the adoption of a suitable management scheme to maintain adequate angling stocks.

Since the fish populations have recovered from a very low level of abundance it was not possible to investigate this phenomenon.

Changes in cyprinid growth rates due to variations in population densities and hence competition do not appear to be large for the Sixteen Foot populations.

The growth rate of common bream is fast compared to other British waters whilst those of roach and pike are slower. These growth rates are similar to those from other waters in the Anglian region.

Zander growth rates are similar to those observed in other British waters and would appear to be normal for such a climate and geographical location.

A trend in growth rates is apparent and is due largely to changes in population density and presumably competition. Roach and common bream showing good growth when their populations had declined, whilst the piscivore growth rates increased later as the prey populations recovered. Significantly good 0+ growth rates were only seen for strong year-classes.

5.3 Mortality and Survival

5.3.1 Introduction

It is necessary to have a knowledge of mortality or survival rates before the population dynamics of a fishery can be described, since together with recruitment they will determine both population structure and abundance. They also need to be quantified for the assessment of year-class strength in section 5.4.

5.3.2 Methods

Calculations of mortality and survival depend on the formulation of a relationship between abundance and time. This can be done by following a cohort through time (e.g. by mark and recapture) or else by comparing the relative abundance of different year-classes or age-groups (e.g. by ageing a catch or catches). The accuracy of such calculations will depend on the assumptions underlying the models used. Whilst variations in mortality between year-classes, years or ages of fish may act to obscure the actual rates.

Variations in the piscivore populations would be expected to cause changes in mortality of their prey. However it was shown in section that pike and zander predated mainly on 0+ fish; by excluding these younger age-classes of fish from the calculations the survival rate of fish that have recruited to the fishery can be calculated. There will be less variation in the value thus calculated since mortality is known to vary widely for 0+ fish although it becomes relatively constant subsequently (Mann, 1965; Williams, 1963, 1967).

Variations in recruitment can be allowed for by combining the data from all years of the study thereby smoothing out the effect of variable year-class strengths.

The calculation of survival achieved via simple catch curves where the logarithm of frequency of occurrence of fish in a particular size class are plotted against that size class were first used by Edser (1908) and later by Heineke (1913) and Baranov (1918). Ricker (1948) by plotting the logarithm of frequency of occurrence of aged fish against age produced a quick and easy way of estimating survival from single or multiple catch data.

$$S = \frac{\text{antilog}_e (a+b (x+ 1))}{\text{antilog}_e (a + bx)} \times 100$$

Where S = mean survival rate
 a = constant
 b = constant See Figures 18,19 and 20
 x = age

A linear regression analysis of log % frequency of fish in age group x against age x being used to calculate a and b.

5.3.3 Results

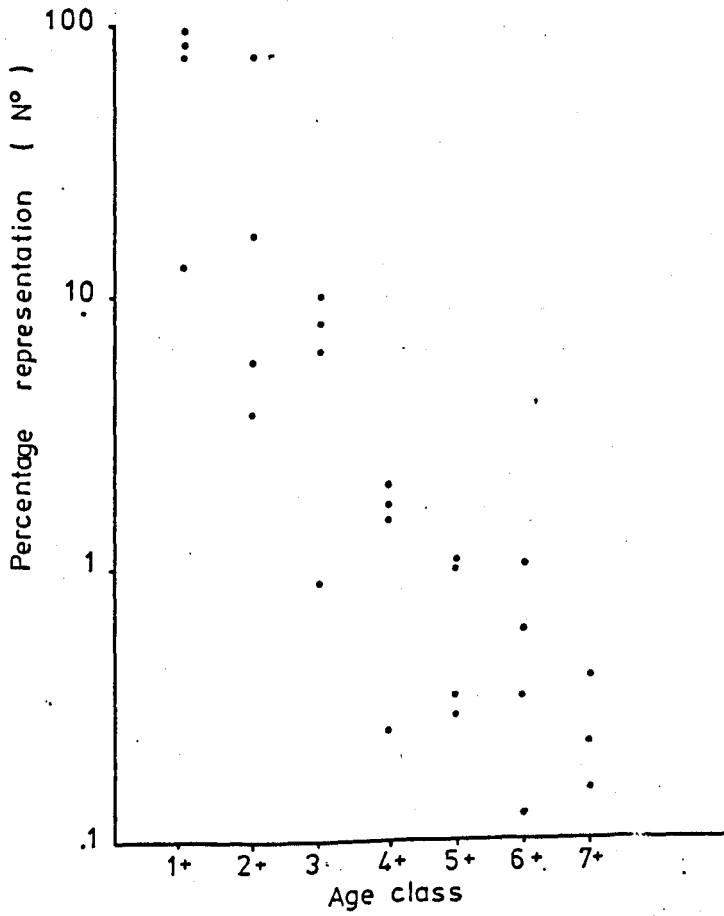
Survival estimates for roach, common bream and pike are given in Table 54 these were obtained from the data plotted in Figures 18,19 and 20.

Survival of roach (38.14%) is liable to be underestimated since 1979, 1980 and 1982 were strong year-classes compared to the ones prior to them: similarly an estimate of 72.48% for common bream is liable to be an underestimate. The pike population had lost most of the older fish so that the data mainly cover fish that were not subject to the cull (i.e. 1977 onwards). One would expect high survival until the pike population recovered (see section 4) due to the lessening of cannibalism and this is confirmed by a value of 78.82%.

Figure 18

Mortality of Roach

$$Y = -0.9638 x + 4.63500$$

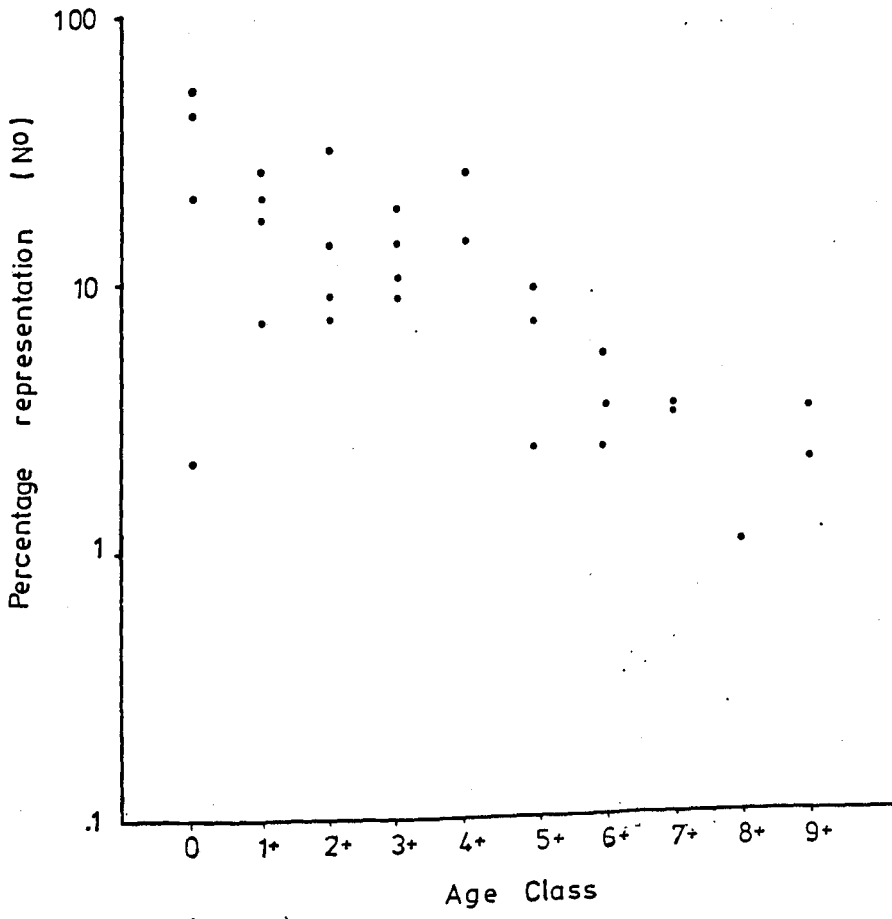


Derived from Table 56

Figure 19

Mortality of Common Bream

$$Y = -0.321776 + 2.83480$$

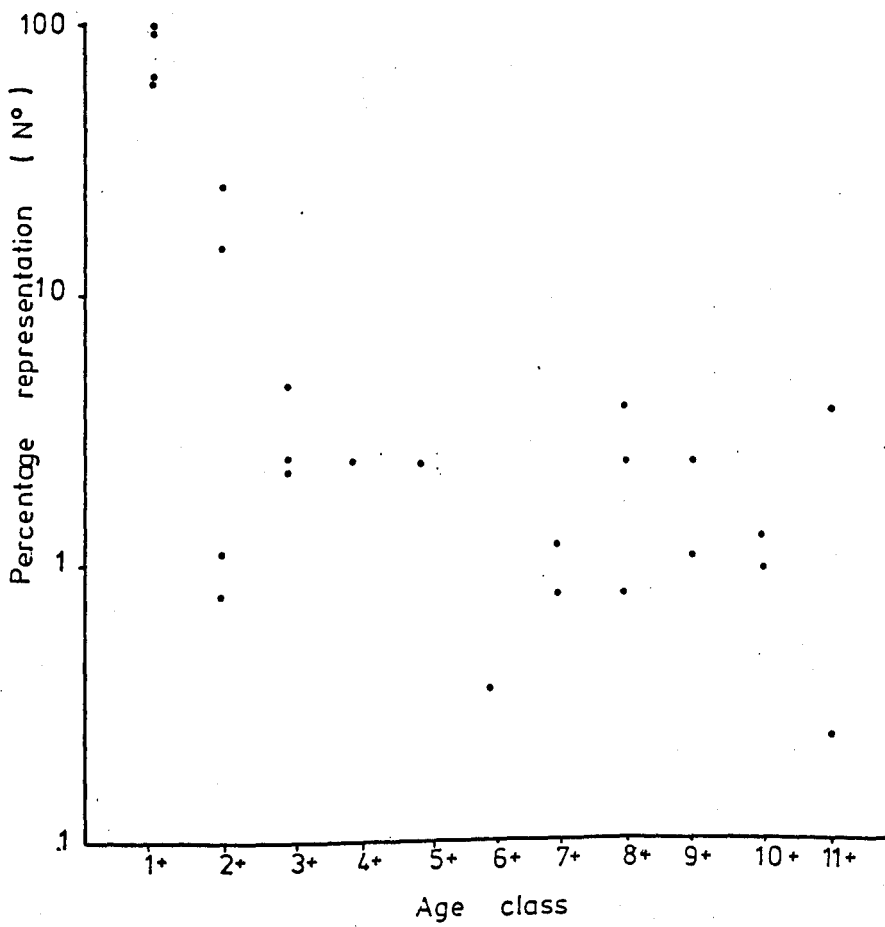


Derived from Table 57

Figure 20

Mortality of Pike

$$Y = -0.23800 x + 3.20893$$



Derived from Table 60

Table 54 Estimated annual survival rates of roach, common bream and pike derived from Sixteen Foot Seine data (1980 - 1984).

Species	Annual Survival Rate (%)
Roach	38.1
Common Bream	72.5
Pike	78.8

An estimate of survival for zander can not be obtained from the present data since the seine which could provide an unbiased sample of the population caught only relatively few zander. Few old fish were found in the population and this would suggest that mortality was high, showing the effectiveness of the control of the zander population by culling.

5.3.4 Discussion

Common bream are relatively long lived and often exhibit variable recruitment (Goldspink, 1981), in such cases a high survival rate will be necessary to maintain a stable population. Roach year-class strengths are generally less variable than common bream and show lower survival rates; the importance of this for the population dynamics will be discussed more fully in chapter 6.

The present survival rates are comparable to other similar waters (Table 55 for roach), and suggests that older fish are not subject to increased mortality despite the presence of the zander.

The high survival rate of the pike population could be as a result of the lessening of intraspecific predation following the cull and points to the importance of cannibalism in the density dependent regulation of pike populations.

The absence of older zander is probably the result of a low survival due to its continued culling and would suggest that the present methods of removing zander are efficient.

TABLE 55 Annual survival rates of roach from the Anglian region

WATER	ESTIMATED ANNUAL SURVIVAL RATE
River Ancholme	44%
Fossey, Till and Middle Witham	33%
South Forty Foot Drain	41.8%
Sibsey Trader	44.9%
River Witham (Lincoln to Boston)	43%
River Steeping	48%
Moretons Leam	45%
River Nene (Wellingborough to Peterborough)	49%
River Nene (Oundle to Peterborough)	41%
North Level Drains	43%
South Holland Drains	34%
Welland and Deeping Drains	33%

Fish age z + and older
Based on Fish > 10cm

From Jordan, 1984

5.4 Year-class strength

5.4.1 Introduction

Variations in year-class strength are often important in influencing stock levels (see Section 2.6); such variations are commonly seen over wide geographic areas and so it is thought that climate operating through feeding conditions is the determining factor. Localised ecological conditions or man's activities may also produce effects specific to a particular fishery. It is necessary therefore to describe the recent history of the Sixteen Foot Drain fish populations in the light of the background variations in other fisheries so that the processes peculiar to it can be examined.

5.4.2 Methods

The catch data presented in Section 2 were broken down into the component year-classes (for roach, common bream, zander and pike) using the length/frequency distributions and an age/length key (Bagenal and Tesch, 1978). (A process largely similar to that used for the calculation of growth from age data in Appendix G). This allows an analysis of year-class strengths to be made.

Before attempting any analysis on the raw data (Tables 56,57,58,59, and 60) it is necessary to be aware of biases that may lead to misinterpretation.

Two factors determine the relative age composition of a population, the original number in a cohort (i.e. recruitment) and their subsequent decline (i.e. mortality). If mortality is relatively constant between year-classes, years and ages then differences will be due to variations in recruitment. Mortality tends to be highly variable for o+ fish although it is relatively constant for older fish (see Section 2.6).

The intensity of mortality due to piscivorous fish is liable to have varied during the recent past. However, the data on diet (see Section 4) and mortality (Section 5.3) suggest that this will only have been an important factor for o+ fish. Problems in interpreting year-class strength due to variations in mortality can be avoided therefore by only using older fish in the subsequent calculations.

The comparison of year-class strengths within a population by Kempe's (1962) method is largely the same as that used in Section 5.3.5 to compare growth rates.

TABLE 56 Relative year-class strengths of roach in seasons 1980 to 1984, seine catches

Season		1+	2+	3+	4+	5+	6+	7+	8+
1980-81	Yr-class	'79	'78	'77	'76	'75	'74	'73	'72
	No	2980	177	28	8	9	4	2	3
	%	92.81	5.51	.87	.25	.28	.12	.06	.09
1981-82	Yr-class	'80	'79	'78	'77	'76	'75	'74	
	No	131	778	79	17	10	6	4	
	%	12.78	75.90	7.71	1.66	.98	.59	.39	
1982-83	Yr-class	'81	'80	'79	'78	'77	'76	'75	
	No	680	149	55	18	3	3	2	
	%	74.73	16.37	6.04	1.98	.33	.33	.22	
1983-84	Yr-class	'82	'81	'80	'79	'78	'77	'76	'75
	No	7,490	327	886	134	92	90	14	6
	%	82.86	3.62	9.80	1.48	1.02	1.00	.15	.07
	%Standard	65.80	25.35	6.11	1.34	.65	.51	.21	.04

TABLE 57 Relative year-class strength of common bream between 1980 and 1984, Seine catches

Season		1+	2+	3+	4+	5+	6+	7+	8+	9+	10+	11+	12+	13+	14+	15+	16+	17+
1980-81	Yr-class	79	78	77														
	No	86	1	2														
	%	96.63	1.12	2.25														
1981-82	Yr-class	80	79	78	77	76			73	72	71	70	69					
	No	52	12	2	2	2			3	2	1	3	1					
	%	65.00	15.00	2.50	2.50	2.50		3.75	2.50	1.25	3.75	1.25						
1982-83	Yr-class	81	80					75	74									
	No	124	1					1	1									
	%	97.64	.79				.79	.79										
1983-84	Yr-class	82	81	80			77	76	75	74	73	72	71	70	69	68		66
	No	517	212	39			3	10	20	9	8	2	5	4	1	1		1
	%	62.14	25.48	4.69		.36	1.20	2.40	1.08	.96	.24	.60	.48	.12	.12		.12	
	% Std.	80.35	10.60	2.36	.63	.13	.09	0.50	1.74	2.77	1.49	1.00	.46	.12	.3	.3		.3

TABLE 58 Relative year-class strengths of zander between 1980 and 1984, Seine catches.

Season		0+	1+	2+	3+	4+	5+	6+	7+	8+	9+
1980-81	Yr-class	80									
	No										
	%										
1981-82	Yr-class	81		79							
	No	7		1							
	%	87.50		12.50							
1982-83	Yr-class	82	81		79	78					
	No	2	2		1	1					
	%	33.33	33.33		16.67	16.67					
1983-84	Yr-class		82	81	80	79	78	77			
	No		9	4	6	2	1	1			
	%		39.13	17.39	26.09	8.70	4.35	4.35			
Mean	%	30.21	43.11	7.47	10.69	6.34	1.09	1.09			

TABLE 59 Relative year-class strengths of zander between 1980 and 1984, trawl catches

Season		0+	1+	2+	3+	4+	5+	6+	7+	8+	9+
1980-81	Yr-class	80	79	78							
	No	4	4	1							
	%	44.44	44.44	11.11							
1981-82	Yr-class	81	80	79	78	77	76	75			
	No	105	22	13	2	1	1	2			
	%	71.92	15.07	8.09	1.37	.68	1.37				
1982-83	Yr-class	82	81	80			77			74	
	No	40	13	4			1			2	
	%	66.67	21.67	6.67			1.67			3.33	
1983-84	Yr-class	83	82	81	80	79					
	No	2	3	1	3	2					
	%	18.18	27.27	9.09	27.27	18.18					
Mean	%	50.30	27.11	8.74	7.16	4.72	.59	.34		.83	

TABLE 60 Relative year-class strength of pike between 1980 and 1984, Seine catches.

Season		0+	1+	2+	3+	4+	5+	6+	7+	8+	9+
1980-81	Yr-class	80	79	78	77						
	No	6	3	1	1						
	%	54.55	27.27	9.09							
1981-82	Yr-class	81	80	79	78		76	75	74		72
	No	6	5	9	3		2	1	1		1
	%	21.43	17.86	32.14	10.71		7.14	3.57	3.57		3.57
1982-83	Yr-class	82	81	80	79	78	77	76			
	No	18	3	6	6	6	1	1			
	%	43.90	7.32	14.63	14.63	14.63	2.44	2.44			
1983-84	Yr-class	83	82	81	80	79	78	77	76	75	74
	No	2	20	7	18	25	9	5	3	1	2
	%	2.17	21.74	7.61	19.57	27.17	9.78	5.43	3.26	1.09	2.17
Mean	%	30.51	18.55	15.87	13.50	10.45	4.84	2.86	1.71	.27	1.44

An average or standard of percentage age composition is calculated for each age class (i.e. II, III, IV etc.), by summing the % value of each year-class at that age and finding the arithmetic mean. The strength of any particular year-class can then be calculated by expressing the sum of its percentage composition at each age-class over the mean sum of percentage composition at each age. This enables the relationship of the strength of each year-class to the average value of all the material to be expressed.

An analysis like Kempe's which averages the data over the range of values has disadvantages in that it cannot be used for data collected from one sampling occasion, and that care needs to be exercised in its interpretation if weak or strong year-classes are clustered. In the later case a year-class although weak in absolute terms, may appear to be strong when contrasted with other weak year-classes. Therefore it is important to use a second method of assessing year-class strengths.

An annual survival rate that describes the relative abundance of a cohort throughout its lifetime was used by Linfield (1981b) to calculate a standard or expected age composition with which actual observations could be compared. By assessing the deviations from the expected values relative year-class strengths could be gauged.

Seine data are used wherever possible because of its unselective nature compared to trawling.

5.4.3 Results

A Kempe type analysis (Table 61) of roach year-classes showed that prior to 1978 all the year-class were poor, including 1975 which had previously been shown to be good in other Anglian Waters (Linfield, 1981b). A strong year-class was produced in 1979 followed by other strong year-classes in 1981 and 1982. The 1979 and 1981 year-classes were also strong for common bream (the poor showing of the 1982 cohort was probably due to the small amount of data for common bream in this later period, Table 62). 1977, 1976, 1975 and 1970 were also strong but it must be noted that during this period absolute abundance was low and so such an analysis of relative abundance may be misleading.

The 1978 to 1973 year-classes of pike were poor whilst 1979, 1980 and 1982 were strong (see Table 64), c.f. roach and common bream. The 1978 and earlier year-classes would have been removed by the cull and so this result is not surprising. 1981 produced a poor pike year-class, this contrasts with roach and common bream which produced strong year-classes in that year but poor ones in 1980. One would normally expect synchronisation of both pike and prey year-classes (Section 2.6).

The only strong zander year-class was 1981 (Tables 63 and 64), although it must be realised that seining for zander was relatively inefficient and so that data would not be as comprehensive as for the other species.

Difficulties arise with this type of analysis since year-class strengths are averaged over the years of the study, so if year-class strengths tend to cluster then the index of relative strength may not reflect absolute strength. So whilst 1980 appears to be weak for both roach and common bream it could still be strong compared to earlier year-classes.

TABLE 61 Index of relative year class strength of roach, between 1982 and 1972 (after Kempe, 1962).

Year Class	Index of year-class strength	
	Seine	Trawl
1982	126	13
1981	118	159
1980	40	57
1979	179	162
1978	48	67
1977	45	47
1976	63	87
1975	82	129
1974	67	104
1973	31	76
1972	225	-

TABLE 62 Index of relative year-class strength between 1980 and 1984 of common bream (after Kempe, 1962)

Year Class	Index of year-class strength	
	Seine	Trawl
1982	77	117
1981	135	169
1980	76	32
1979	119	103
1978	25	54
1977	138	65
1976	200	51
1975	108	211
1974	95	46
1973	73	16
1972	39	57
1971	32	116
1970	138	224
1969	73	65
1968	10	98
1967	-	-
1966	10	394

TABLE 63 Index of relative year-class strength for zander between 1983 and 1974 (after Kempe, 1962)

Year Class	Index of year-class strength	
	Seine	Trawl
1983	-	36
1982	99	121
1981	171	120
1980	29	100
1979	56	148
1978	82	6
1977	23	18
1976	-	12
1975	-	70
1974	-	401

TABLE 64 Index of relative year-class strength for pike between 1980 and 1984 (after Kempe, 1962)

Year Class	Index of year-class strength	
	Seine	Trawl
1983	7	153
1982	133	84
1981	56	32
1980	136	147
1979	173	143
1978	99	49
1977	54	106
1976	65	-
1975	48	-
1974	91	4
1973	-	-
1972	209	-

To surmount this problem the relative strength of each year-class can be compared with its expected strength (Linfield, 1981b) for each year of the study. It would be expected that if the cull's *raison d'etre* is correct then each year-class since 1979 in its first year of assessment should be strong.

Linfield analysis:

It is possible to assess year-class strength by plotting $\log (\% \text{ No.})$ against age-class, weak year-classes will fall below the regression line and strong ones above it. However, if year-class strengths cluster at one end of the line then the slope will be biased. To overcome this problem, since in this present study pre-cull year-class strengths are liable to be weaker than post-cull ones, it is possible to compare observed with expected year-class strength, assuming a mean mortality level derived from U.K experience.

Certain difficulties arise in such an analysis of the Sixteen Foot populations since it might be expected that the introduction of the zander and the subsequent piscivore cull would have influenced prey mortality rates; causing them to vary between years and year-classes. This means that the results of the analysis would be affected by variations in mortality as well as recruitment.

The peculiarities of the Sixteen Foot populations means that an average mortality rate derived from other waters may not be an accurate estimate. Whilst a mortality rate calculated from the Sixteen Foot data may be an overestimate due to a trend in earlier year-classes to be weaker. An analysis has been performed therefore using mortality rates from other waters as well as those calculated during the present study since these can be expected to bracket the true rate.

A problem will still exist, however, if mortality rates have varied over the population. In chapter 4, however, it was argued that the major effect of piscivory will be to cause variations in survival of 0+ prey fish and since these are excluded from the analysis variations in year-class strength will be due to recruitment rather than mortality for the prey populations.

The analysis will be restricted to the prey populations since the cull and any subsequent increase in recruitment due to a lessening of intraspecific predation will mean that it is not accurate to describe the mortality rates of the piscivore populations by a mean value.

The cull of pike, and the subsequent reduction in intraspecific predation, in the 1980 and 1981 season appears to have resulted in the 1979 and 1980 year-classes being strong. Year-class strengths of piscivores and their prey tend to be synchronised, that this was not so in 1981 would have been due to the preceeding strong year-class increasing the incidence of cannibalism.

Linfield (1981b), in his analysis used a mean survival rate (of 60%) assumed from general U.K. experience for roach; although values calculated for Anglian populations averaged 40%. He assumed that a succession of weak year-classes in the early part of the data would result in an artificially high mortality rate, if calculated from his own data. Following his analysis he concluded that poor year-classes were produced between 1971 and 1974 (Table 65).

TABLE 65 An analysis of year-class strengths in Anglian rivers (from Linfield, 1981). Ranking of year-class strengths for years where actual percentage representation is twice the expected.

		Year										
		'77	'76	'75	'74	'73	'72	'71	'70	'69	'68	'67
Roach	Expected	4	24.4	14.7	8.8	5.3	3.2	1.9	1.1			
	Mean for selected data	25.6	23.2	38.6	5.0	3.7	1.9	1.3	.3			
	Difference	-15.1	-1.2	+23.9	-3.8	-1.6	-1.3	-.6	-.8			
	% Difference	-37	-5	+163	-43	-30	-41	-32	-73			
	Yr-class strength ranked				1							
Common Bream	Expected	32.5	22.1	15.0	10.2	6.9	4.7	3.2	2.2	1.5	1.0	.7
	Mean for selected data	6.8	8.8	26.5	8.8	11.5	13.8	5.8	6.3	5.8	4.8	1.8
	Difference	-25.7	-13.3	+11.5	-1.4	+4.6	+9.1	+2.6	+4.1	+4.3	+3.8	+1.1
	% Difference	-79	-60	+77	-14	+67	+194	+81	+186	+287	+380	+157
	Yr-class strength ranked						3		4	2	1	5

The mortality estimates obtained from the data collected in this present study (see Section 5.3) was very close to those published by Jordan (1984) for other Anglian fisheries and an analysis of roach year-class strength will be performed using both the general U.K. figure of 60% and the Anglian figure of 41.1% and the results compared.

The survival rates for common bream were 68%, 70% and 72.5% (from U.K. experience Linfield, 1981; Jordan 1984; and present study respectively) and so the figure of 68% quoted by Linfield (1981b) is used to make the results of this study comparable.

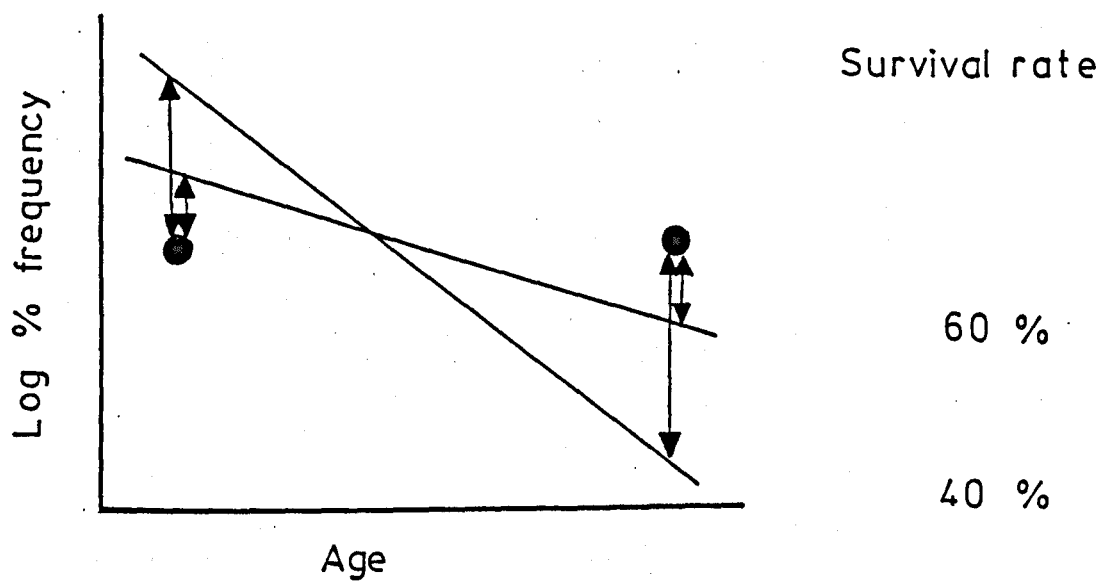
When year-class strengths calculated for roach of 1+ in age and older was analysed by the methods of Linfield using survival rates of 41.6% and 60% (Tables 66 and 67), the 1979, 1981 and 1982 year-classes were shown to be strong in both cases, in their first year of assessment. All other year-classes were weak with the exception of 1974 in 1981/82 and 1977 in 1983/84 (these were not particularly strong however).

Making different assumptions about the mean survival rate will affect the results of the analysis. Assuming a mean survival rate of 40% compared to 60% will result in young weak year-classes appearing weaker and strong older year-classes appearing stronger (Figure 21).

That survival rates of 40% and 60% both gave similar results is due to a tendency for recent year-classes to be strong in the 1980's.

A similar result was also obtained for common bream (Table 68) each year-class being strong in its first year of assessment.

Figure 21 Effect of using different expected survival rates on estimate of year-class strength.



↕ Deviation of observed % frequency from expected

TABLE 66 An analysis of year-class strength (after Linfield, 1981) roach (mortality=58.4)

Age Class		1+	2+	3+	4+	5+	6+	7+	8+
Expected		58.4	24.3	10.1	4.2	1.8	0.7	0.3	0.1
1980-1980	Year Class '79		'78	'77	'76	'75	'74	'73	'72
	Mean	92.8	5.5	0.9	0.3	0.3	0.1	0.1	0.1
	Difference	+34.4	-18.8	-9.2	-3.9	-1.5	-0.6	-0.2	0
	% Difference		+58.9	-77.4	-91.1	-92.9	-83.3	-85.7	-66.7
1981-1982	Year Class '80		'79	'78	'77	'76	'75	'74	
	Mean	12.8	75.9	7.7	1.7	1.0	0.6	0.4	
	Difference	-45.6	+51.6	-2.4	-2.5	-0.8	-0.1	+0.1	
	% Difference		-78.1	+212.3	-23.8	-59.5	-44.4	-14.3	+33.3
1982-1983	Year Class '81		'80	'79	'78	'77	'76	'75	
	Mean	74.7	16.4	6.0	2.0	0.3	0.3	0.2	
	Difference	+16.3	-7.9	-4.1	-2.2	-1.5	-0.4	-0.1	
	% Difference		+27.9	-32.5	-40.6	-52.4	-83.3	-57.1	-33.3
1983-1984	Year Class '82		'81	'80	'79	'78	'77	'76	
	Mean	82.9	3.6	9.8	1.5	1.0	1.0	0.2	0.1
	Difference	-24.5	-20.7	-0.3	-2.7	-0.8	+0.3	-0.1	0
	% Difference	42.0	85.2	3.0	64.3	44.4	42.9	33.3	

TABLE 67 An analysis of year-class strength (after Linfield, 1981) roach (mortality=40%)

Age Class		1+	2+	3+	4+	5+	6+	7+	8+
Expected		40.6	24.4	14.7	8.8	5.3	3.2	1.9	1.1
1980-1981	Year Class	'79	'78	'77	'76	'75	'74	'73	'72
	Mean	92.8	5.5	0.9	0.3	0.3	0.1	0.1	0.1
	Difference	+52.2	-18.9	-13.8	-8.5	-5.0	-3.1	-1.8	1.0
	% Difference	+128.6	-77.5	-93.9	-96.6	-94.3	-96.9	-94.7	-90.9
1981-1982	Year Class	'80	'79	'78	'77	'76	'75	'74	
	Mean	12.8	75.9	7.7	1.7	1.0	0.6	0.4	
	Difference	-27.8	+51.5	-7.0	-7.1	-4.3	-2.6	-1.5	
	% Difference	-68.5	+211.1	-47.6	-80.7	-81.1	-81.3	-78.9	
1982-1983	Year Class	'81	'80	'79	'78	'77	'76	'75	
	Mean	74.7	16.4	6.0	2.0	0.3	0.3	0.2	
	Difference	+34.1	-8.0	-8.7	-6.8	-5.0	-2.9	-1.7	
	% Difference	+84.0	-32.8	-59.2	-77.3	-94.3	-90.6	-89.5	
1983-1984	Year Class	'82	'81	'80	'79	'78	'77	'76	'75
	Mean	82.9	3.6	9.8	1.5	1.0	1.0	0.2	0.1
	Difference	+42.3	-20.8	-4.9	-7.3	-4.3	-2.2	-1.7	-1.0
	% Difference	+104.2	-85.2	-33.3	-83.0	-81.1	-68.9	-89.5	-90.9

TABLE 68

An analysis of year class strength (after Linfield, 1981), common bream (mortality = 32%)

		Age Class															
		II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	
XVII																	
Expected		32.5	22.1	15.0	10.2	6.9	4.7	3.2	2.2	1.5	1.0	.7					
1980-81	Year Class	'79	'78	'77													
	Mean	96.6	1.12	2.25													
	Difference	+64.1	-21.0	-12.8													
	%Difference	+197.2	-94.9	-85.0													
1981-82	Year Class	'80	'79	'78	'77	'76	'75	'74	'73	'72	'71	'70	'69				
	Mean	65.0	15.0	2.5	2.5	2.5			3.8	2.5	1.3	3.8	1.3				
	Difference	+32.5	-7.1	-12.5	-7.7	-4.4			+1.6	+1.0	+0.3	+3.1					
	%Difference	+100.0	-32.1	-83.3	-75.5	-63.	+72.7	+66.7	+30.0	+442.9							
198 -8	Year Class	'81	'80	'79	'78	'77	'76	'75	'74	'73	'72	'71	'70				
	Mean	97.6	.8					.8	.8								
	Difference	+65.1	21.3					-2.4	-1.4								
	%Difference	-96.4						-75.0	-63.6								
1983-84	Year Class	'82	'81	'80	'79	'78	'77	'76	'75	'74	'73	'72	'71	'70	'69	'68	'66
	Mean	62.1	25.5	4.7			.4	1.2	2.4	1.1	1.0	.2	.6	.5	.1	.1	.1
	Differences	+29.4	+3.4	-10.3			-4.3	-2.0	+2.0	-0.4	+0.3	-0.5					
	%Difference	+91.1	+15.4	-68.7			-91.5	-62.5	+9.1	-26.7	30	-71.4					

Linfield (1981b) on performing an analysis of year-classes strengths within the Anglian region found that year-class strengths of roach and common bream spawned between 1879 and 1968 tended to be synchronised; no strong year-classes were produced between 1971 and 1974 (Table 65), although 1972 was relatively strong for common bream the absolute abundance was in fact low. During the 1977 to 1978 season it would have been expected that the bulk of sport should have been provided by these weak year-classes, the strong 1975 year-classes not producing good sport until 1979 (the year that it did in fact improve).

Tables 69 and 70 summarise data on year-class strength from selected Anglian Waters surveyed by the AWA Roach year-classes from 1974 and earlier appear to be strong; this contrasts with the pattern found in the Sixteen Foot Drain where the recent year-classes were strong.

In analysing year-class strength it is preferable if the abundance data have been collected unselective, however, the relative inefficiency of seining for zander compared to trawling makes it difficult to base an analysis on seine data alone.

The abundance of o+ zander is known to determine subsequent standing crop, therefore if the proportion of o+ zander in the population is compared between years for trawl catches much useful information can be gained.

TABLE 69 A comparison of year-class strengths for selected Anglian rivers, roach

		Common Bream		Total		'81	'80	'79	'78	'77	'76	'75	'74	'73	'72	'71	'70	'69	'68
		No/ha	kg/ha	No/ha	kg/ha														
Expected						33	22	15	10	7	5	3	2	2	1	1			
South Forty Foot						33	5	5	5	7	2	6	6	5	7	10			
Moretons Leam	90	6.3	2570	243	10	7	2	1	1					+					
North Level Drains	70	5.0	16510	311	93	1	2	1	1	2	1								
South Holland Drains	30	12	2960	215	9	12	19	53	5	2									
Welland & Deeping IDB	10	10	15900	148	33	15	18	5	5	10	20	19	5	2					
Sibsey Trader	405	186	3136	366	1	14	18	5	5	10	19	19	5	2					
R Steeping					14	29	32	62	1	4	1	1	1	1	1	1			
Mean						28	12	14	19	4	4	7	6	2	2	2			
Difference						-5	-10	-1	+9	-3	-1	+4	+4	0	+1	+1			
% Difference						-15	-45	-7	+90	-43	-20	+133	+200	0	+100	+100			
Cut off channel		100	51	2,000	221	56	14	3		1	1	4	3	5	7	4	4		
Great Ouse (H'don)	500	89	3,800	182	8	11	3				7	16	21	11	10	11			
Yaxley Lode	100	86	4,800	236	68	14	4	1				5	3	3	2	-			
Mean						44	13	3	0	0	3	8	9	6	6	5			
Difference						+11	-9	-12	-10	-7	-2	+5	+7	+4	+5	+4			
% Difference						+33	-41	-80	-100	-100	-40	+167	+350	+200	+500	+400			

TABLE 70 A comparison of year-class strengths for selected Anglian rivers, common bream

	Common Bream		Total		'81	'80	'79	'78	'77	'76	'75	'74	'73
	No/ha	kg/ha	No/ha	kg/ha									
Expected					41	24	15	9	5	3	2	1	
River Lark	2,230	36.5	2,700	104	86	2	3	3	1	2	3	+	
Great Ouse (H'don)	1,200	58.7	2,800	164.9	45	28	9	6	3	2	4	1	
Cut Off Chanel	900	89	2,000	221	25	25	7	8	7	12	9	7	
Great Ouse (Bedford- Brampton)	2,200	67.4	4,800	235.8	25	52	12	4	4	+	2	+	
Yaxley Lode	2,300	44	3,800	182	13	79	5	2	+	+	1	+	
Mean					39	37	7	5	3	3	4	2	
Difference					-2	+13	-8	-4	-2	0	+2	+1	
% Difference					-5	+54	-53	-44	-40	0	+100	+100	
						41	24	15	9	5	3	2	1
Hobhole Drain					34	27	5	3	14	17	+	+	
Moretons Leam	1,330	77.5	2,570	243	19	27	13	15	14	11	1	+	
Welland & Deeping IDB	940	39.2	1,590	148	35	33	18	11	2	+	+		
Sibsey Trader	2,075	104	3,136	366	15	63	13	4	3	3	+	+	
River Witham					23	29	21	9	6	11	1	+	
Mean					25	36	14	9	8	8	+	+	
Difference					-16	+12	-1	0	+3	+5	-1	-1	
% Difference					-39	+50	-6	0	+60	+	-50	-100	

TABLE 71 Contribution of 0+ Zander to population

Year	% contribution of 0+ zander to total population
1980-81	44.4
1981-82	71.9
1982-83	66.7
1983-84	18.2

Zander were culled from 1979 onwards and the relative strength of 0+ fish will be increased in 1980-81. No fish older than 2+ (i.e. $\frac{1}{3}$ 240 mm) were sampled (Table 58 and 59) since these will have been removed by the cull. Older fish (up to the 1975 year-class) were sampled in the 1981-82 season although the 1979, 1980 and 1981 year-class predominated. (The presence of older fish in the later seasons will be due to the greater sampling effort employed).

The population is still dominated by young fish however, and this is a reflection of the efficiency of the continuing cull.

Kempe's analysis Table 64 is not strictly applicable to the zander data since older age groups will be subject to increased mortality due to the cull as shown by the 1978 to 1975 year-class being poorly represented.

The lack of older fish in 1981, 1982 and 1983 will have resulted in a reduction in the potential level of cannibalisation and so presumably increased survival of 0+ fish.

Pike

An analysis of seine catches by the methods of Kempe (Table 63) shows the 1978 to 1973 year-classes of pike to be poor whilst 1979, 1980 and 1982 were all strong. The 1978 and earlier year-classes would have been the ones removed by the cull and so this is not surprising. The absence of older fish would have meant that the 1979 year-classes would be subject to less cannibalism and so have experienced increased survival rates.

In 1981 the strength of the pike year-class was poor although the 1981 prey year-classes were strong (and weak in 1980); synchronisation of predator and prey year-classes may have been prevented by the increased recruitment of pike in 1979 and 1980 resulting in increased cannibalisation on the following cohort.

The recovery of the pike population can be followed in Table 60. In the 1980-81 season no fish older than 3+ were sampled (the larger fish having been removed by the cull). The decrease in cannibalism increasing that survival rates so allowing a quick recovery of the pike population. This contrasts with the zander where the continuation of the cull has prevented a recovery (e.g. biomass of pike and zander was 21.6 kg/Ha and 4.7 kg/Ha respectively in the 1983-84 season).

Comparison of growth and year-class strength

Strong year-classes are known to be produced when growth of 0+ fish is good, due to increased survival rates (see Section 2.6), a comparison of relative year-class strength and relative growth data is therefore presented in Table 72.

TABLE 72 Comparison of Kempe's index for relative growth and strength of year classes

Year Class	ROACH			COMMON BREEM			ZANDER			PIKE		
	YrClass strength	Yr Class growth	Seasonal growth	Yr Class strength	Yr Class growth	Seasonal growth	Yr Class strength	Yr Class growth	Seasonal growth	Yr Class strength	Yr Class growth	Seasonal growth
1983							(36)			7		
1982	126*		91	77			99(121)		104	133		104
1981	118*	91	97	135		118	171(120)*	107	105	56		92
1980	40	95	108	76	115	111	29(100)	100	100	136	100	101
1979	179	103	104	119	121	95	56(148)	105	98	173	9	98
1978	48	103	97	25	105	94	82(6)	99	92	99	106	125
1977	45	105	86	138	114	96	23(18)	95	88	54	101	
1976	63	102	96	200	100	96	(12)	93	93	65	111	
1975	82	99	73	108	100	98	(70)	96				
1974	67	85		95	100	95						
1973	31	84		73	96	94						
1972	225			39	90	83						
1971				32	99	107						
1970				138*	91							
1969				73								
				10								

(-) indicates trawl data

* indicates that 0+ growth was significantly good

Table 72. Strong year classes are shown when 0+ growth is good; no pattern is apparent for relative year-class growth, seasonal growth, or year-class strength

5.4.4 Discussion

The populations of roach and common bream have recovered from the low biomass levels recorded at the beginning of the study; this has largely come about because of strong year-classes since 1979. The 1979, 1981 and 1982 year-classes were relatively strong in the Sixteen Foot populations although this pattern was not seen in other comparable Anglian waters.

Good 0+ growth appears to be the factor that encourages strong year-classes. This will generally be due to environmental conditions producing good feeding conditions (for yearling fish with subsequent reductions in competition) which will result in good growth and a decrease in mortality due to predation (see Section 2.6). Subsequent mortality tends to be constant between years and so year-class strength is established in the first year.

A reduction in predator densities would be expected to reduce mortality (and hence year-class strength) even when 0+ growth rates were poor, whilst a reduction in density of older prey would result in increased growth rates (if 0+ fish were competing with their older conspecifics) and hence survival. Good growth was shown by 0+ fish after the cull and this is probably as a result of good feeding conditions due to low population levels. 1980 was a good year-class in waters within Anglia generally, whilst the 1979, 1981 and 1982 year-classes were not. So good growth and survival is probably as a result of local conditions.

Factors governing the density of o+ fish and the resulting importance for competition, growth, production, survival and year-class strength will be discussed in Chapter 6.

A strong 1981 year-class of zander might have been expected following the removal of older individuals, since the likelihood of cannibalisation of the younger cohorts would have been reduced, a similar result occurring in 1982-83. While the cull of zander continues increased recruitment of o+ zander may occur. A reduction in o+ recruitment due to the cull could occur if the spawning stock is so reduced that spawning success is significantly decreased.

Common bream and roach all showed better growth rates (both for year-class and season) in the latter years, when low biomass levels would have resulted in reduced competition (Figures 11, 12, 15, 17).

Zander predate predominantly on juvenile fish and so would be expected to show good growth rates in the latter period when prey recruitment was good and this was indeed the case (Figures 13, 14, 16).

In contrast pike showed no such pattern; it does not predate on juvenile fish stocks to the extent that the zander does and so growth rates would not be expected to follow prey year-class strength so closely.

Low prey populations levels would be expected to result in reduced competition and hence increased growth and survival rates, whilst a reduction in piscivore densities would be expected to improve survival even if growth rates were poor.

The aim of the cull was to reduce predator biomass and hence prey mortality, thereby increasing year-class strengths. If predation by piscivores was the only factor operating one would expect strong year-classes even if growth rates were poor in the latter period. It is probable therefore that favourable environmental conditions also played a role in the recovery of fish stocks.

The efficiency of the cull can be seen by the poor representation of older zander age classes. The pike population has recovered following the cull, the reduction in cannibalism following the cull presumably being responsible along with improving feeding conditions.

5.5 Conclusions

The growth rate of common bream is fast compared to other British waters whilst those of roach and pike are slower. These growth rates are similar to those from other waters in the Anglian region and it is unlikely that there is a problem of cyprinid food supply peculiar to the Middle Level System.

Zander growth rates are similar to those observed in other British waters and would appear to be normal for such a climate and geographical location.

A trend in growth rates is apparent and is due largely to changes in population density and presumably competition. Roach and common bream showing good growth when their populations had declined, whilst the piscivore growth rates increased later as the prey populations recovered.

Significantly good 0+ growth rates were only seen for strong year-classes.

The values of survival or mortality of roach and common bream are comparable with those encountered within other similar waters in Anglia; where the zander is absent. This might be expected despite a large zander biomass since predation would fall heaviest on the 0+ fish and so affect recruitment rather than the survival rates of the older age-classes which are relatively constant.

The consequences of this is that measures must concentrate on the protection of recruitment in order to protect the fishery.

The recovery of the roach and bream stocks is probably due to the production of relatively strong year-classes since 1979. These year-classes were relatively stronger than those in other Anglian waters. Favourable environmental conditions as well as reduced predation rates probably being responsible.

The pike population has recovered due to strong year-classes in 1979, 1980 and 1982. The normal synchronisation of prey and piscivore year-classes probably breaking down in the case of the 1980 and 1981 year-classes due to the influence of cannibalism; a reduction in which would have helped the production of young pike and hence the recovery of its population.

Zander biomass has not recovered since the adult population has continued to be culled the populations being dominated by o+ fish. That good recruitment of o+ fish may produce a large standing crop of zander is not likely to be a worry since the cull of zander appears to be highly effective.

CHAPTER 6.

THE IMPACT OF PISCIVORES ON THE FISH COMMUNITY

6.1 Introduction

The exploration, in the previous sections of the mechanisms operating within the fish community will allow the role of piscivory in a lowland coarse fishery to be discussed. Of particular interest are the differences between zander and pike predation and how these are influenced by the specific ecological conditions prevailing in an habitat. Such an understanding is necessary before management options can be discussed.

6.2 The recruitment : stock relationship

Recruitment and/or the production of the 0+ age group, needs to be quantified so that changes between year-classes can be followed. The major points of interest are the factors that determine 0+ production and its variation between years; data from a three year study would not have covered a sufficient period to provide answers to these questions and so data from the literature must be presented.

Cyprinid recruitment is known to vary with environmental conditions (see section 2.6) and so it is difficult to make predictions about future year-class strengths. Pivnicka (1982) studied the fish populations of the Klicava Reservoir and obtained data on production and biomass over a period of 12 years. The total production of all age groups and species was comparable with other waters with average to good productivity and are similar to the data presented for the Thames by Matthews (1971). An analysis of Pivnicka's data was attempted therefore since it enables the stock: recruitment relationship to be investigated.

Table 7 presents Pivnicka's data on roach. Biomass levels ranged from 100 Kg/Ha to 200 kg/Ha, a range that is also typical for rivers in the Anglian region (see chapter 3) and production from 5.5 Kg/Ha/yr to 61.1 Kg/Ha/yr. An analysis of this data showed no relationship between 0+ production and the biomass of potential spawners (ie the total biomass of roach in the previous year), Table 74 and Figure 22.

The biomass levels, mortality estimates and growth rates within the populations studied by Pivnicka are the same order of magnitude as the Sixteen Foot Drain roach populations and so it is reasonable to assume that the values of production will be comparable. The importance of

TABLE 73

Data on production and biomass of roach from Pivnicka (1982)

	Year-class											
	'67	'68	'69	'70	'71	'72	'73	'74	'75	'76	'77	'78
Biomass (kg/Ha)	181.7	118.2	170.7	140.9	151.0	138.7	194.5	169.1	138.9	124.1	109.9	101.6
Production (Total) (kg/Ha/Yr)	64.5	33.2	120.4	64.5	92.1	64.1	164.9	103.9	58.1	67.5	40.0	44.1
Production (1st Age-Class) (kg/Ha/Yr)	18.0	8.5	53.8	10.4	28.8	6.6	61.6	27.3	11.5	21.3	5.5	-

Figure 22 O+ production plotted against biomass of roach in previous year (Data from Pivnicka, 1982).

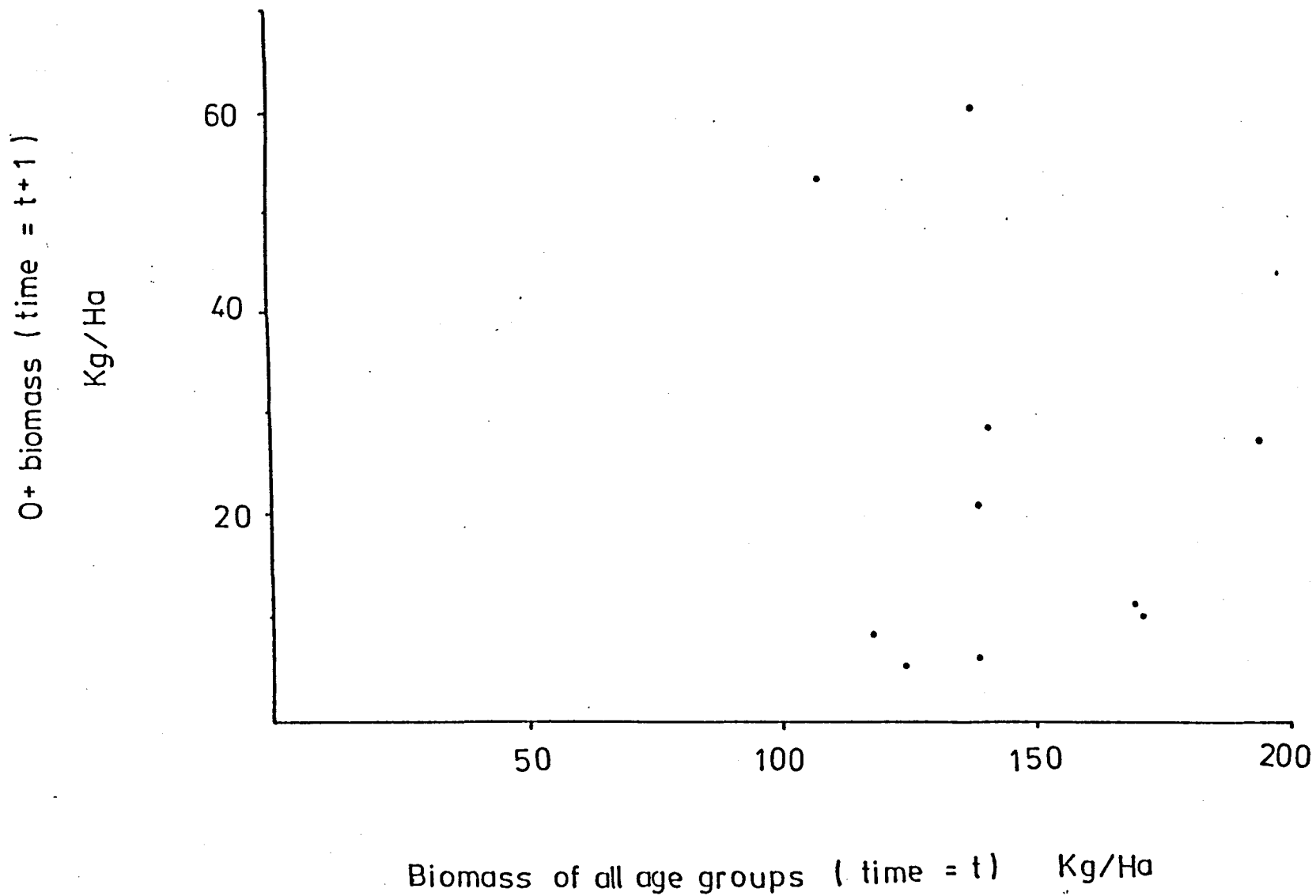


TABLE 74 Correlation of roach biomass with production of O+roach at time t^{-1}

		Correlation Coef. (r)	Significance	n
Biomass at	t - 1	-0.3978	ns	10

those four variables in describing the dynamics of a population will be detailed in section 6.4 during the construction of the model of predation.

The collection of suitable data may in future make it possible to determine a stock/recruitment relationship of the parabolic type where maximum recruitment occurs at an intermediate population density. The scatter of points in Figure 22 due to factors other than population density may act to disguise just such a relationship.

Although recruitment of roach is not predictable from a knowledge of the adult stock (since it varies due to climatic conditions section 2.6) its likely range may be described and so it will be possible to explore probable patterns of recruitment and the potential impact of the zander.

6.3 Affect of mortality rate on population structure

Mortality within a population tends to be highly variable for 0+ fish, leading to variations in recruitment at age I (see section 2.6) but relatively constant after this (see section 5.3). Therefore, in increasing the effect of variations in mortality on prey populations (due to various levels of predation) and predator populations (due to culls of different intensities) it will be adequate to assume that a given level of mortality is constant over all age classes; variations in 0+ mortality influencing recruitment.

It is first necessary to describe the normal structure of a population before one can consider how it is changed by an increase in mortality. The natural mortality of roach and common bream populations was shown in section 5.3. It is difficult to give a value for the normal natural mortality of zander, since in Britain populations are either being culled or else have not been present in a water long enough to have stabilized, while in most other countries zander are a prized food fish, which means that fishing mortality can be very high (eg 81% during the 3rd year of life in the IJsselmeer, Willemsen, 1977). Boiko (1963) obtained an estimate of the rate of natural mortality by studying zander remains from excavated ancient bottom-layers. The mortality rates calculated by Boiko are given in Table 75. His data suggest that the zander has very high survival rates for the younger age classes.

Pike populations in this country are not exploited to the extent of zander populations and it is easier therefore to find values for natural mortality in the literature. Bregazzi and Kennedy (1980) quote a survival rate of 0.59 for Slapton Ley whilst Mann (1976) quotes values of 0.42 for males and 0.63 for females in southern English rivers.

TABLE 75 Survival rates of an unexploited zander population.

Age (Yrs.)	% Survival	% Individuals Surviving
1	100	100
2	100	100
3	100	100
4	99.3	99.3
5	96.3	95.6
6	85.7	82.0
7	74.0	60.7
8	69.1	41.9
9	65.7	27.5
10	61.6	16.9
11	61.3	10.4
12	56.1	5.8
13	53.1	3.1
14	35.3	1.1

Survival (S) after age 6 = 66.9%

From Boiko; 1964.

The biomass of a particular year-class at various points in its life can be calculated if growth rate, recruitment and mortality are all known. If recruitment at age I is taken as being constant the biomass of other age classes relative to this first age-class can be calculated for a known level of mortality. This enables the pattern of biomass of the population to be determined.

e.g. Calculation of the relative biomass of each age class of a population.

$$\begin{array}{l} \text{Biomass of a cohort} \\ \text{at age } t \text{ relative} \\ \text{to a biomass of } 1 \\ \text{at age } I \end{array} = \frac{(\text{weight at age } t)s^{(t-1)}}{\text{weight at age } I}$$

s = mean survival rate

t = age of a cohort in years

I = age at 1 year.

Figures 23, 24, 25, and 26 show how the relative biomass of a cohort changes over its life time for zander, pike, roach and common bream. The age/length relationships were obtained from length/weight (Tables D.1 and D.2, Appendix D) and length/age (Tables F.9, F.10, F.11 and F.12, Appendix F) data.

Whilst most of these curves are for constant rates of mortality a variation in mortality with age can be modelled by a composite curve (see Figure 27). A decrease in mortality with age tending to shift the maximum biomass to an older age class whilst an increase will shift it to a younger one.

Figure 23 Relative biomass of zander by age class in populations with various mean survival rates.

Survival rate of population

Boiko's estimate	x
65%	●
60%	■
50%	◆
40%	▲
30%	⊕
20%	*

Figure 24 Relative biomass of pike by age class in populations with various mean survival rates.

Survival rate of population

70%	X
60%	●
50%	■
40%	◆
30%	▲
20%	*

Figure 25 Relative biomass of roach by age class in populations with various mean survival rates.

Survival rate of population

70%	×
60%	●
50%	■
40%	◆
30%	▲
20%	⊙
10%	*

Figure 26 Relative biomass of common bream by age class in populations with various mean survival rates.

Survival rate of population

70%	×
60%	●
50%	■
40%	◆
30%	▲

Figure 26

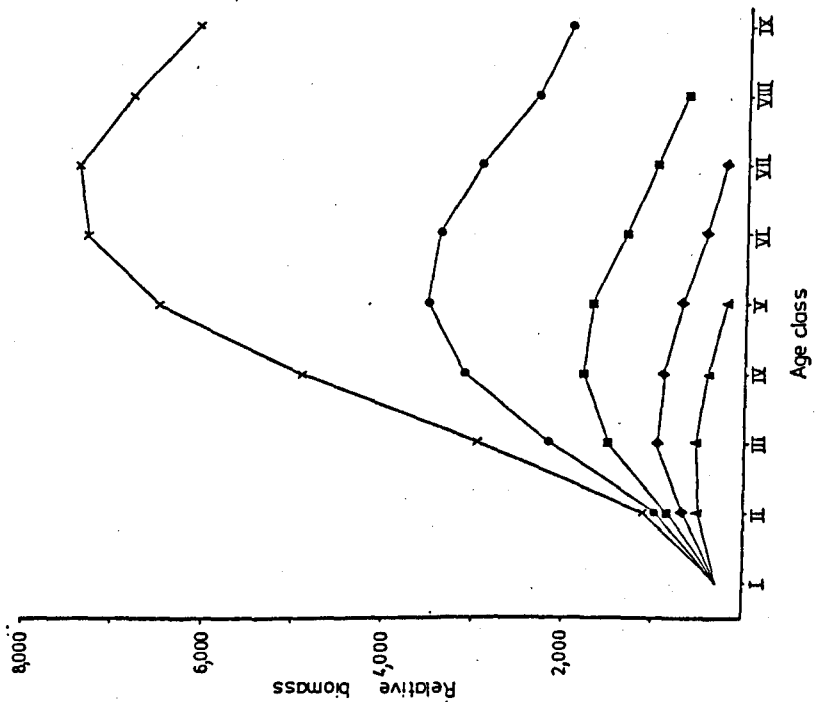


Figure 25

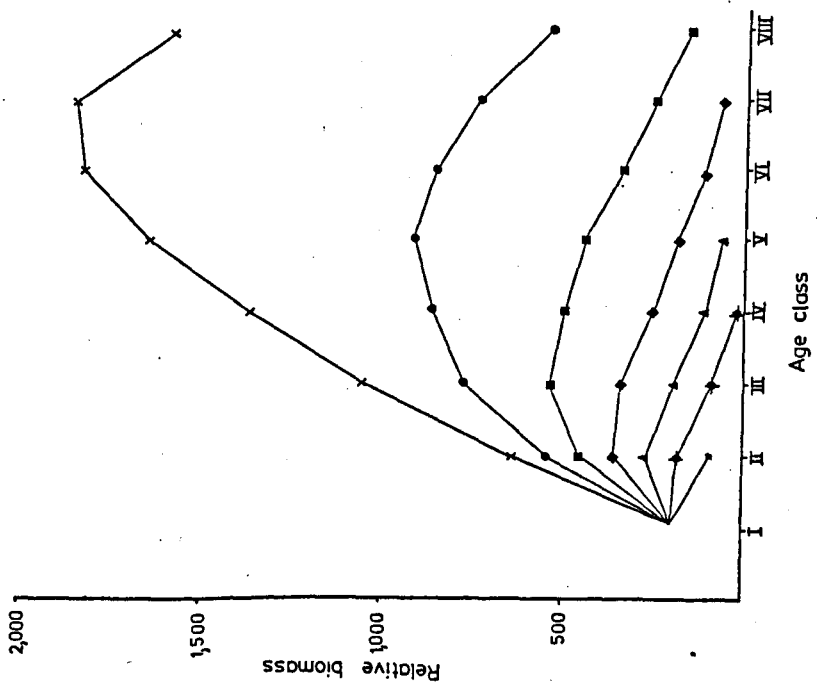
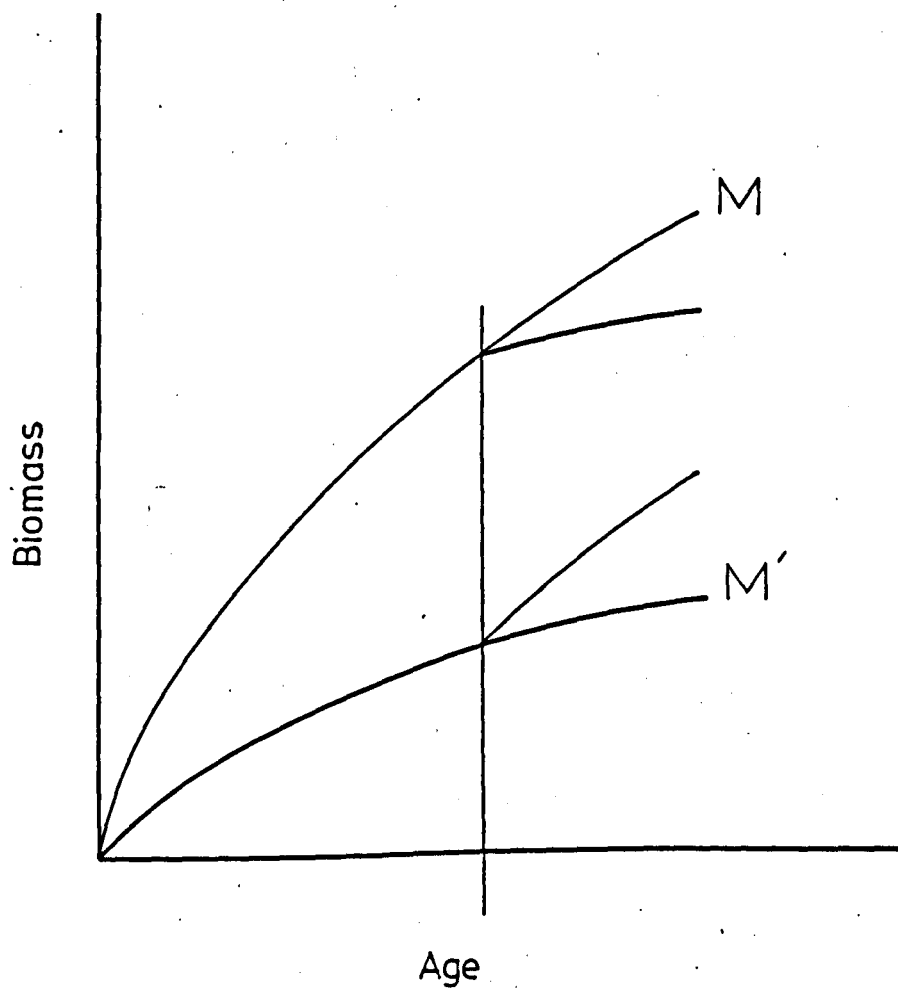


Figure 27 Composite population growth curves

(Mortalities: $M' > M$)

An important point to note here is that variations in growth rates often accompany changes in population density due to changes in competitive interactions (see section 5.2). Roach, common bream and zander were all shown to exhibit such variations in growth related to population densities. One would expect an increase in production per unit biomass at the higher mortality levels causing the lower curves in figures 22,23,24 and 25 to shift upwards.

In section 5.4 it was shown that the major effect of competition was to cause 0+ growth to vary with food supply and that 0+ growth influenced recruitment and year-class strength rather than a cohorts subsequent growth rate (see Table F.13, Appendix F). These variations although significant are relatively small and don't lead to stunting (see Linfield, 1979), this could lead to total biomass levels being relatively constant at various levels of mortality. Variations in mortality (and recruitment) alone being responsible for variations in biomass.

Total biomass will decrease as the mortality of a population increases. The proportion of younger age-classes would be expected to increase but this will also depend on the stock/recruitment relationship. If cannibalism is important in population regulation then recruitment might increase due to the reduction in older fish, resulting in a smaller decrease in total biomass than expected.

As mortality increases, peak biomass occurs at younger age classes of pike, roach and common bream, whilst the zander population only shows such a shift at a survival rate of 40%. Since size of prey is related to the size of the predator (section 4.4.3) proportionally more small fish may be predated; this may have a profound influence on an attempt to increase prey recruitment if a reduction in intraspecific predation also increases piscivore recruitment (this will be discussed in section 6.5) so that biomass levels (and hence predation rates) are not significantly reduced.

An increase in mortality of roach and common bream will mean that the population will be dominated by the younger age groups. This has important implications for the management of the fishery, since size as well as biomass determine the subjective quality of a fishery to the angler.

6.4 Predation and consumption of prey

The impact of a piscivore population depends not only on its total consumption but also on the prey species and size range predated. Differences in predation patterns of the various piscivore age-classes also need to be considered as will relationship between predator abundance, prey abundance and consumption. A detailed analysis of pike and zander diets was made in Chapter 4 and this provides the basis for the calculations in the following sections.

The relative annual ration of a cohort can readily be derived.

Annual ration of
a cohort at age t
relative to a biomass = Annual ration x $\frac{\text{weight of a cohort at age t}}{\text{weight at age I}}$
of 1 at age I

The consumption of the population can then be found by summing the above expression over the piscivores life span.

Annual ration of a
population with a
biomass at age I
of 1 \sum Annual ration x $\frac{\text{weight at age t}}{\text{weight at age I}}$

This gives the pattern of consumption of a cohort over its lifespan or the population in one year (assuming constant mortality and recruitment).

The annual consumption of a piscivore was taken as 250% of its biomass.

It is possible to calculate the relative consumption of roach age classes by various piscivore populations with various mortality rates.

e.g.

$$\left[\begin{array}{l} \text{Consumption of roach} \\ \text{(aged } t \text{) by a piscivore} \\ \text{cohort (aged } t \text{)} \end{array} \right] = \left[\begin{array}{l} \text{Annual ration of a} \\ \text{population with a} \\ \text{biomass at age 1} \\ \text{of 1} \end{array} \right] \times \left[\begin{array}{l} \text{Relative consumption} \\ \text{of roach (aged } t \text{)} \\ \text{by piscivore} \\ \text{(aged } t \text{)} \end{array} \right]$$

The relative biomasses of piscivores with a given level of mortality are shown in Figs 23 and 24, section 6.3 and the relative consumption of a roach age-class by any particular piscivore age-class in Tables 76 and 77.

(Values are relative to a piscivore biomass of unity at age I.)

This is for a population of predators preying exclusively on roach; It will be possible to construct a single piscivore single prey model bearing in mind that absolute predation rates on roach will vary by a fixed proportion from those calculated (.9 and .8 for zander and pike respectively).

The values so derived assume that the efficiency of the piscivore does not change with either its own or with prey population density. In section 4 the type of predation exhibited by pike and zander was discussed. It was argued that the zander was more likely to over predate prey stocks than pike (since in the case of the zander predation rate was proportional to piscivore density and so would remain relatively constant as prey population density changed) and so cause instability.

TABLE 76 Relative consumption of roach age-classes by zander

Zander biomass (Unit biomass)		Relative consumption of roach by unit biomass of zander in a year		
		0+	1+	2+
0+	1	2.5		
1+, 2+ & 3+	1	1.54	.96	
>, 4+	1	.06	1.08	1.37

Derived from Table 26 and section 4 (annual ration = 250%)

TABLE 77 Relative consumption of roach age-classes by pike

Pike biomass (unit biomass)		Relative consumption of roach by unit biomass of pike in a year				
		0	1	2	3	>4
0+	1	1.97	0.53			
1+	1	0.50	2.00			
2+ & 3+	1	0.09	0.65	0.49		1.20
>4+	1	0.02	0.45	0.17	0.26	1.60

Derived from Table 27 Section 4
(Annual ration = 250%)

These calculations will allow the relative consumption of each age group of prey to be followed over a cohorts life span, enabling either the effect of a strong cohort passing through the population or the consumption of a population with constant recruitment and mortality to be assessed.

Figures 28 and 29 show how patterns of predation vary over the life span of a zander or pike year-class; this is for predation on roach by populations with various mortality rates. The consumption by the entire population is shown in each of Figures 30 and 31 (Tables 78 and 79).

To assess the effect of a strong piscivore year-class it is necessary to sum its consumption of a particular prey year-class over time (Figures 32 to 44).

This data enables two important predictions about the pattern of predation to be made.

- i) What year-classes of prey will be subject to the greatest predation due to the production of a strong predator year class.
- ii) What age-classes of prey are most vulnerable?

The heaviest predation due to a zander year-class will fall on a roach year-class of age 0+ produced 3 years after the zander cohort, until the zander's mortality rate exceeds 60% when the zander predaes predominantly on the year-class of roach produced in the same year (Figure 28). The same pattern is seen for 1+ roach, although 2+ roach are consumed proportionally more two years after the production of a zander year-class.

Pike predate on a wider age range of roach Figure 29 (1+ prey being the most important) and predation by a pike year-class does not fall predominantly on subsequent roach age-classes as it does for zander.

Figures 30 and 31 show that 0+ prey are more important to zander than pike, especially at the higher mortality rates. This is for absolute levels of consumption, percentage consumption and hence mortality of 0+ roach will be much greater than that of older age-classes due to its relatively lower biomass (Figures 25, section 6.3).

The pattern of predation by a strong zander year-class means that the heaviest predation pressure falls on the roach year-class produced three years after it (Figures 32 to 38); until the mortality of the zander population falls to 60% when synchronisation will occur. Pike in comparison always predate predominantly on prey year-class produced in the same year (Figures 39 to 44).

There are two very important differences between zander and pike predation.

- a) Predation by a particular piscivore year-class is heaviest on the same year-class of roach for pike whilst for zander it is the following year-classes that experience the greatest predation pressure. Increasing mortality of zander will cause zander predation to fall heaviest on that produced during the same year, but will not affect pike predation.
- b) As the mortality of the zander population increases the 0+ fish become the predominant prey; pike, however, still predate mainly on the older age groups.

Figure 28 Relative consumption of roach age classes by a zander year-class over its life span from populations with various mortality rates.

Figure 29 Relative consumptionn of roach age-classes by a pike year-class over its lifespan from populations with various mortality rates.

Figure 28

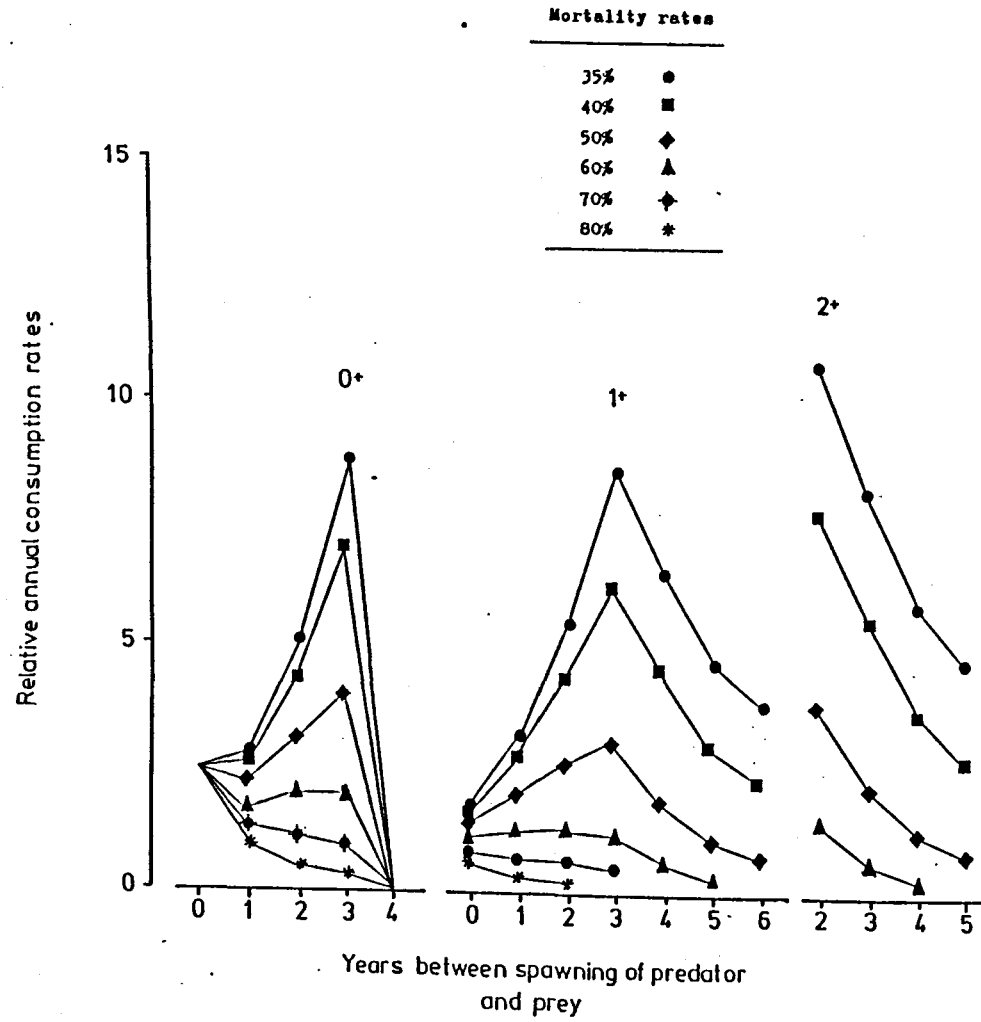


Figure 29

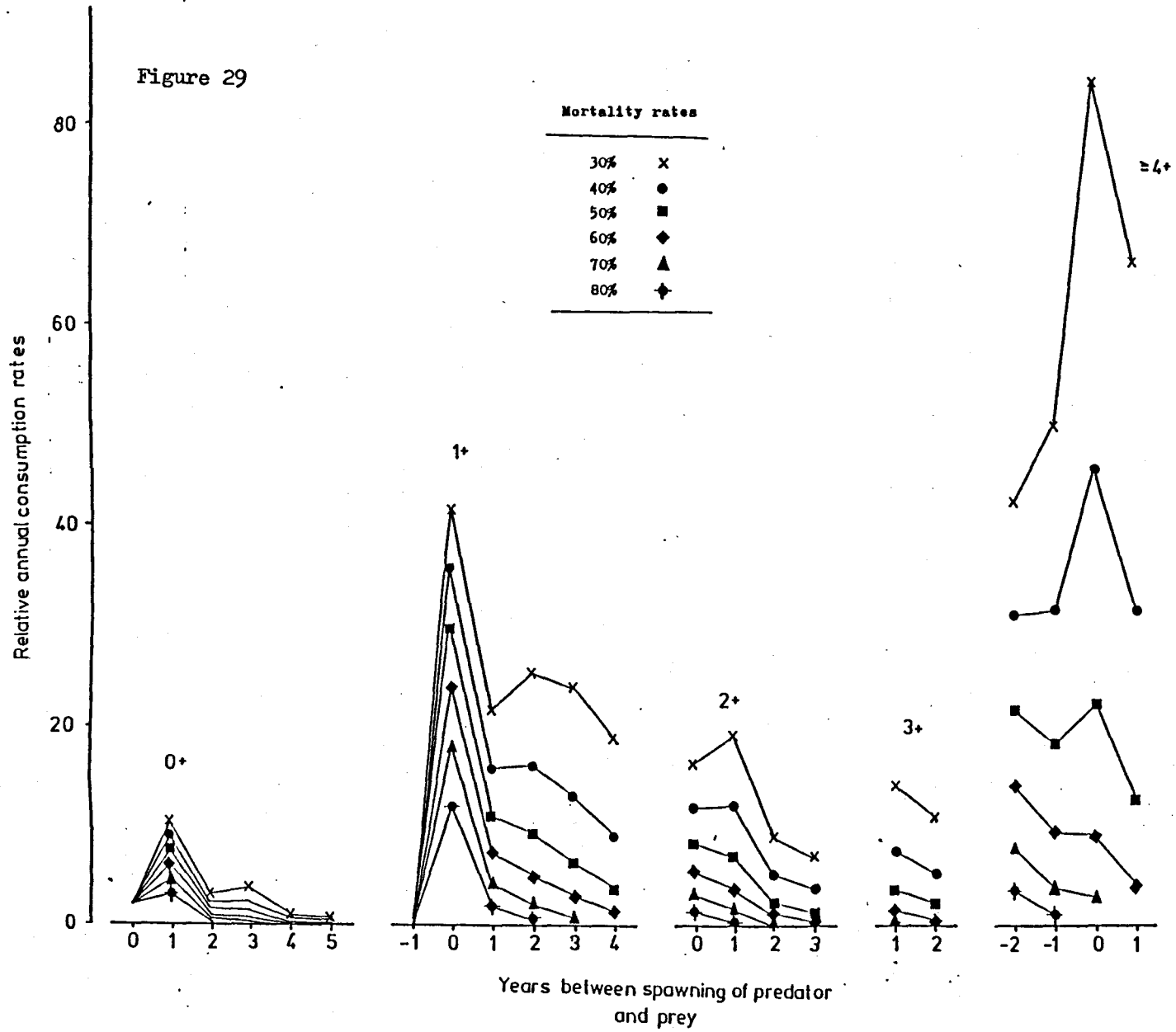


TABLE 78 The consumption of roach age classes by a population of zander assuming constant mortality and recruitment (biomass of 0+ zander = 1)

Survival	Biomass (relative)	Potential annual consumption of roach (relative to biomass of 0+ zander)			
		0+	1+	2+	Combined
Boiko's	181.40	59.14	190.47	203.89	453.50
35%	33.50	20.00	33.92	29.83	83.75
40%	24.50	17.19	24.24	19.82	61.25
50%	12.90	12.08	12.11	8.07	32.25
60%	6.50	8.31	5.48	2.46	16.25
70%	3.50	5.75	2.45	0.55	8.75
80%	2.10	4.19	1.06		5.25

TABLE 79 The consumption of roach age classes by a population of pike assuming constant mortality and recruitment (biomass of 0+ pike = 1)

Survival	Biomass (relative)	Potential annual consumption of roach (relative to biomass of 0+ zander)					
		0+	1+	2+	3+	4+	Combined
30%	187.8	20.70	130.71	50.52	24.70	242.87	469.50
40%	115.70	16.21	89.09	31.68	12.63	139.65	289.25
50%	68.50	12.62	59.87	18.67	5.67	74.41	171.25
60%	39.08	9.69	39.51	10.02	2.16	36.31	97.70
70%	20.90	7.31	25.05	4.76	0.47	14.66	52.25
80%	10.50	5.25	14.64	1.75		4.61	26.25

Figure 30 Relative consumption of roach age classes by various pike populations with constant mortality and recruitment rates.

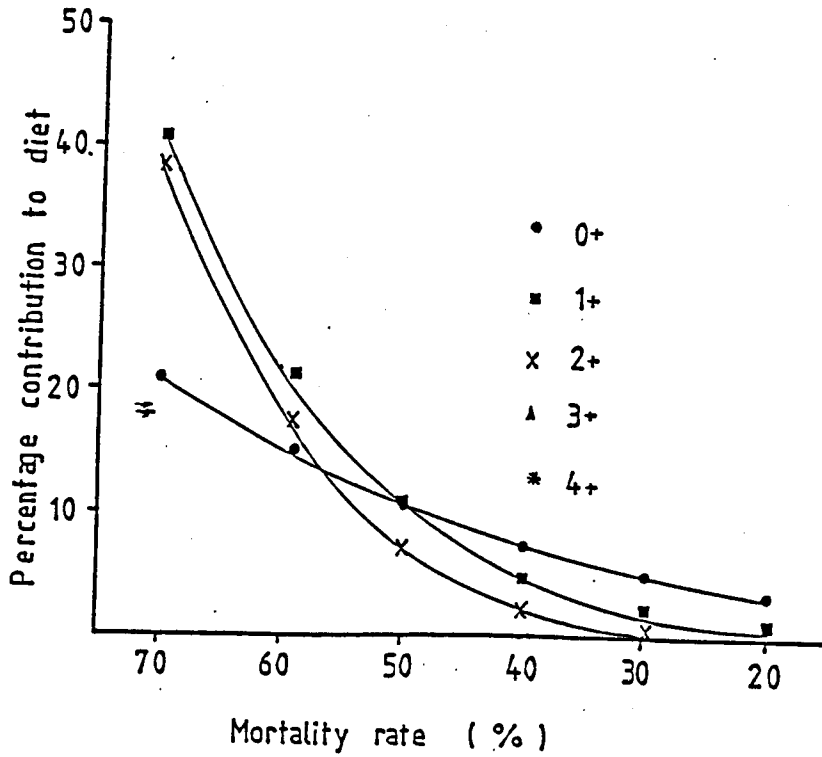
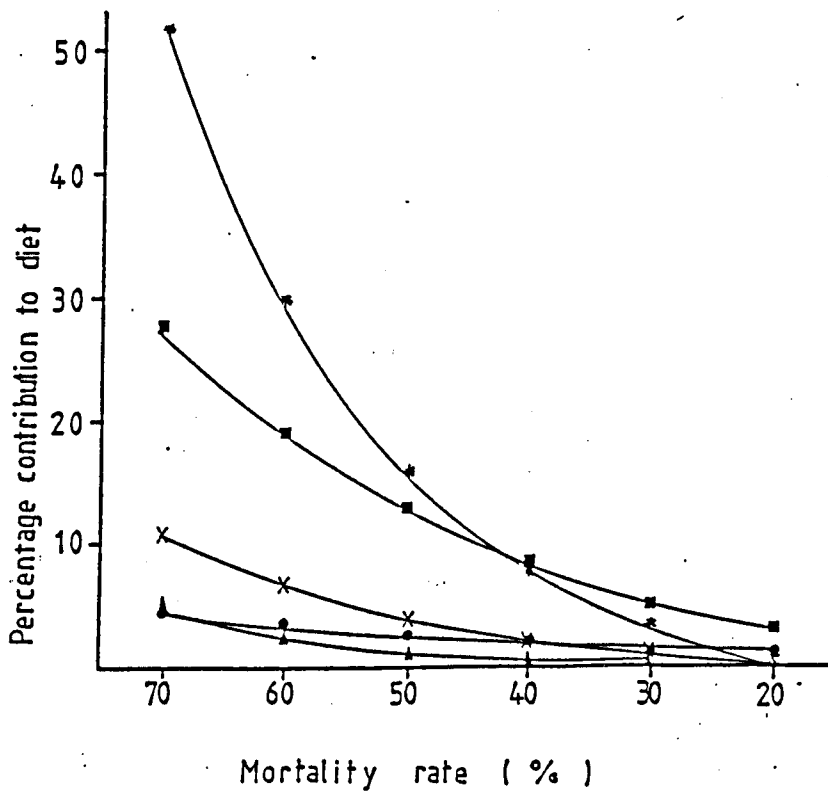


Figure 31 Relative consumption of roach age classes by various zander populations with constant mortality and recruitment rates.



Figures 32-38 Relative consumption of roach age classes by a zander cohort over its life span.

Figure	Survival rate
32	Boiko's estimate
33	65%
34	60%
35	50%
36	40%
37	30%
38	20%

Roach age class

All combined	●
0+	▲
1+	◆
2+	■

The x axis shows the degree of synchronisation between predator and prey year-classes (ie predation on a roach year-class produced 2 years before a piscivore year-class is shown in column -2).

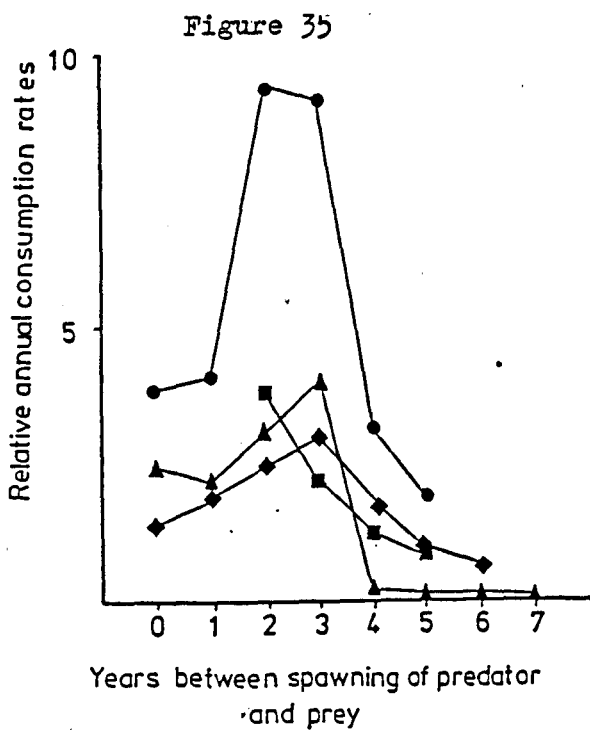
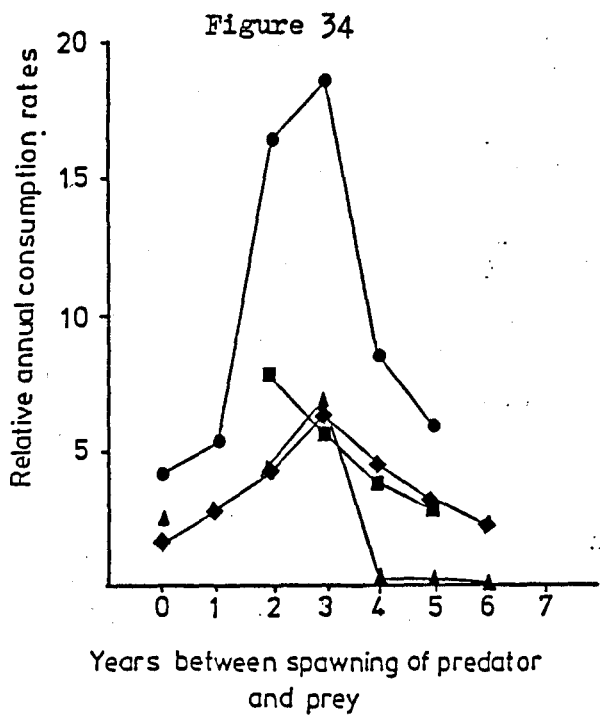
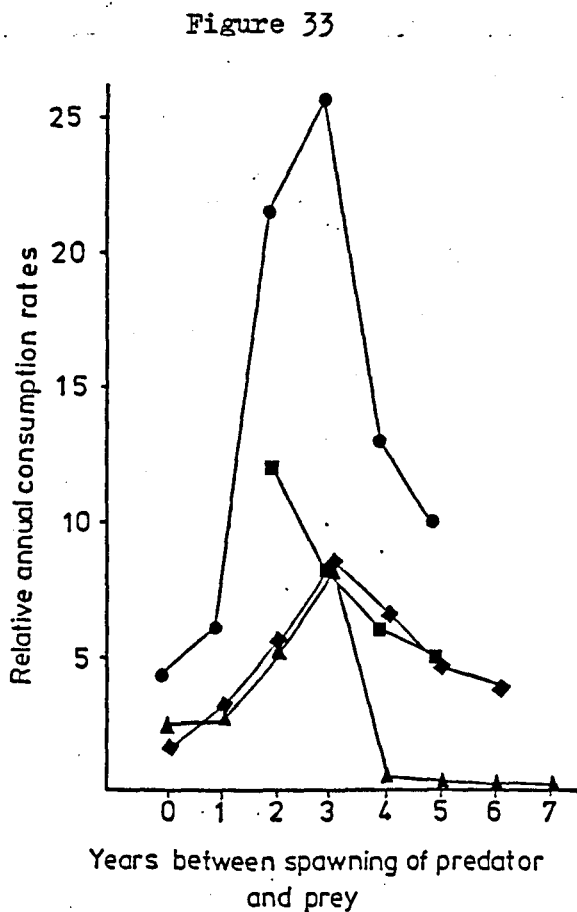
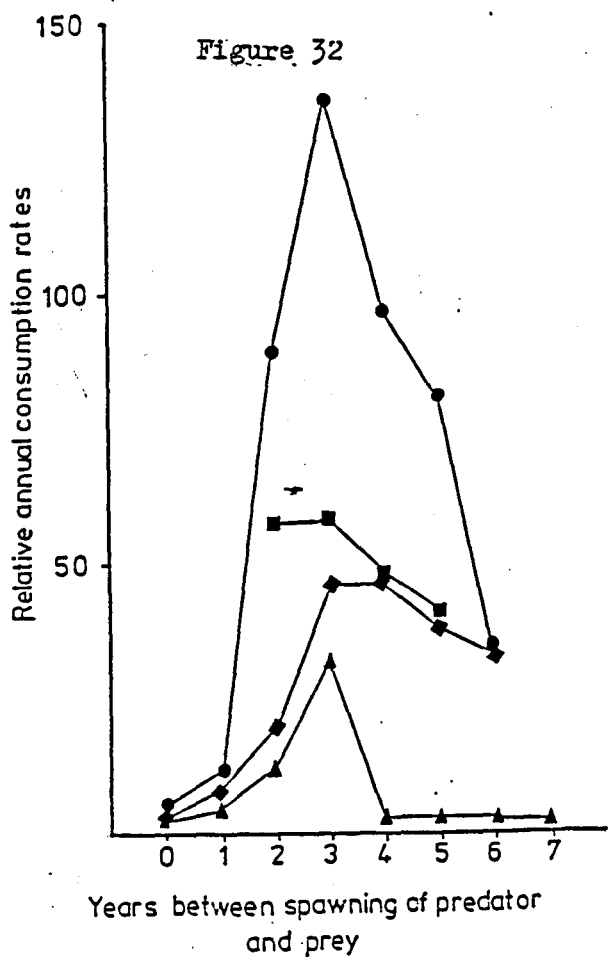


Figure 36

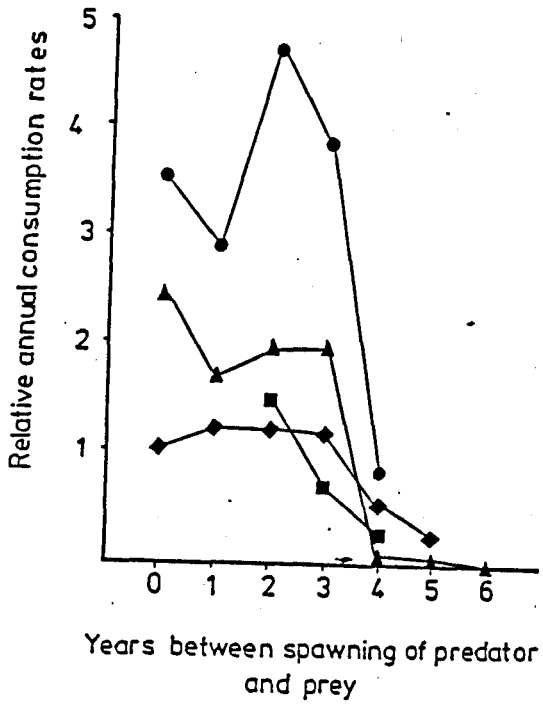


Figure 37

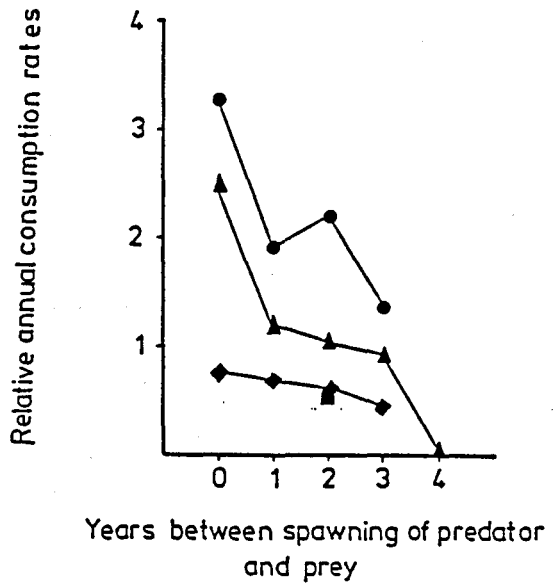
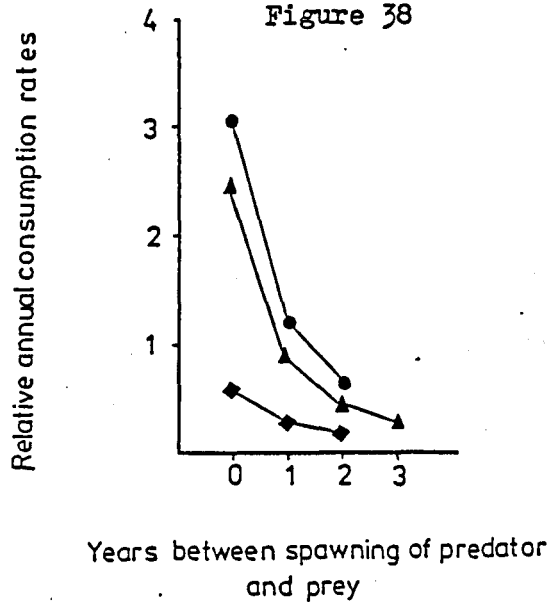


Figure 38



Figures 39-44 Relative consumption of roach age classes by a pike cohort over its life span.

Figure	Survival rate
39	70%
40	60%
41	50%
42	40%
43	30%
44	20%

Roach age class	
All combined	●
0+	▲
1+	◆
2+	■
3+	*
>4+	X

The x axis shows the degree of synchronisation between predator and prey year-classes (ie predation on a roach year-class produced 2 years before a piscivore year-class is shown in column -2).

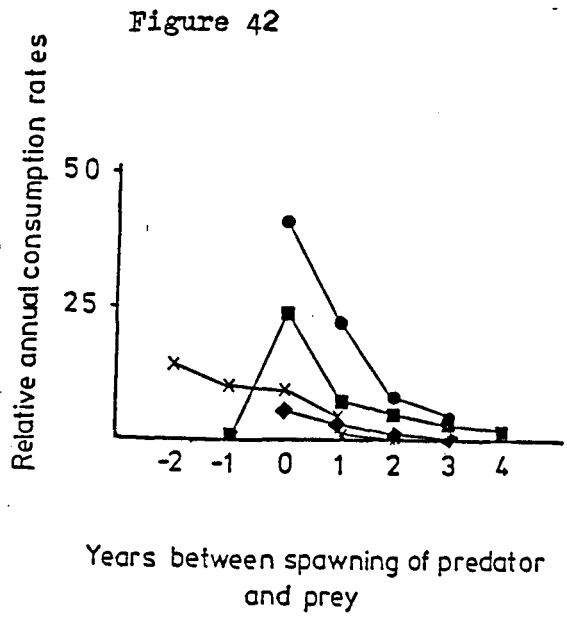
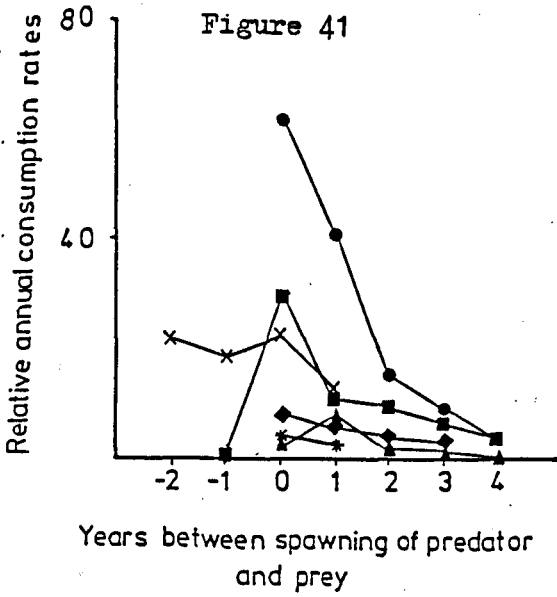
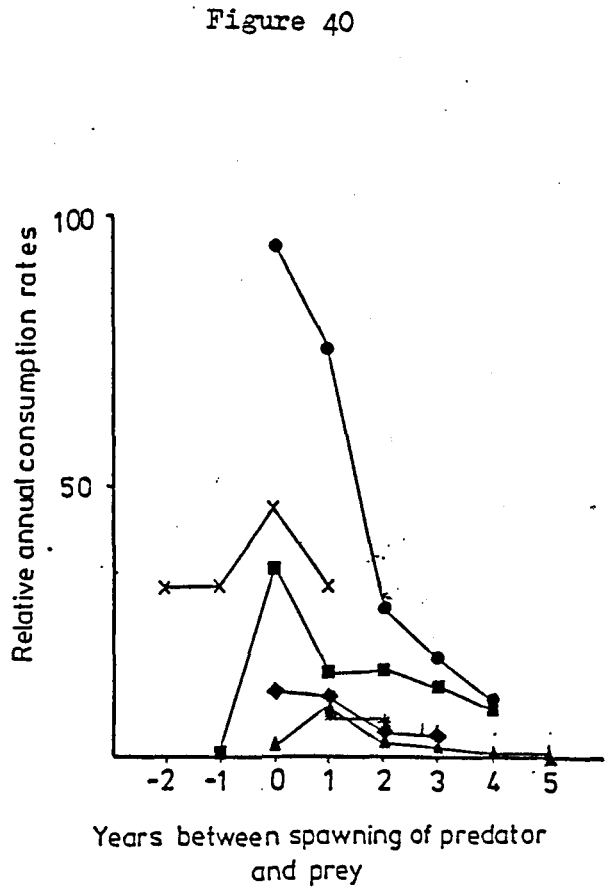
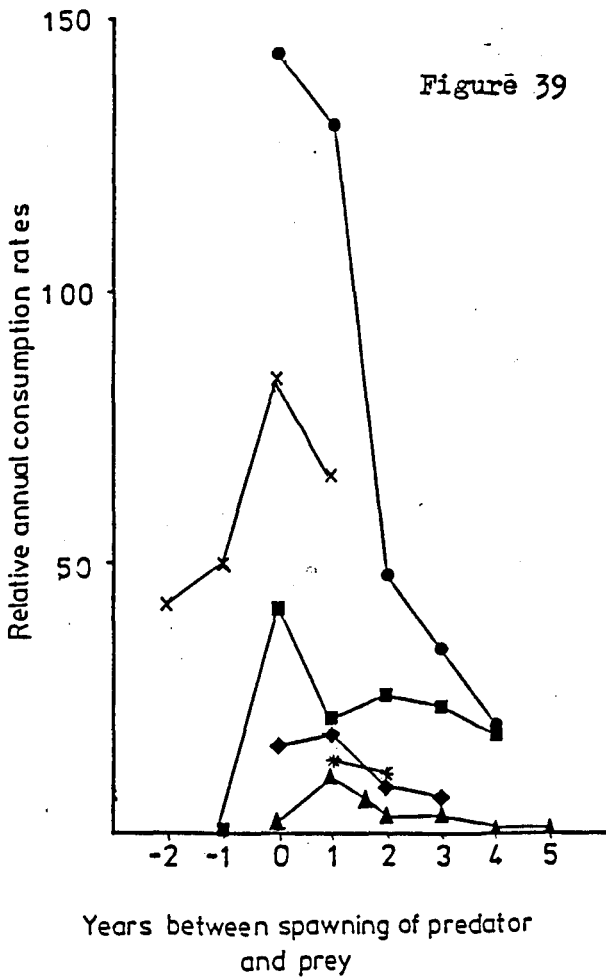


Figure 43

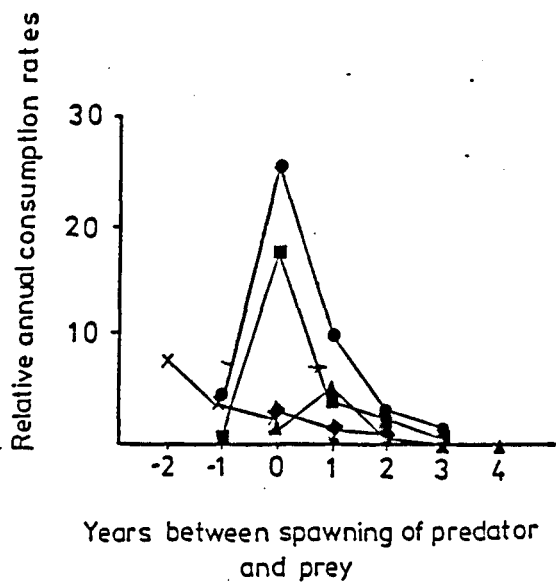
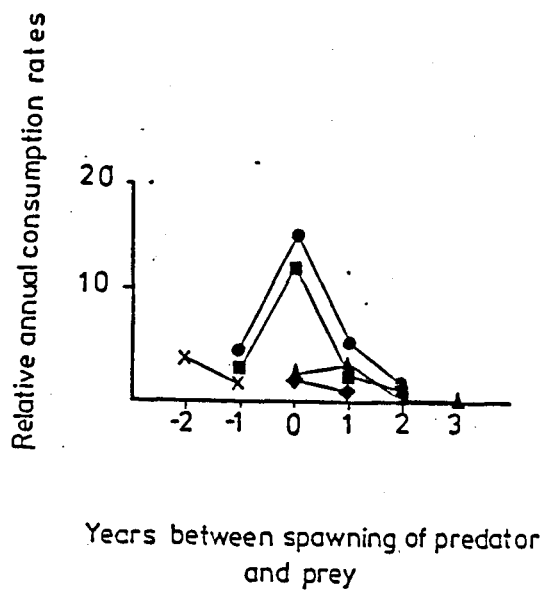


Figure 44



This means that whilst pike predation will be heaviest on strong prey year-classes (prey and piscivore year-classes tending to be synchronised, see sections 2.6) there is no such link between zander and roach. Heavy predation by zander on a weak roach year-class will occur if environmental conditions produce poor recruitment three years after good zander recruitment. Since predation pressure is not necessarily linked to prey density (especially if zander predation is of the Ricker type A) instability may result.

Consumption of a particular roach year-class by zander therefore may be determined by past conditions. This means that the zander may exert heavy predation pressure on a relatively weak year-class so resulting in over-predation and hence produce gaps in the prey's population structure.

Older prey become more important for zander as the mortality of its population increases, such a trend from older to younger prey is not so readily apparent for pike.

Absolute levels of biomass and hence predation rates will be reduced as the mortality of a population increases as long as recruitment is not increased, following a reduction in cannibalism. Recruitment of zander should not be greatly affected, however, that of pike may be (see section 4.4.4) and this will be discussed in section 6.5.

6.5 The affect of piscivore removal

The response of a piscivore population to culling (and ultimately that of its prey also) will depend on the nature of intraspecific predation or cannibalism that it exhibits.

Cannibalism can act as a density dependant regulating mechanism for predator populations, the intensity of cannibalism depending on the rate of encounter between predators (ie density). The structure of the population will also be important since it is the larger individuals which are the potential cannibals and the smaller ones the prey. A lack of older fish will lead to increased survival of the younger ones and a recovery of the predator stock; alternatively a surfeit of small fish will lead to an increase in the absolute level of predation.

The status of the prey populations may also influence the outcome of cannibalism, since they may buffer the predator population against cannibalism during periods of high prey abundance. This may result in the synchronisation of predation rates and prey abundance, resulting in stabilization of prey abundance.

These interactions are important for the stability of the fish community; piscivores may differ in the exact nature of the type of cannibalism, however, and it is important to understand the factors that produce these differences.

A cull of piscivores will change the pattern of cannibalism within its population these changes depending on:

- i) The feeding biology of the piscivore
- ii) Density of the piscivore population
- iii) Density of the prey populations

- iv) Age structure of the piscivore population
- v) Age structure of the prey population
- vi) Growth rates of the piscivore
- vii) Growth rates of the prey.
- viii) Community composition
- ix) Habitat characteristics
- x) The nature of piscivore recruitment
- xi) Percentage of piscivores removal
- xii) Duration of culling
- xiii) Size of piscivores culled.

The size range that a piscivore feeds on is important in a discussion of cannibalism since along with the growth rates of the younger age classes of piscivore it determines that incidence of cannibalism, since in years of good growth cannibalism is likely to be reduced (see section 4.4.4). High densities of prey during such period will also tend to buffer young piscivores against cannibalism, since 0+ piscivore and prey year-class strengths tend to be synchronised (section 2.6). It can be seen that both the density and age structure of the prey populations will influence the intensity of cannibalism. Similarly the density of the various piscivore age classes will determine the incidence of cannibalism since it is the older individuals that are the potential cannibals and the younger ones the prey.

In habitats where encounter rates between piscivores are low (eg due to structural diversity or high prey densities) then piscivore juveniles might be better able to escape predation. If piscivore recruitment is determined by cannibalism then a cull of older age classes would be expected to increase recruitment, however, if environmental or climatic factors are of greater importance then the removal of older piscivores should not increase recruitment; it may even reduce it if recruitment is directly proportional to stock.

The availability of prey types and their buffering effect will also determined the intensity of cannibalism.

2,971 kg of pike out of an estimated biomass of 2,780 kg were removed from the Middle Level System! Fish spawned in the years prior to 1979 would have been the ones removed by the cull, since fish larger than 10lbs were returnable alive and 0+ and 1+ fish are less vulnerable to angling (the main culling method).

The pike population recovered from a level of 5.0 kg/ha in 1981 following the cull to 21.6 kg/ha by 1983 (the relative strength of the 1979, 1980 and 1982 year-classes being strong).

Whilst the aim of the cull was to increase the survival of 0+ prey this may not occur if survival of juvenile pike is increased. Knowing the consumption of each roach age class by pike populations with different mortality rates (Figure 31) it is possible to calculate the increase in pike population biomass (ie the increase in recruitment) necessary to maintain consumption of any particular prey age group (assuming a datum pike population with a mean mortality rate of 40%, see section 5.3)

The increase in biomass of a pike population with a mean mortality rate (M) needed to maintain consumption of roach aged t at the level predated by a pike population with a mean mortality rate of 40%

$$= 100 \times \left[\frac{\text{annual consumption of roach aged } t \text{ by a pike population with a mortality rate of } 40\%}{\text{annual consumption of roach aged } t \text{ by a pike population with a mortality rate } M} \right] - 1$$

Table 80 shows the increase in recruitment needed in one age class of pike (1+) to maintain 0+ roach mortality at its previous level.

% increase in biomass of one pike year-class necessary to maintain consumption of roach at the same level as a pike population with a mortality of 40%.

$$= 100 \times \frac{\text{total consumption of } 0+ \text{ roach by pike pop. (mort=40\%)} - \text{Total consumption of } 0+ \text{ roach by pike pop. (mort = M)}}{\text{Total consumption of } 0+ \text{ roach by a single pike age group (mort = m) that consumed most } 0+ \text{ roach}}$$

These values are obtained from Tables I.5 to I.17 and Table 78.

Tables 80 and 81 show the percentage increase in recruitment needed to maintain consumption of 0+ roach by various pike populations following a cull. Table 80 shows the increase needed in a single pike year-class (ie. as the result of a cull for one season), whilst Table 81 shows the mean increased needed in each year following a continuous cull.

The increase in level of recruitment that would result in the consumption of 0+ prey not being reduced can be seen to be not particularly great; even at mortality levels equivalent to intensive culls. It would be advisable therefore to assess the affect of changes in recruitment before conducting a cull since predation to the predator biomass removed. This is especially likely since the relationship between predator biomass and prey consumption may change with the average size of piscivore (Johnstone 1960).

TABLE 80 Increase in recruitment of one pike year-class that would be necessary to maintain consumption of 0+ roach (to the level consumed in a population with a mortality of 40%) in a population which has been reduced by culling equivalent to various mortality rates.

Mortality of pike population	Increase in recruitment (Percentage)					
	0+	1+	2+	3+	>4	Combined
50%	48.18	98.82	158.78	192.27	295.02	279.29
60%	110.14	210.26	413.36	698.00	747.97	649.32
70%	199.11	360.18	909.46	2587.23	1600.38	1065.17
80%	370.27	636.56	2284.73	-	3902.89	1783.05

TABLE 81 Increase in recruitment necessary to restore consumption of roach age group to that consumed by pike population with a 40% mortality.

Mortality rate of pike population	Increase in recruitment (Percentage)
50%	28.45
60%	67.2
70%	121.75
80%	208.76

This intensive cull of short duration, by reducing the incidence of cannibalism, would cause subsequent year-classes to experience increased survival (helping to promote a recovery in the pike population, assuming spawning and or recruitment is not limited). If the cull had been prolonged it may have caused a shift to a smaller average size in the population (see Figure 24). Such a phenomenon was described by Frost and Kipling (1967) in Windermere but other responses have also been recorded. Broughton and Fisher (1981) found that following a cull of pike in Grafham Water both the number and average weight of the larger fish increased whilst Otto (1979) in contrast found that on removing pike from a small Swedish lake the average size of pike initially rose before the number of small pike increased; a phase where small and large pike were present in equal numbers then followed.

Such variations between waters are probably due to the relative importance of the factors influencing competition and recruitment. A reduction in pike density would increase growth rates and condition factors if food was limited, whilst if recruitment was limited by spawning success rather than by cannibalism then no great increase in 0+ survival should be seen.

The nature of a cull, by the way in which it influences the pattern of mortality of the various age classes, will help determine its eventual outcome. The pike cull in the Sixteen Foot Drain was extensive and although of only short duration, an increase in survival of pike was seen, resulting in a pattern of recruitment that was no longer synchronous with its prey.

Recruitment potential is unlikely to be limited in the Middle Level System to the same extent as it would be in a lake (due to the availability of marginal spawning and nursery areas), the population being limited by intraspecific predation due to the habitat having a fixed carrying capacity.

As pike population density increases the rates of encounter between pike and the incidence of cannibalism will also increase. Since the availability of cover is determined by habitat structure pike density will tend to be stable (Grimm, 1981).

The cull would therefore tend to increase the survival of year-classes from 1979 onwards. The production of strong year-classes in 1979 and 1980 resulting in increased predation of the 1981 year-class and so causing the breakdown in synchronisation of piscivore and prey year-class strengths.

The response of a particular pike population to culling will depend on habitat and cull characteristics (and their effect on feeding conditions and hence mortality and recruitment). The response in the Sixteen Foot Drain to an extensive cull for one season was an increase in survival of juvenile pike.

The removal of zander commenced in 1979 and is continuing to date; the cull removing 1,415 kg of zander in the 1980-81 season (out of an estimated biomass of 630 kg). The zander population has not changed greatly from its 1981 level (.2 kg/ha to 4.7 kg/ha) and whilst the population is dominated by 0+ fish these are unlikely to produce a large standing crop since the cull appears to be highly effective.

Zander aged II and older will be the ones most vulnerable to angling and so 0+ recruitment is unlikely to be directly affected by the cull. The pattern of variation in year-class strength shown by pike is not apparent in this case. The role played by the older cannibalistic fish will be limited since they have continued to be culled. The growth rate of 0+ fish is more important in determining zander recruitment than is the density of adult fish, recruitment is unlikely to have been greatly increased by a cull of zander therefore.

Culling of zander would appear to be successful in controlling them. Indeed on the continent it is in constant danger of being over fished (Deelder and Willemsen, 1969), since it has a relatively low productivity (Hofstede, 1974).

A cull of pike will only succeed if the removal of the older potentially cannibalistic pike does not result in the increased recruitment of younger age classes of pike to a level where predation on 0+ prey is increased. It is difficult to assess whether this will occur before undertaking a cull since apart from the intensity of the cull and the size range included in the cull the structure of the habitat will also influence its outcome and is liable to vary between waters. An intensive cull should reduce the potential predation pressure and so increase recruitment. However, this may not occur if predation pressure varies with prey density so compensating for low prey densities. Tables 80 and 81 showed the increase in recruitment that would be necessary to negate the effects of a cull.

6.6 The impact of zander predation on roach

Variations in recruitment are common for zander (see section 2.6), Willemsen (1983) records that these variations can be in excess of 2 orders of magnitude; this can result in populations being dominated by a particularly strong year-class. In considering the potential for the zander to cause over-predation we are mainly interested in the worst possible situation and need to know for what patterns of piscivore and prey recruitment it will occur. It was shown in section 6.4 that whilst zander and its prey year-class strengths are generally synchronised a zander year-class will exert its greatest level of predation on the following prey year-classes.

This could result in the zander destabilizing its prey populations since predation pressure will not be linked to prey density.

The following calculations are made in an attempt to show exactly what impact various levels of zander recruitment will have on a fishery and the influence of variations in prey and zander populations. These are based on a two species population of roach and zander, in reality one is not dealing with such a simple system since alternative prey and additional sources of mortality will also exist. However, it is necessary to limit the complexity of the model.

The effect of an additional mortality (due to zander predation) is calculated using values (obtained from Table I), where the roach populations are already subjected to various levels of mortality. This will enable the result of introducing another mortality factor in the form of zander predation to be judged.

Where prey other than roach are available for the zander it would be expected that the total consumption of roach would be reduced. (The actual magnitude of this reduction will depend on the nature of prey choice often related to density, although this may not be a linear relationship and may include switching between prey classes). In the absence of any complex model to describe prey choice it is proposed that the ratio of roach to other prey items can be used to include the effect of alternative prey;

Biomass of zander at age I required to consume a given percentage of the roach population with recruitment (R) and mortality (M)

$$= \frac{wt.Nt + wt+1.Nt+1}{2} \times \frac{Mz}{100} \times \frac{1}{Zc}$$

Wt = mean weight of roach aged t

Nt = mean density of roach aged t

Mz = (percentage) extra mortality due to zander

Zc = annual consumption of roach aged t+1
relative to unit zander biomass at age I.

(WtNt) and (Wt+1 Nt+1) are obtained from Table I.3 and Zc from Tables I.5, I.6, I.7, I.8, I.9, I.10 and I.11, Appendix I.)

The values in Tables 83, 84, 85, 86, 87, and 89 are calculated assuming a production of 0+ roach of 50 kg/Ha/yr and a consumption by zander of 50% of this production.

TABLE 82 The biomass of zander recruiting at age I that would consume 50% of the roach population with 0+ production of 50 kg/ha/Yr

Roach age-class predated	Age class of zander predating	Survival rate of zander population						
		Boiko	65%	60%	50%	40%	30%	20%
0+	I	5.000	5.000	5.000	5.000	5.000*	5.000*	5.000*
	II	2.900	4.531	4.771	5.787	7.396	10.163	13.587
	III	1.041	2.461	2.900	4.058	6.250	11.574	27.174
	IV	0.396*	1.437*	1.804*	3.125*	6.250	13.587	40.323
	V	4.960	26.596	36.765	73.529	178.571	625.000	
	VI	4.864	34.722	50.000	125.000	416.667		
	VII	5.981	48.077	78.125	250.000	1250.000		
	VIII	0.421	59.524	104.167	312.500	74.292		

* Age at which consumption of a cohort is greatest

TABLE 83 The biomass of zander recruiting at age I that would consume 50% of the roach population assuming a 0+ production of 50 kg/ha/Yr (for a roach population with a mortality of 30%)

Roach age-class predated	Age class of zander predating	Survival rate of zander population						
		Boiko	65%	60%	50%	40%	30%	20%
1+	II	19.517	30.347	32.209	39.179	49.528	68.182*	90.517*
	III	7.009	16.562	19.517	27.344	42.000*	78.358	181.034
	IV	2.668	9.598	12.153	21.000	42.000*	90.517	276.316
	V	1.157	6.155*	8.523*	17.384*	44.118	122.093	
	VI	1.136*	8.102	11.851	30.347	97.222		
	VII	1.397	11.315	17.979	54.124	238.636		
	VIII	1.637	13.889	24.306	80.769			
	2+	IV	3.932	20.910*	28.969*	58.919*	149.834*	411.364*
V		3.858*	27.524	40.258	103.311	327.899		
VI		4.745	38.413	61.149	183.943	837.963		
VII		5.560	47.135	82.573	275.915			

TABLE 84 The biomass of zander recruiting at age I that would consume 50% of the roach population assuming a 0+ production of 50 kg/ha/Yr (for a roach population with a mortality of 40%)

Roach age-class predated	Age class of zander predating	Survival rate of zander population						
		Boiko	65%	60%	50%	40%	30%	20%
1+	II	17.193	26.374	34.515	34.515	43.632	60.065*	79.741*
	III	6.175	14.590	17.193	24.089	37.000*	69.030	159.483
	IV	2.350	8.455	10.706	18.500	37.000*	79.741	243.421
	V	1.020	5.422*	7.508*	15.315*	38.866	107.558	
	VI	1.001*	7.137	10.440	26.734	85.648		
	VII	1.231	9.968	15.839	47.680	210.227		
	VIII	1.442	12.235	21.412	71.154			
	2+	IV	1.434*	7.625*	10.563*	21.484*	54.636*	150.000*
V		1.407	10.036	14.680	37.671	110.565		
VI		1.730	14.007	22.297	67.073	305.556		
VII		2.028	17.188	30.109	100.610			

TABLE 85 The biomass of zander recruiting at age I that would consume 50% of the roach population assuming a 0+ production of 50 kg/ha/Yr (for a roach population with a mortality of 50%)

Roach age-class predated	Age class of zander predating	Survival rate of zander population						
		Boiko	65%	60%	50%	40%	30%	20%
1+	II	15.335	23.844	25.307	30.784	38.915	53.571*	71.121*
	III	5.507	13.013	15.335	21.484	33.000*	61.567	142.241
	IV	2.096	7.541	9.549	16.500	33.000*	71.121	217.105
	V	0.909	4.836*	6.696*	13.659*	34.664	95.930	
	VI	0.892*	6.366	9.312	23.844	76.389		
	VII	1.098	8.890	14.127	42.526	187.500		
	VIII	1.286	10.913	9.097	63.462			
	2+	IV	1.086	5.776*	8.003*	16.276*	41.391*	113.636*
V		1.066*	7.603	11.121	28.539	90.580		
VI		1.311	10.611	16.892	50.813	231.481		
VII		1.536	13.021	22.810	76.220			

TABLE 86 The biomass of zander recruiting at age I that would consume 50% of the roach population assuming a 0+ production of 50 kg/Ka/Yr (for a roach population with a mortality of 60%)

Roach age-class predated	Age class of zander predating	Survival rate of zander population						
		Boiko	65%	60%	50%	40%	30%	20%
1+	II	13.011	20.231	21.472	26.119	33.019	45.455*	60.345*
	III	4.673	11.041	13.011	18.229	28.000	52.239	120.690
	IV	1.778	6.399	8.102	14.000	28.000*	60.345	184.211
	V	0.772	4.103*	5.682*	11.589*	29.412	81.395	
	VI	0.757*	5.401	7.901	20.231	64.815		
	VII	0.931	7.543	11.986	36.082	159.091		
	VIII	1.091	9.259	16.204	53.846			
	2+	IV	.760	4.043*	5.602*	11.393*	28.974*	79.545*
V		.746*	5.322	7.785	19.977	63.406		
VI		.918	7.428	11.824	35.569	162.037		
VII		1.075	9.115	15.967	53.354			

TABLE 87 The biomass of zander recruiting at age I that would consume 50% of the roach population assuming a 0+ production of 50 kg/ha/Yr (for a roach population with a mortality of 70%)

Roach age-class predated	Age class of zander predating	Survival rate of zander population						
		Boiko	65%	60%	50%	40%	30%	20%
1+	II	11.152	17.341	18.405	22.388	28.302	38.961*	51.724*
	III	4.005	9.464	11.152	15.625	24.000*	44.776	103.448
	IV	1.524	5.484	6.944	12.000	24.000*	51.724	157.895
	V	0.661	3.517*	4.870*	9.934	25.210	69.767	
	VI	0.649*	4.630	6.772	1.7341*	55.556		
	VII	0.798	6.466	10.274	30.928	136.364		
	VIII	0.935	7.937	13.889	46.154			
2+	IV	0.521	2.773*	3.841*	7.813*	19.868*	54.545*	
	V	0.512*	3.650	5.338	13.699	43.478		
	VI	0.629	5.093	8.108	24.390	111.111		
	VII	0.737	6.250	10.949	36.585			

TABLE 88 The biomass of zander recruiting at age I that would consume 50% of the roach population assuming a 0+ production of 50 kg/ha/Yr (for a roach population with a mortality of 80%)

Roach age-class predated	Age class of zander predating	Survival rate of zander population						
		Boiko	65%	60%	50%	40%	30%	20%
1+	II	8.829	13.728	14.571	17.724	22.406	30.844*	40.948*
	III	3.171	7.492	8.829	12.370	19.000*	35.448	81.897
	IV	1.207	4.342	5.498	9.500	19.000*	40.948	125.000
	V	0.524	2.784*	3.856*	7.864*	19.958	55.233	
	VI	0.514*	3.665	5.361	13.728	43.981		
	VII	0.632	5.119	8.134	24.485	107.955		
	VIII	0.740	6.283	10.995	36.538			
2+	IV	0.282	1.502*	2.081*	4.232*	10.762*	29.545*	
	V	0.277*	1.977	2.891	7.420	23.551		
	VI	0.341	2.759	4.392	13.211	60.185		
	VII	0.399	3.385	5.931	19.817			

TABLE 89

The Biomass of zander populations (with various mortality rates) that would consume 50% of the 0+ production of roach with a recruitment of 50 kg/ha/Yr.

Survival rate of zander population	Biomass of zander population (kg/Ha)
Boiko	76.4
65%	42.0
60%	35.5
50%	26.7
40%	19.4
30%	15.2
20%	12.3

TABLE 90 Annual Consumption of 0+ roach by various populations of zander (kg/ha/yr).

Survival rate of population	Biomass of zander population (kg/ha)				
	1	2	4	8	16
Boiko's estimate	0.33	0.65	1.31	2.62	5.23
65%	0.59	1.19	2.38	4.76	9.52
60%	0.70	1.41	2.81	5.63	11.25
50%	0.94	1.88	3.75	7.50	15.01
40%	1.29	2.57	5.14	10.29	20.58
30%	1.64	3.29	6.57	13.14	26.29
20%	2.00	3.99	7.98	15.96	31.92

Values are derived from Tables I.5 to I.11 where the biomass of 0+ roach consumed relative to total biomass of various zander populations are shown.

Table 90 shows the biomass of roach that would be consumed by various zander populations. The present biomass of zander is about 4 kg/Ha and so the potential consumption of roach can be seen. Only the consumption of 0+ roach is shown since this has been identified as the age class on which zander predation produces the greatest effect.

The mortality rate of the zander population is not known at present but from this table it would appear that predation due to the zander is unlikely to be high enough at present to cause population declines, assuming the mean level of roach recruitment to be 50kg/ha/yr (section 6.2).

The likelihood of the zander causing declines in its prey populations is increased by its predation pressure being strongest on the 0+ prey age-groups. Environmental conditions can mean that the consumption of the zander population is high (due to the production of a strong year-class) and is concentrated on a weak year-class, over predation may occur if predation pressure is proportional to the predator density.

The likelihood of a decline in prey fish stocks may be predicted, however, if certain population statistics are known; these are the average mortality and recruitment rates of the zander and its prey stock and their levels of recruitment. If average values are taken for the mortality rates and the probable range for prey recruitment, by using Tables 84 to 89 it will be possible to determine the potential impact of any level of zander recruitment. This will permit the levels of 0+ zander recruitment that may cause problems to be identified and hence appropriate action to be taken.

It is not the piscivore: prey ratio that is important but the absolute biomass of zander since the most important zander predation is on 0+ fish and the use of a piscivore: prey ratio would suppose that the stock: recruitment relationship is predictable. The knowledge of what levels of 0+ zander recruitment will be liable to cause problems in the fishery will permit management actions to be implemented at the earliest stage possible.

Piscivore to prey ratios are only useful when they link the consumption of a predator to the production of prey; this depends on the age structures and levels of recruitment and since both are known to be variable the value of such a ratio as a diagnostic aid to the health of fish community is limited.

A cull of zander should be able to maintain its population at a low level. This will be helped by its desirability as a food fish, indeed in continental waters where it is generally fished for the table it is in constant danger of being over exploited (Deedler and Willemsen, 1969). Its low productivity (5 kg/ha/yr is a good production) means that it is in permanent danger from overfishing (Hofstede, 1974).

It should be easy to achieve a mortality level for the zander population of more than 50% so that the greatest consumption of a prey year class at age 0+ is by zander spawned in the same year. This will increase stability since year-class strengths of zander and its prey are generally synchronised.

6.7 The influence of the zander on the ecology of the Sixteen Foot Drain

The introduction of the zander is liable to alter the trophic web due to a modification of the interaction between species: these interactions will mainly be in the form of competition and/or predation (see section 2.12). The zander may change the population structure of its prey due to selective predation, which in turn may produce a "knock on effect" resulting in perturbations even lower down the trophic web. If the zander predate on a limited resource that had previously been exploited by indigenous species populations, this competition may not only be with piscivores since 0+ zander feed initially on zooplankton (see chapter 4 for a detailed description of the diet of the zander).

This section discusses the consequences of the zander's colonisation on the ecology of the Middle Level System and to detail any evidence that will illustrate its effect.

The zander's main competitor is the pike (see section 4.4.5) but it may also compete to some extent with the facultative piscivores perch and eels. The diets of juvenile perch and zander are very similar, because they both feed first mainly on Rotifera (Belyi 1972; Brezeanu 1972) or nauplius larvae, switching after a few days to an increasing proportion of adult copepods (Rogowski and Tesch 1961; Willemsen 1969).

Willemsen (1977) found that zander and perch 6-10mm long in the IJsselmeer started feeding on zooplankton of nearly identical compositions, both qualitative and quantitatively. Zander switch to a piscivorous diet sooner than perch, the size of perch that predate on fish has been recorded by numerous authors and varies widely; values given are 10 mm (Willemsen, 1977), 150 mm (Roper, 1936; Deelder 1951; Bauch, 1963), 200mm (Holcik, 1969), 260mm (Hartmann, 1975) and 260-280 mm (Chikova, 1970) although in some case the diet may even remain non-piscivorous (Klemetsen, 1973).

The perch population in the Sixteen Foot Drain is not large (see section 3), probably being limited by perch ulcer disease, and few fish of a size that would be piscivorous were found. Perch are only liable to compete with zander as juveniles and since the growth rates of zander does not appear to be limited by food shortage (see sections 5.3 and 5.4) it is unlikely that competition between these two species is occurring or that the zander is significantly altering the zooplankton populations directly. The absolute level of 0+ zander predation is only likely to be small compared to other planktivores and so any direct effect on the zooplankton will also be small.

The most likely area of competition will be with the pike or eels; competition with the former was dealt with in section 4.4.5. Changes in the relative abundance of pike and zander may be due to changes in the habitat rather than to competition although if the zander were to cause perturbations in the fish community these would also affect the pike. Such changes could be in the form of population declines or in species or size composition; this is assuming that the pike is limited by food rather than intraspecific competition. The present biomass of pike (21.6 kg/ha, section 3) would need approximately 50 kg/ha/yr of prey to sustain it so if the zander were to drastically reduce the prey populations it might be expected that the pike population would suffer.

The eel does not predate exclusively on fish and would be able to exploit a range of prey. If the zander were to cause a population crash it would be expected that the invertebrate populations that had previously been exploited would now be more readily available to the eel.

This change in trophic interactions lower down the food web is of particular interest. The zander by preying selectively could alter the composition of its prey populations which might then produce an identifiable effect on their prey populations. Such a change could be irreversible; a new equilibrium becoming established that would be stable even on the elimination of the zander.

The Sixteen Foot zander predate mainly on 0+ shoaling cyprinids (section 4.4.1) ie. roach and bream; the result of this is that under certain circumstances a population crash of these species may occur. Species that weren't subject to high levels of predation by zander may respond by utilizing the resources that become available.

The major items in the diet of roach are filamentous algae, molluscs, detritus oligochaetes and chironomid larvae whilst for common bream it is zooplankton, molluscs, aquatic insect larvae and chironomid larvae (section 4.4.6). The main food of roach is unlikely to be limited and so one would not expect a significant increase in food available to alternative species following a decline of roach. A reduction in predation on molluscs could benefit eels and tench, although since the later may be recruitment rather than food limited this is doubtful. Eels might benefit but then the reduction in fish prey may have a negative effect on their productivity. The most likely beneficiary would be the ruffe which is protected to a degree by its defensive spines; its main prey item was shown to be chironomid larvae (section 4.3.6) which may be predated to a lesser degree following a decline in the cyprinid population.

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The Sixteen Foot Drain population of ruffe is not large (see section 3) and even in 1981 when the roach and common bream were at a low level it still had a relatively low biomass. It is impossible to say whether the ruffe benefited in a reduction in roach and bream biomass without a clear understanding of how the various populations are limited.

Growth rates can often indicate whether a population is food limited and they suggest that this is only an important factor for 0+ fish (see section 5.4), on which the zander will only have an effect if it appreciably thins them out. More important are environmental conditions in determining potential food supply and hence competition.

No new stable equilibrium appears to have been established; (witness the recovery of biomass levels, section 3) and it would appear that in the Sixteen Foot Drain fish community any catastrophic effects due to the zander will be on recruitment.

A reduction in the densities of 0+ cyprinids would result in the nature of predation on the zooplankton community changing. Invertebrate predators such as Chaobororus sp might replace the cyprinids as the main planktivores and this could result in a change in both the quantitative or qualitative composition of these herbivores with a corresponding change in the phytoplankton community. If phytoplankton is limited by nutrients rather than predation then mean summer transparencies might not vary much. However if transparencies were to be reduced it would be expected that filamentous and benthic algae growth would benefit the macrozoobenthos. These changes can only be proposed, since this type of data was not collected. Manipulation of pelagic food webs by the management of the top level predators can produce observable effects down through the food chain (Benndorf et al, 1984) and it is likely that some observable effects due to the introduction of the zander might have been recorded. It is unlikely that these would have been irreversable, however, since the Sixteen Foot Drain fish populations have now recovered.

6.8 Conclusions

The roach and common bream populations have recovered as a result of good year-classes since 1979, following the cull in 1980-81. These good year-classes were also seen in other waters and are presumably a result of favourable environmental conditions.

The strategy behind the cull was to reduce the predation pressure on the prey stocks so that a recovery would not be prevented because of the relatively high biomass of piscivores to prey. This appears to have been successful.

It is argued that the ratio of predator to prey biomass is of less importance than a knowledge of the type of predation and the influence of population structure and recruitment, as these all influence production and consumption rates and it is the balance between these that determines the behaviour of any equilibrium.

Whether a recovery would have been prevented if the cull had not occurred is difficult to say with certainty, since this would have depended on the future recruitment of the zander and its prey. The original decline was probably as a result of strong zander year-classes (and hence high predation levels) being followed by poor prey recruitment. Zander biomass was already low at the time of the cull and if it had remained so it is unlikely that it would have greatly reduced cyprinid recruitment.

Variations in the zander biomass combined with variations in year-class strength of its prey population could cause future declines if the zander population were to be left uncontrolled. The zander has a low production (5 kg/ha/year being good (Hofstede, 1974)) so that continental water are in danger of being overfished. This means that it should be relatively easy to control the zander population by encouraging anglers to remove i t .

A highly efficient method of removing zander as shown by the cull figures (see section 1.2.2).

The effect of the zander is liable to be most marked in waters like the Middle Level systems which are particularly suited to the zander and it may not present as big a threat elsewhere.

The recruitment potential of the zander is good although uncertain (Hofstede, 1974) and in a habitat where management reduces spawning and nursery areas, recruitment of prey is liable to be threatened (see section 2.7); This could result in increased variation between prey year-class strengths which would be likely to increase the potential risk of over predation.

The feeding behaviours of the zander and pike will result in differences in their efficiency on piscivores in a habitat like the Sixteen Foot Drain and so one would expect different responses in the fish community.

The zander is an open water predator adapted to hunting in low light conditions in turbid water, whilst the pike relies on cover to stalk or ambush prey for which it requires clear water to locate. The zander is ideally suited to a habitat like the Sixteen Foot Drain which is turbid with much reduced macrophyte cover. It is to be expected that there will be few refuges for prey and that the zander will be much more efficient than the pike in this situation. Its tendency to over predate will be compounded by the nature of its predation (Ricker type A) the intensity of which is proportional to its own density. At low prey densities predation will still be high unlike the pike where at low prey densities its predation pressure will be much reduced; - Ricker type B where predation pressure is proportional to prey density - resulting in a stabilization of the predator prey balance.

In a more complex environment the availability of prey refuges would greatly reduce the zanders efficiency and so prevent it from over predating its prey stocks.

It is possible to suggest the type of water in which the zander is liable to be the greatest threat. This will be characterised by

- i) Large open areas of water
- ii) General turbidity
- iii) Relatively little macrophyte growth
- iv) Homogeneity
- v) Recruitment potential of prey being reduced
- vi) Good potential zander recruitment

The spread of zander into these waters should be prevented. This can best be done by educating the public about the potential danger posed by the zander so encouraging its removal and hopefully minimising its impact and containing its spread.

The zander may pose no threat in waters that are more structurally diverse than those found in the Middle Level System (especially if its recruitment is limited) so that its efficiency as a predator is much reduced.

The cull was undertaken not purely on ecological grounds since the value of any type of fishery and hence the nature of management action taken to protect it is ultimately dependant on subjective judgements. Obviously ecological principles would be to ensure continuity and maximisation of the resource, but community and size structure will depend also on the preference of the customer (the angler).

The Middle Level system is an important match fishing area. For such a fishery to be successful most areas should produce fish with large catches being possible. Size of fish is less important than total weight so a fishery containing small individuals which are more productive (per unit biomass) would be suitable (i.e. a roach population of small average size). The presence of a few shoals of large fish (i.e. common bream) may turn the match into a lottery, since success may well depend on the right area being drawn. Therefore if shoals of fish are present they should be common enough to give a reasonable number of competitors a chance of a large potentially match winning weight.

At the opposite extreme to the match angler is the specialist angler who generally aims to catch large specimens of a target species, catch rate being less important than size. The most important species in the Middle Level System to such anglers is the pike.

It can be seen that there is liable to be conflict between the two groups of anglers requirements. The match angler wants a high standing crop of fish which will be achieved generally by a small average size of non-predatory fish, whilst the specimen hunter wants a few large piscivorous individuals. This is obviously a polarisation of angling strategies for the sake of argument. Pleasure angling will also be important, where a range of fish of a reasonable size at a high enough biomass to ensure good catch rates will be the desired objective.

Pike anglers saw a healthy fishery as being necessary for the continued success of their fishery and hoped that any management action would restore the equilibrium which had been disturbed by the introduction of the zander. They were prepared to cull the zander and pike at the time but viewed the culling of pike as only a temporary measure

The angling groups who want a productive non-piscivore fishery will view pike and zander as being harmful whilst the piscivore angler will not want to encourage such a fishery by killing his quarry unnecessarily. This polarisation of interests was very much to the fore at the time the cull was first proposed.

Predation by pike would not tend to cause destabilisation of prey stocks within the Middle Level System since maximum pike densities are liable to be determined by physical characteristics of the habitat (see section 4.4.4) which help to maintain pike stocks below the level where over predation would occur, especially since pike predation is proportional to prey densities. This means that if the destabilizing influence of the zander is removed then the balance between pike and its prey species should be restored. The cull of pike was intended to reduce the predation pressure on the prey stocks so that strong year classes would be produced. The cull of pike would be successful therefore only if recruitment of pike was not promoted causing the predation pressure on those prey year-classes to remain the same or be increased. It was shown in section 6.5 that the cull of pike probably did decrease the consumption of these year-classes and so was successful in its objective. It is likely, however, that a cull of zander alone would have resulted in a recovery of the prey stocks since recruitment of the pike stock would have been below the levels recorded after the cull.

There were worries at the time that once relatively large pike and low prey biomasses had become established that pike by predated on the prey year-classes produced each year would prevent any recovery. The younger age classes would have a high production per unit biomass and so would be supported by lower predator to prey biomass than a prey population of a older average age.

It is doubtful that this would have occurred, however, since it is to be expected that larger pike would prefer larger prey and if these weren't present then they would be more likely to cannibalise the younger pike, which would be the proportion of the pike population mainly predated on young age classes of prey. This factor (along with the pikes efficiency being directly proportional to prey density) should result in an eventual recovery of the prey stocks, following a zander only cull.

Culling of zander in waters where it has potential to over predate its prey stocks and it is not being exploited would be advisable. In diverse water where recruitment is limited it may propose no problem however.

The most efficient method of achieving a cull of the zander in the Middle Level System will be by angling and it is necessary therefore to publicise the role of the zander in such fishery and its potential for harm to ensure co-operation from the angling public and the prevention of its spread by misguided vandalism. The cull will be of benefit to both the match or coarse angler as well as the pike angler through protection of the prey stocks.

The x axis shows the degree of synchronisation between predator and prey year-classes (ie predation on a roach year-class produced 2 years before a piscivore year-class is shown in column -2).

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APPENDIX A Study site data

Figure A.1 The profile of the Sixteen Foot Drain.

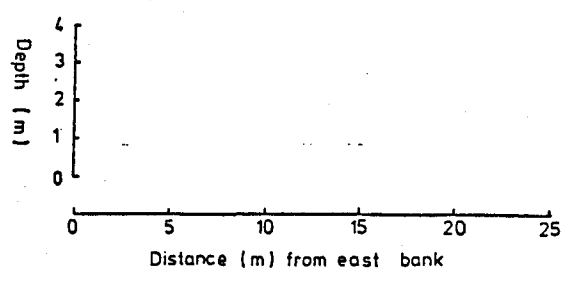
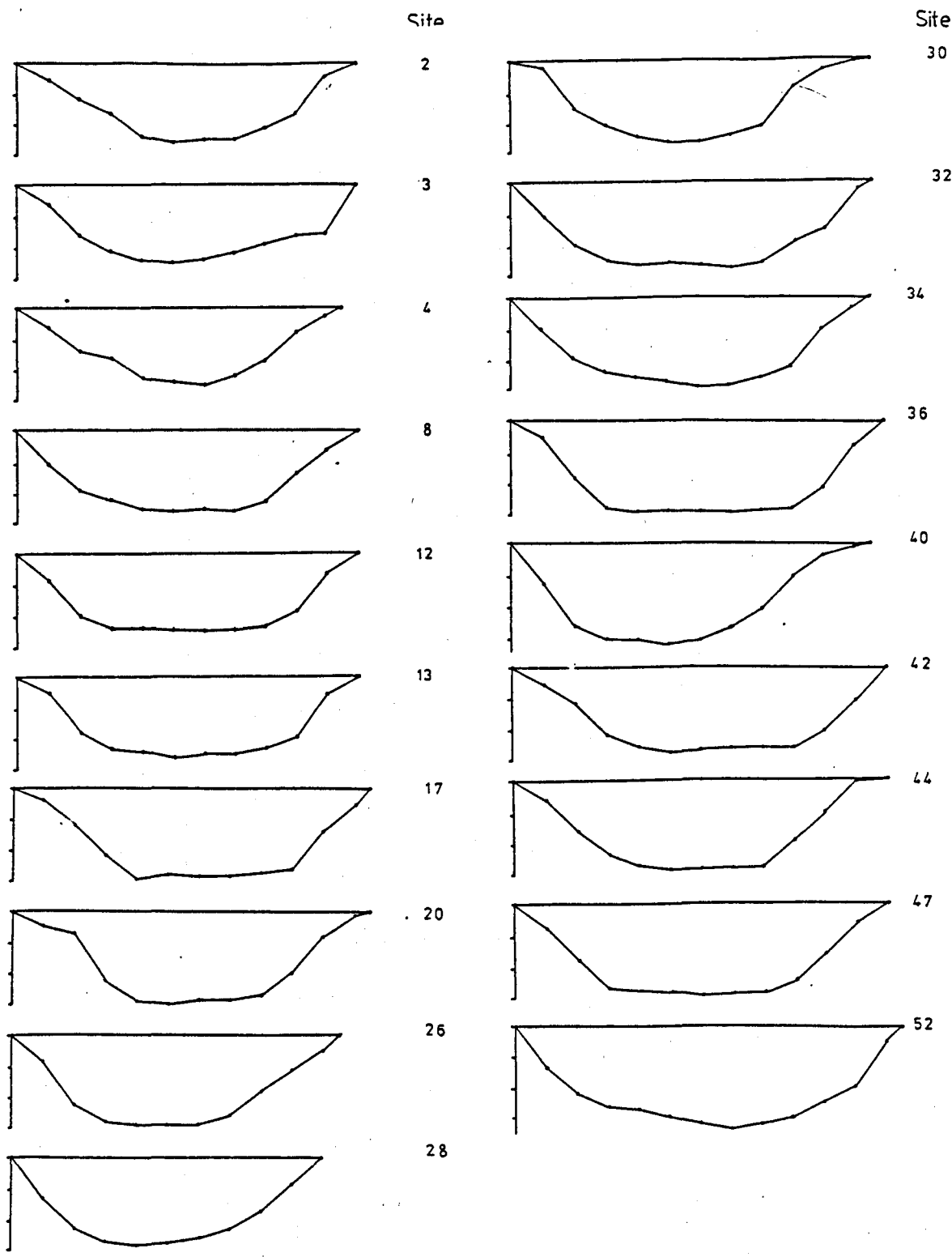


TABLE A1 Profile of Sixteen Foot Drain

Site	Distance from 40' Drain (m)	Channel Width (m)	Distance from East Bank (m)														
			2	4	6	8	10	12	14	16	18	20	22	24	26		
			Depth of Channel (m)														
2	500	22	.52	1.15	1.65	2.40	2.60	2.50	2.50	2.10	1.60	.40					
3	750	22	.60	1.60	2.12	2.40	2.50	2.40	2.20	1.90	1.00	1.57					
4	1000	21	.60	1.40	1.60	2.30	2.40	2.50	2.20	1.70	.85	.25					
8	2000	22	1.05	1.90	2.20	2.50	2.55	2.50	2.55	2.25	1.32	.60					
12	3000	22	.85	2.00	2.40	2.40	2.40	2.45	2.40	2.30	1.85	.60					
13	3250	22	.50	1.80	2.30	2.40	2.55	2.50	2.50	2.35	1.95	.50					
17	4250	23	.40	1.20	2.20	3.00	2.85	2.90	2.90	2.80	2.65	1.40	.55				
20	5000	23	.40	.75	2.25	2.90	3.00	2.90	2.90	2.70	2.00	.80	.15				
26	6500	21	.85	2.25	2.80	2.90	2.90	2.90	2.60	1.80	1.15	.50					
28	7000	20	1.35	2.30	2.70	2.80	2.75	2.60	2.30	1.70	.85						
30	7500	23	.20	1.55	2.10	2.45	2.65	2.65	2.40	2.10	.85	.30	.50				
32	8000	23	1.05	2.00	2.50	2.65	2.60	2.70	2.80	2.60	1.90	1.50	.20				
34	8500	23	1.00	1.95	2.40	2.65	2.70	2.90	2.85	2.65	2.25	1.00	.30				
36	9000	24	.50	1.85	2.80	2.90	2.95	2.95	2.95	2.90	2.80	2.20	.70				
40	10000	23	1.25	2.60	3.00	3.05	3.20	3.10	2.70	2.10	1.05	.35	.05				
42	10500	24	.50	1.15	2.15	2.55	2.75	2.70	2.60	2.60	2.65	2.10	1.10				
44	11000	24	.55	1.60	2.35	2.70	2.86	2.80	2.85	2.80	1.95	1.05	.05				
47	11750	24	.75	1.80	2.70	2.80	2.85	2.95	2.95	2.85	2.50	1.60	.65				
52	13000	25	1.35	2.15	2.60	2.65	2.90	3.10	3.30	3.10	2.85	2.40	1.90	.45			

TABLE A.2 Fish species caught in the Sixteen Foot Drain

SPECIES		STATUS
Roach	<u>Rutilus rutilus</u> (L)	Abundant
Common Bream	<u>Abramis brama</u> (L)	Common
Silver Bream	<u>Blicca bjoerkna</u> (L)	Common
Roach x Common bream hybrid		Common
Rudd	<u>Scardinius erythrophthalmus</u> (L)	Occasional
Bleak	<u>Alburnus alburnus</u> (L)	Common
Dace	<u>Leuciscus leuciscus</u> (L)	Rare
Chub	<u>Leuciscus cephalus</u> (L)	Rare
Gudgeon	<u>Gobio gobio</u> (L)	Rare
Spined Loach	<u>Cobitis taenia</u> (L)	Common
Carp	<u>Cyprinus carpio</u> (L)	Rare
Tench	<u>Tinca tinca</u> (L)	Common
Ruffe	<u>Gymnocephalus cernuus</u> (L)	Abundant
Perch	<u>Perca fluviatilis</u> (L)	Common
Pike	<u>Esox lucius</u> (L)	Common
Zander	<u>Stizostedion lucioperca</u> (L)	Common
Three spined stickleback	<u>Gasterosteus aculeatus</u> (L)	Common
Nine spined stickleback	<u>Pungitius pungitius</u> (L)	Occasional
Eels	<u>Anguilla anguilla</u> (L)	Abundant

TABLE A3 Raw data for selected water quality determinands 4/82 - 6/83

Date	Horseways Corner					Ancaster Farm					Cottons Corner				
	pH	Temp °C	DO % Satn	BOD mg/1	Ammonia mg/1	pH	Temp °C	DO% Satn	BOD mg/1	Ammonia mg/1	pH	Temp °C	DO% Satn	BOD mg/1	Ammonia mg/1
4/82	4.3	8	118	2.7	<0.05						8.7	13.2	116	4.2	0.09
5/82	-	13.5	137	2.7	<0.05										
7/82	-	18.0	148	5.7	<0.05										
8/82	6.6	21.0	118	7.7	<0.05						8.2	18.0	81	4.4	0.06
9/82	10.2	16.0	69	3.4	<0.05										
10/82	7.3	12.0	71	3.8	0.40						7.5	10.0	59	2.0	0.60
11/82	5.6	12.0	65	2.0	0.33										
12/82	7.5	2.0	59	1.5	0.60										
1/83	8.1	5.5	90	2.6	<0.05						8.09	4.0	86	1.1	0.46
2/83	8.1	4.0	89	1.2	0.54										
3/83	7.9	5.0	98	1.1	1.07										
4/83	8.4	7.0	114	3.6	0.24										
5/83	8.0	12.5	90	2.1	0.03	8.0	12.0	95	2.5	0.40	7.9	12.0	89	2.3	0.35
6/83	8.1	19.5	112	3.9	<0.05	8.0	19.5	109	4.9	0.26	8.2	19.5	-	5.0	<0.05
7/83	8.2	23.5	123	9.0	<0.05	8.1	23.0	112	7.4	<0.05	8.4	-	-	7.6	0.31
8/83	7.8	18.0	57	1.6	<0.05	8.2	20.5	61	1.8	0.17	8.5	10.0	117	5.4	<0.05

From Eckstein, 1983

TABLE A.4 Site comparisons for selected water quality determinands

Determinand	Sites Tested	F Test Value (F Test Value to fail)	Acceptance	Pooled Variance	t Test Value	n-2
Dissolved	HC/AF	2.28(1.41)		1166.312	0.102	18
Oxygen	HC/CC	2.62(6.28)		1087.64	0.068	20
	AF/CC	1.15(7.77)		518.37	0.206	8
Biochemical	HC/AF	1.15(4.76)		5.324	0.573	18
Oxygen	HC/CC	1.16(4.42)		4.972	0.611	24
Demand	AF/CC	1.33(5.89)		4.925	0.110	10
Ammonia	AC/AF	3.92(14.1)		0.075	0.326	18
	HC/CC	1.88(4.42)		0.073	0.205	24
	AF/CC	2.09(14.6)		0.039	0.216	10

HC Horseway's Corner
 AF Ancaster Farm
 CC Cotton's Corner

From Eckstein, 1983

TABLE A.5 Macro-invertebrates recorded from Sixteen Foot Drain

SPECIES

TRICLADA

Dugesia lugubris (Cirard)

HIRUDINEA

Pisciola geometra (Linn)Glossiphonia complanata (Linn)Batrachobdella paludosa (Carena)

MOLLUSCA

Bithynia tentaculata (Linn)Valvatapiscinalis (Mull)Valvata macrostoma (Steenbach)Potamopyrgus tenkinsi (Smith)Unio pictorum (Linn)Andonata cygnea (Linn)Sphaerium corneum (Linn)Pisidium subtruncatum (Malm)Dreissena polymorpha (Pallas)

CRUSTACEA

Crangonyx pseudogracilis (Bousfield)Asellus aquaticus (Linn)Corophium curvispinum (Latreille)

COLEOPTERA

Dytiscus sppHyphydrus sppHaliplidae sppElmidae spp

HEMIPTERA

Mesovelia furcata (Mulscant, Reg)

NEUROPTERA

Sialis lutaria (Linn)

EPHEMEROPTERA

Caenis horaria (Linn)

TRICHOPTERA

Lype phaeopa (Stephens)Cacetus spp

SPECIES

DIPTERA

(Qualicidae) Chaoborus spp.(Ceratopogonidae) spp.)(Chironomidae)Chironomus 'thummi' gpChironomus 'plumosus' gpCryptochironomus spp.Kierfferulus tendipediformis

(Goetghebaer)

Eukiefferiella spp.Endochironomus 'nymphiodes' gpGlyptotendipes sppPolypedilum spp.Paracladius conversus (Walker)Paratendipes sppMicrospectra sppMacropelopia sppProcladius sppAnatopynia sppOrthocladius sppMicrotendipes spp

OLIGOCHAETA

Tubifex tubifex (Muller)Limnodrilus hoffmeisteri (Clap)" Cervix (Brink)" Claparedeanus (Ratzel)" Udekemianus (Clap)Potamotheix hammoniensis (Mich)" moldaviensis (Nej et Mr)Rhyacodrilus coccineus (Vej)Psamoryctes barbatus (Grabe)Peloscolex benedeni (Ude Kem)Stylaria lacustris (Linn)

ARACHNIDS

Hydrachnelle spp

From Eckstein, 1983

Table A.6 Substrate of Sixteen Foot Drain

Substrate type	% Occurrence
Soft Mud	9.4
Peat	15.6
Mud and Clay	6.3
Clay	46.9
Sand	12.6
Sand and Clay	3.1
Gravel	6.3

APPENDIX B Habitat Characteristics Influencing Spawning and Recruitment

Success

B.1 Introduction

In order to safeguard spawning and recruitment it is necessary to understand how these may be modified by man's activities, since weed control dredging and fluctuating water levels are a necessary part of the management of the Middle Level System for Land Drainage.

B.2 Methods

Spawning sites were identified and their vegetation described Table B.1; similarly the importance of the aquatic vegetation in providing nursery areas for fry was assessed.

The aquatic flora of the Sixteen Foot has already been described in Section 1 4.6 and these sites were inspected for eggs in May-June 1982 and fry in July 1983.

Two sites are known to be used annually by the Sixteen Foot roach and bream population for spawning; the Forty Foot at Horseways (Map Ref.TL 425 872) and (Map Ref.TL 482 970).

These sites were inspected each day during the spawning season for visual signs of spawning activity (i.e. concentrations of mature fish bow waving or splashing on the surface) and for the presence of ova. Ova were found by either sweeping with a pond net or by examining vegetation that had been collected by hand or by grapnel.

When fish were known to be spawning, the entire length of the drain was surveyed by boat for visual signs of spawning activity with detailed examination of the vegetation at the selected sites.

In July a similar survey noting the presence of fry was conducted to determine the nursery areas.

B.3 Results

Roach and bream were only seen to spawn at the two sites given above and ova were found only at these sites. The main spawning substrate was Glyceria maxima. Whilst the roots appeared to be the most important location for the deposition of eggs, eggs were also found on the stems. The eggs were always deposited at the margins from the surface down to a depth of about .80 m.

A survey of the fish populations had shown mature and gravid fish to be distributed along the entire length of the drain at spawning time, although there did appear to be a concentration of roach near to Horseways. This suggests that concentrations of fish at traditional spawning sites is either short lived or that the difficulty in locating spawning sites may result in some sites being missed. Whatever the case, it is certain that spawning sites are used annually and that they are extremely localised.

TABLE B.1

SUMMARY TABLE: Cyprinid Fry Survey, June 1982

Site	Fry Occurrence +/-	Fry	Observations Vegetation
2 West	-		<u>Carex</u> clumps on margins
2 East	-		
3 West	+	Shoals seen amongst <u>Phragmites</u> stands	<u>Phragmites</u> and <u>Carex</u> along margins, mainly algal mats submerged and floating, <u>Nymphaea alba</u> in parts.
3 East	+	small shoal	<u>Agrostis</u> and <u>Phragmites</u> fringe, with algal mats (sub. + float.), <u>Potamogeton perfoliatus</u> present.
4 West	+	Numerous shoals	<u>Carex</u> margin
4 East	+	Several shoals	<u>Phragmites</u> fringe, algal mats and <u>P. perfoliatus</u>
8 West	+	Fry caught in F.B.A. net	Isolated <u>Juncus effusus</u> stands, some <u>P. perfoliatus</u> mainly algal mats.
8 East	+	Shoals of fry along entire margin	Some <u>Carex</u> , mainly floating algal mats.
12 West	+	Continuous shoals	Some <u>Carex</u> , mainly floating algal mats.
12 East	+	1 or 2 sparse shoals	Dead <u>Phragmites</u> , mainly floating algal mats.
13 West	+	Continuous shoals	Stands at <u>Carex</u> and <u>Typia</u> algal mats predominate.
13 East	+	Dense fry shoals	<u>Carex</u> margin, with <u>Sagittaria sagittifolia</u> and <u>P. pectinatus</u> .
17 West	-		
17 East	+	Dense isolated shoals	<u>Agrostis</u> and <u>Phragmites</u> fringe, algal mats.
20 West	+	Small shoals	Algal mats with odd patches of <u>Nymphaea alba</u> .

Site	Fry occurrence +/-	Observations Fry	Vegetation
20 East	+	Dense shoals amongst algal mats	<u>Nuphar lutea</u> and algal mats.
26 West	-		Mainly algal mats, fringe of <u>Carex</u> and <u>Juncus</u> .
26 East	-		Algal mats some bankside <u>Carex</u> and <u>Juncus</u> .
28 West	-	Tench observed exhibiting typical spawning behaviour. No eggs found.	Algal mats.
28 East	+	Several dense shoals	Algal mats with patches of <u>N. lutea</u>
30 West	-	Tench observed exhibiting typical spawning behaviour. No eggs found.	<u>Carex</u> margin (100%) dense algal mats.
30 East	+	Very dense fry shoals	Dead Phragmites, algal mats and isolated patches of <u>N. lutea</u> .
34 West	+	Small shoals	Phragmites and algal mats
34 East	+	Small isolated shoals	Algal mats
36 West	-		
42 East	-		Algal mats and <u>Carex</u> .
44 East	-		Algal mats, <u>P. pectinatus</u>
47 West	-		Algal mats, <u>Phragmites</u>
47 East	-		<u>Carex</u> fringe on margins, <u>N. lutea</u> patches.
52 West	-		Bare pilings with algal mats.
52 East	-		<u>Carex</u> .

B.4 Discussion

Roach spawn primarily on vegetation, although since they are also known to spawn on rocky substrates (Holcik and Hruska, 1966; Penaz and Prokes, 1972) they are classed as phytolithophilous spawners (Balon, 1975). Svardson (1951), Zuromska (1967), Wilkonska and Zuromska (1967) Peczalska (1968) and Goldspink (1977) refer to Phragmites communis as being the principal spawning substrate with eggs being deposited on the submerged parts of the plants in shallow water. Mills (1981) found Fontinalis antipyretica to be the main spawning substrate in the Frome, Diamond, in press; observed spawning on Elodea canadensis occasionally with a covering of Cladophora glomerata, in the Leeds Liverpool Canal and on roots of the willow Salix sp. in a small lake in Wales. Roach are also known to spawn on Salix roots in the Welsh River Dee (Pearce, pers comm.) Klee (1979) found a variety of spawning substrates in an extensive survey of the Middle Level System, observing eggs of roach, bream, rudd and tench on Myriophyllum spicatum, Potamogeton crispus, Nuphar lutea, Hippurus vulgaris, Cladophora spp, Spirogyra spp, Zygnema sp and roots of Salix sp.. By far the most important substrate in common with this study were the submerged parts of Glyceria maxima.

Spawning in all the cases mentioned occurred in the marginal shallows at depths shallower than .80 m with the majority of eggs being deposited at depths much shallower than this.

Where fish spawn on emergent vegetation fluctuating water levels may greatly reduce survival of eggs and in these cases water levels may need to be controlled.

The sites identified in this study were localised and returned to annually, this is a commonly observed phenomenon (Svardson, 1951; Wilkomska and Zuromska, 1967; Goldspink, 1977; Klee, 1979; Diamond, (in press), Pearce, pers comm) and will have important management consequences.

The strategy of concentrating spawning in localised areas may be an attempt to swamp predators and increase survival of eggs (Diamond 1983). Such a tactic means that relatively small isolated areas can have a large bearing on the status of a fishery. It is important therefore that such traditional sites be protected since if they are damaged or destroyed survival of fry may be reduced, until the old site recovers or new sites become established. Since they are restricted in their extent it should be relatively easy to protect them.

It will be necessary to arrange both short term protection over the spawning period and long term protection of such sites.

(a) Short term protection during spawning period.

- i) maintenance of water levels
- ii) cessation of weed control
- iii) cessation of dredging

(b) Long term protection.

- i) Protection of spawning substrate, this may mean no weed control or else cutting to maintain serial stage of vegetation type.

- ii) Protection of marginal shallows, by control of dredging.
- iii) Control of pleasure craft where these are likely to harm sites (e.g. Horseways Lock).
- iv) If spawning sites need to be damaged due to land drainage or navigational interests then this should be restricted to as few sites as possible, to allow adequate recruitment.

It was not possible to observe zander spawning although mature gravid fish were caught in the Sixteen Foot Drain. Whilst zander spawn in the shallows they do so on bare bottom in turbid water and it will be difficult to locate them doing so. It would appear that the control of zander populations by destruction of spawning sites or eggs will not be feasible. Control depending rather on limiting the spread of zander and destruction of older fish.

Pike are known to spawn at a greater number of sites in the Middle Level System than cyprinids although they do share spawning sites (Klee, 1979). They spawn in advance of the cyprinid population presumably to ensure an adequate supply of food for the fry. The protection of cyprinid spawning areas should therefore ensure protection for pike also.

B.5 Nursery areas

Aquatic macrophytes are important in providing nursery areas for fry since apart from their role as primary producers they provide cover. The loss of weed cover may mean that recruitment is reduced due to increased vulnerability to predation (see Section 4) or else exposure to greater extremes of environmental conditions.

The June survey (Table B.1) showed fry to be distributed along the entire margins of the drain, mainly amongst mats of blanket weed (*Cladophora* sp.) that were rising to the surface. Where patches of the lilies Nuphar lutea and N. alba were established shoals of juveniles fish as well as fry were common.

APPENDIX C Population sampling data

Figure C.1 Match census form.

AN INVESTIGATION INTO THE COARSE FISHERY OF THE SIXTEEN FOOT DRAIN
ANALYSIS OF ANGLERS MATCH CATCHES

This survey is being conducted by the Freshwater Fisheries Group of Liverpool University. It will form part of our investigation (sponsored by the Anglian Water Authority) into the impact of the Zander on the fisheries of the Middle Level system.

The questionnaire below is designed to obtain information about the general quality of angling. Your cooperation in filling out this form, especially if you catch nothing, will be greatly appreciated.

On completing this form could you return it to a steward at the weigh in.

Questionnaire

Peg No _____

Total No of fish caught (estimated if necessary) _____

Total weight of fish caught _____

	Species caught (in order of weight)	Estimated no. of this species	Largest individual of this species caught (length or weight)	Smallest individual of this species caught (length or weight)
1st	_____	_____	_____	_____
2nd	_____	_____	_____	_____
3rd	_____	_____	_____	_____
4th	_____	_____	_____	_____
5th	_____	_____	_____	_____
6th	_____	_____	_____	_____
7th	_____	_____	_____	_____
8th	_____	_____	_____	_____

Please tick box where appropriate

1. Did you consider fishing today to be Good O.K. Bad

2. When did you last fish at this venue?

3. How does sport on the Middle Level system compare with:

a) The last occasion that you fished here Better Same Worse

b) 1982 - 1983 Season Better Same Worse

c) 1981 - 1982 Season Better Same Worse

d) 1980 - 1981 Season Better Same Worse

e) 1970's Better Same Worse

f) 1960's Better Same Worse

Any other comments

Years of fishing experience

TABLE C.1 Results of 1983 Great Ouse Championships

1st	49lb - 0oz
2nd	45lb - 6oz
3rd	42lb - 12oz
4th	25lb - 6oz
5th	23lb - 11oz
6th	18lb - 3oz
7th	18lb - 2 1/2 oz
8th	16lb - 15 1/2 oz
9th	16lb - 3oz
10th	12lb - 5 1/2 oz

TABLE C.2 Summary of trawl catches, g/m trawled.

	May 1981	September 1981	October 1981	February 1982	March 1982	April 1982	May 1982	August 1982	December 1982	March 1983	May 1983	July 1983	September 1983
Roach	.2681	.1167	.3139	.5265	.2640	.0912	.1024	.1662	.9555	.0149	.2253	.0626	.2565
Common Bream	.0101	.0344	.0017	.0196	.0300	.0211	.0044	.1635	.2417	.0533	.0899	.3204	.2834
Silver Bream		.0054		.0161	.0009	.0017	.0001	.0123	.0448		.0120	.0501	.0022
Tench	.0003			.0008	.0003					.0008			.0002
Roach x Bream	.0015						.0017	.0058	.0124		.0167	.0005	.0004
Perch	.0147	.0029	.0048	.0142	.0148	.0217	.0324	.0164	.0140	.0123	.0073	.0087	.0035
Ruffe	.0023	.0256	.0138	.3150	.0016	.0973	.1314	.2041	.1320	.0024	.0383	.0257	.1356
Chub	.0002												
Gudgeon												.0010	
3 spined stickleback				.0042	.0014	.0006			.0010				
Rudd			.0012										.0005
Spined loach				.0035	.0012	.0143			.0010	.0136	.0100	.0048	.0043
Eel				.0029	.0003		.0013					.0005	
Pike	.0023		.0068	.0055	.0015	.0040	.0025	.0012	.0009	.0018	.0040		
Zander		.0003	.0054	.6043	.0016	.0116	.00155	.00115	.0148	.0012	.0047	.0005	.0016
Total No of Sites	11	20	30	25	15	17	8	19	11	21	10	16	18

TABLE C.3 Summary of trawl catches, no/m trawled.

	May 1981	September 1981	October 1981	February 1982	March 1982	April 1982	May 1982	August 1982	December 1982	March 1983	May 1983	July 1983	Septembe 1983
Roach	4.1723	2.5552	.5660	3.5353	1.4804	2.0020	2.3313	3.1659	13.8616	1.3420	6.2514	4.9485	1.0067
Common Bream	2.3212	3.8145	1.1498	.3813	2.7831	12.6817	1.2548	16.2699	5.1982	6.5338	4.5350	1.3994	.8496
Silver Bream		.0819	.0014	.1114	.0010	.1054	.0126	.1664	.5967	.0162	.1913	.1455	.0163
Tench	.5347			1.1307						4.7033			2.4231
Roach x Bream	.0764	.0010	.0004	.0029			.0713	.0784	.2167	.0384	.0780	.0149	.0162
Perch	.1402	.1500	.0338	.3680	.3716	.1622	.1360	.1296	.2310	.0372	.0740	.0433	.1166
Ruffe	.3794	.8087	.1175	2.5588	.3320	1.2364	1.0909	1.4288	.9717	.2176	.2993	.1480	.7529
Chub	.0010												
Gudgeon				.0002									.0003
3 spined stickleback			.0009		.0011	.0006			.0010	.0004			
Rudd			.7480						.0195				
Spined Loach		.0002		.0037	.0012	.0064				.0010	.0100	.0054	.0085
Eel				.7132	.0173		.0699	.0205					.1267
Pike	.3720	.9389	.3202	.3038	.3910	1.2181	.5102	.3858	.2885	.3508	5.4000	.0673	
Zander	.0478	.2277	.8888	.5822	.3421	4.2578	24.2133	.2856	.5571	.5153	2.2293	.0003	.7642
Total													
No of Sites	11	20	30	25	15	17	8	19	11	21	10	16	18

TABLE C.4 Summary of seine catches, biomass Kg/Ha

DATE	19/1/81	19/1/81	20/1/81	21/1/81	23/3/81	24/3/81	22/7/81	23/7/81	15/9/81	5/7/82	6/7/82	7/7/82	8/7/82	9/7/82	12/7/82
SITE	16	1	34	54	34	16	34	10	47	4	16	19	24	28	32
Roach	.008	.386	21.730	.030	16.000	.200	45.240	32.800	112.513	1.50	2.28	3.12	4.90	.88	.95
Common Bream			1.510		1.636	.002	.090	1.500	88.540	13.44	2.27	.28	.03	.03	
Silver Bream									2.54	.08	.46				
Roach x Bream			.650		.160				.282		.06				
Rudd			.350				5.040		4.090	.95	.87	1.03	.06	.05	
Tench	2.006								7.610	24.55	5.07	7.31	6.66	17.85	
Bleak			1.120		.260	.044		1.360		23.28			.18	.08	
Chub															
Dace			.012												
Spined Loach															
Gudgeon															
Perch	.168	.042	.360	.010	.120	.100	1.660	.370	2.820	.133	.03	.46	.48	.05	.17
Ruffe		.204	.007	.010	.073		.180	.400	.100	.03	.10	.05	.04	.03	.32
Eels										5.71	.35	.79	.56	1.20	
Zander	.236	.130		.100	2.000	.120	25.030	17.090	8.14	2.22	2.16	.02	.06	.40	
Pike							1.730	.460	.26	1.20					

DATE	13/7/82	14/7/82	15/7/82	16/7/82	23/5/83	24/5/83	25/5/83	26/5/83	27/5/83	30/5/83	6/6/83	7/6/83	8/6/83	9/6/83
SITE	40	44	48	53	4	16	19	24	28	32	40	44	48	53
Roach	8.74	2.09	2.56	3.53	143.70	289.95	54.27	70.95	67.13	35.13	40.06	36.84	24.45	5.33
Common Bream	.16	.25	5.98	17.31	10.33	5.46	2.38	44.88	29.71	22.64	19.20	1.53	114.4	
Silver Bream			.061	.27	3.45	6.70	.08	2.46	1.08	.30	.40	1.25	.73	.05
Roach x Bream	.20	.02	.027	.62		1.19	.18	.49	.49			5.69	.11	
Rudd		.239	2.24			.01			3.33	.10	56.94		.04	
Tench	22.99			2.78	10.16	11.16		13.18	18.77	5.65	23.89	18.89	14.44	
Bleak	.07	.59		.08	1.80	1.04					1.17	1.17		
Chub						1.03								
Dace						1.03								
Spined Loach							.003			.003	.003		.003	
Gudgeon														
Perch	.06	1.41	1.77	.99	.56	.86	.61	.49	.89	.41	.11	.12	.18	.20
Ruffe	.42	.06	.18	.04	3.79	2.70	1.17	1.48	1.07	.68	1.05	1.08	1.21	.91
Eels		.28		.24	12.54	4.78	10.15	14.92	10.67	11.42	17.50	30.83	14.72	14.13
Zander	.20	1.50	.01	.79		2.84	2.32	11.60	.33	14.64	4.72	5.97	5.84	6.67
Pike	.52	.02	6.17	.40	27.89	20.77	6.38	32.06	20.33	33.94	21.94	29.81	10.62	8.00

TABLE C.5 Summary of seine catches, density No/Ha

DATE	19/1/81	19/1/81	20/1/81	21/1/81	23/3/81	24/3/81	22/7/81	23/7/81	15/9/81	5/7/82	6/7/82	7/7/82	8/7/82	9/7/82	12/7/82
SITE	16	1	34	54	34	16	34	10	47	4	16	19	24	28	32
Roach	2	76	2591	4	940	20	2320	1300	1402	124	69	214	377	92	60
Common Bream			85		62		10	40	80	30		2		4	4
Silver Bream						2				267		10	38		
Roach x Bream			20		13								2		
Rudd			10						56	8	11	25	2	4	
Tench		2					10		10	14	3	4	4		4
Bleak			960		16	2		60	24	240			9	4	
Chub															
Dace			1												
Spined Loach															
Gudgeon															
Perch	8	12	28	2	13	70	50	30	70	16	3	41	29	4	10
Ruffe		1	1	2	11		10	30	10	4	8	8	2	2	2
Eels										17	3	2	4	8	
Zander								10	30	4	3				
Pike	4		1		5	7	10		10	8	5	6	2	4	2

DATE	13/7/82	14/7/82	15/7/82	16/7/82	23/5/83	24/5/83	25/5/83	26/5/83	27/5/83	30/5/83	6/6/83	7/6/83	8/6/83	9/6/83
SITE	40	44	48	53	4	16	19	24	28	32	40	44	48	53
Roach	165	85	182	406	6580	12277	3211	4137	3953	2148	2191	2310	1114	139
Common Bream	12		24	676	495	985	160	181	194	128	235	56	28	152
Silver Bream			8	52	175	662	9	60	134	29	29	22	14	3
Roach x Bream	6	2	2		38	52	20	35	43			6	6	
Rudd		6	24			3			3	12	9		6	
Tench	17			2	6	6		13	18	3	9	11	8	
Bleak	4	12		4	85	52					3	3		
Chub						3								
Dace														
Spined Loach							3			3	3		3	
Gudgeon					9									
Perch	12	6	116	70	52	128	99	48	41	58	23	23	25	5
Ruffe	30	4	22	6	387	212	99	137	107	67	96	100	84	59
Eels		2		2	60	36	52	54	63	29	75	172	103	75
Zander	2	6	2		12	21	3	6	3	12	3	3	13	13
Pike	2	6	8	2	58	39	23	25	25	24	23	30	25	8

APPENDIX D Methods used in diet study

APPENDIX D Methods: diet study

D.1 Introduction

All the fish in this diet study were captured during the sampling programme outlined in Chapter 3, (i.e. by either trawling or seine netting). The advantage of using such active capture techniques, is that they do not depend on the hunger state of the predator (e.g. angling), nor do they induce vomiting (e.g. gill netting), nor delay recovery of the catch which would permit digestion to continue (e.g. traps). The diet data were pooled for fish caught by both methods.

On capture, if stomachs were not examined immediately they were kept on ice in an insulated container until they could be frozen, generally within 2 or 3 hours. All stomachs were assigned a code number, which allowed the diet data to be cross referenced to all the other data obtained during the survey.

D.2 Pike and zander

Stomach contents were emptied into a dish and examined where necessary under a low powered binocular microscope. Contents were identified to species in the case of fish prey, but not more than to genera for other organisms. The occurrence of each prey species was noted, the numbers of each species present in a stomach counted and weighed, and the length of each prey fish measured. Wet weights were used as a measure of the bulk of food items, since this was easiest to obtain. If the prey items

were first dried by blotting with paper towels a consistent result could be obtained for the important prey items. Glenn and Ward (1968) had shown for the stomach contents of the Walleye Stizostedion vitreum vitreum, that there was a good correlation between wet weight and dry weight. Wet weight was further judged to be appropriate, since the diet of the piscivores was to be ultimately related to the biomass levels obtained during the population surveys. If the original length of the prey item was known, then it was possible to reconstruct the live weight using the length/weight relationships calculated for the main species (summarised in Tables D.1 and D.2).

D.3 Identification of prey items

Digestion usually makes the identification of prey items difficult if they have been present in the stomach for some time. However, certain hard parts of an organism may remain recognisable throughout most of the digestion process. Such parts include otoliths, vertebrae and pharyngeal, mandibular and opercular bones. The identification of cyprinids by the pharyngeal bones has been long established, drawings of these bones existing in Wheeler (1978) and Maitland (1972). The identification of percids is possible from opercular bones and otoliths. Type material prepared from fresh specimens was of particular use. These structures also permit the reconstruction of a prey item's original live weight, if the relationship between hard part and fish length is known; tables and graphs have been constructed by numerous authors to aid in this reconstruction (e.g. Lishev, 1950; Kovalev, 1958; Vasarhely, 1958; Horoszewicz, 1960; Skalkin, 1961 and 1965; Schmidt, 1968; Pihu and Pihu, 1970; Fortunatova and Popova, 1973; Borutsky, 1974; Mann and Beaumont, 1980; Fickling and Lee, 1981). Fickling and Lee

TABLE D.1 Summary of length:weight relationships for roach, common bream, silver bream, ruffe and perch.

Length : Weight relationships ($w = a.l + b$)

Species	40mm - 79mm			80mm - 159mm			160mm - 319mm			320mm - 639mm			Combined		
	a	b	r	a	b	r	a	b	r	a	b	r	a	b	r
Roach	-5.2390	3.2040	.9424	-5.6596	3.4043	.9835	-4.8477	3.0549	.9606				-5.4686	3.3234	.9961
Common Bream	-6.3608	3.8367	.9483	-5.1315	3.1606	.9765	-5.9177	3.4864	.9444	-3.9883	2.7258	.9130	-5.2452	3.2131	.9956
Silver Bream													-4.4576	2.8728	.7345
Ruffe	-6.5107	3.9664	.9554	-3.4366	2.3110	.9237							-5.8058	3.5181	.9775
Perch	-4.0423	2.5380	.5583	-5.5038	-3.3235	.9284							-5.4242	3.2827	.9594

TABLE D.2 Summary of length:weight relationships for pike and zander.

Length : weight relationships ($w = la + b$)

SPECIES	INFO	Age Class									Combined
		0+	1+	2+	3+	4+	5+	6+	7+		
PIKE	a	-5.0582	-5.1185	-4.2897	-3.6646	-5.5560	-4.5308	-4.6092	-1.7935	-5.3131	
	b	2.9583	2.9887	2.6659	2.4500	3.1675	2.7990	2.8309	1.8393	3.0748	
	r	.9918	.9811	.9157	.8384	.9543	.9800	.9886	.8929	.9901	
ZANDER	a	-1.7936	-5.1090	-5.6379	-4.8960	-5.2982	-6.5929	-4.7675		-4.6862	
	b	1.3594	3.0187	3.2545	2.9550	3.1119	3.5930	2.9202		2.8264	
	r	.4747	.9956	.9879	.9912	.9766	.9582	.9686		.9189	

Figure D.1 Dimensions of pharyngeal bones.

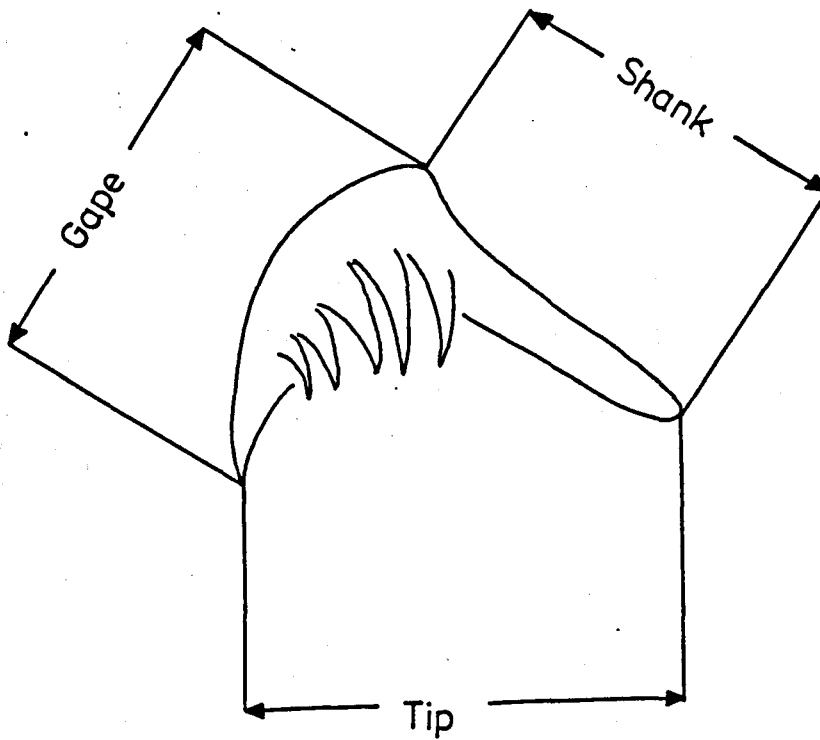


TABLE D.3 Relationships between pharyngeal bone dimensions and fish length

Species	Fish length = b bone length + a								
	Gape			Tip			Shank		
	a	b	r	a	b	r	a	b	r
Roach	-14.8019	0.8274	0.9620	-5.6731	0.7946	0.9631	0.0109	0.4732	0.9593
Common Bream	2.2079	0.4264	0.9376	0.0946	0.6846	0.9671	2.8527	0.4646	0.9609
Silver Bream	-7.5734	0.6177	0.9909	0.2145	0.6302	0.9918	0.1193	0.4768	0.9921

TABLE D.4 Relationship between persistent hard structure and fish length.

Species	Fish length = b otolith length + a		
	a	b	r
Perch	3.0771	0.3642	0.9831

(1981) also developed a method whereby the live length of a fish could be reconstructed, if no suitable hard part existed, from the length after part digestion and the stage of digestion. This latter method was used where no measurable hard part remained but where the prey item was identified.

The relationship for pharyngeal bone against fork length was calculated, for roach, common bream and silver bream: the bone being measured for three dimensions as shown in Figure D.1, and the regression calculated by least mean squares, ruffe otoliths were also measured.

All the relationships between hard parts and fish length that were used in this study, are summarised in Tables D.3 and D.4.

D.4 Roach, common bream, perch, ruffe and eels

Stomach contents of fish other than pike and zander were examined, using a low powered binocular microscope. The occurrence of each prey category was recorded and its volume estimated by the use of a "squash plate" Hellowell (1972). This permitted data on % occurrence, % volume, and 'Relative Importance' (RI) to be obtained. All the fish used in this part of the study were collected during the summer of 1983 by seining and had been deep frozen on capture.

D.5 Modes of analysis

Four types of stomach contents analysis can be undertaken, i.e. numbers, occurrence, weight, and the combination of these three into an index of relative importance, IRI (Pinkas et al, 1971; Prince, 1975). It has been pointed out by numerous authors (e.g. Lagler (1956), Windell and Bowen (1978) and Hyslop (1980)) that an analysis based on numbers contains various biases. However there is the benefit that raw data in this form can be used in contingency tables of the chi-squared type, to analyse statistically differences in feeding mode and preferential selection by a predator. The biases referred to by the above authors will be small in the case of pike and zander. Since the order of size of the main prey items were similar, and prey items such as invertebrates that may occur in large numbers are of only minor interest in this study, they may be grouped together or else ignored.

It is always desirable to accompany statements of foraging behaviour and diet composition with tests of statistical significance. It was pointed out by Crow (1981) this is difficult for the commonly used fisheries indices (e.g. "Index of Relative Importance"), and suggested the use of contingency tables (Sokal and Rohlf, 1969) using the raw data. This also avoids the difficulty of using cumbersome multivariate techniques. Similarly, the assessment of preference has often been done using summary indices (e.g. Ivlev's 1955). For a review of these, see Cheeson (1978) Cock (1978) and Pearre (1982), however, Windell (1978) in a review of methods of stomach contents analysis, states that the trend towards the use of standard statistical techniques is to be encouraged, since it makes the data so presented "more readable, conceptually clear and ..." at the same time "... to have confidence in the results, fisheries indices that have been used in the past should be replaced by the standard techniques that are now a basic component of a biologist's working knowledge".

The G-Test (Sokal and Rohlf, 1969) was used to compare food habits. Its appropriateness to such studies is discussed by Crow (1981). The C and V statistics based on chi-squared (Pearre, 1982) were used to assess preference. The raw data that was analysed was in the form of numbers.

Diet data in the form of percentage weight and percentage frequency are also presented.

G - Statistic

$$G = 2 \sum_{ij} X_{ij} \ln \frac{NX_{ij}}{X_i X_j}$$

Where:

X_{ij} = The number of prey of the i^{th} category eaten by predators in the j^{th} category.

X_j = The total number of prey eaten by predators in the j^{th} predator category.

X_i = The total number of prey in the i^{th} category eaten by all predators.

N = The total number of prey eaten by all the predators.

Degrees of freedom:

G is distributed as a chi-squared random variable with $(R-1)(C-1)$ degrees of freedom.

R = No. of Rows

C = No. of Columns

i. e. :

	Predator 1	Predator 2	.....	Predator j	Sums (N _i)	G _i
Prey 1	X ₁₁	X ₁₂	.....	X _{1j}	X ₁	
Prey 2	X ₂₁	X ₂₂	.....	X _{2j}	X ₂	
Prey i	X _{i1}	X _{i2}	.....	X _{ij}	X _i	
Sums (N _j)	X ₁	X ₂	.....	X _j	N	

G_j

Contingency Table

	Species A	Others Total
Diet	X ₁₁	X ₁₂
Environment	X ₂₁	X ₂₂
Total		N

$$\chi^2 = \frac{(X_{11} \cdot X_{22} - X_{12} \cdot X_{21})^2 \cdot N}{X_{11} \cdot X_{22} \cdot X_{12} \cdot X_{21}}$$

Where d. f. = (R-1)(C-1)

$$V = \pm \left(\frac{\chi^2}{N} \right)^{1/2}$$

$$= \frac{X_{11} \cdot X_{22} - X_{12} \cdot X_{21}}{(X_{11} \cdot X_{22} \cdot X_{12} \cdot X_{21})^{1/4}}$$

$$C = \pm \left(\frac{(X_{11} \cdot X_{22} - X_{12} \cdot X_{21})^2}{X_{11} \cdot X_{22} \cdot X_{12} \cdot X_{21}} \right)^{1/2}$$

$$= \pm \left(\frac{XY}{N} \right)^{1/2}$$

APPENDIX E Diet data

Figure E.1 Size range of zander sampled.

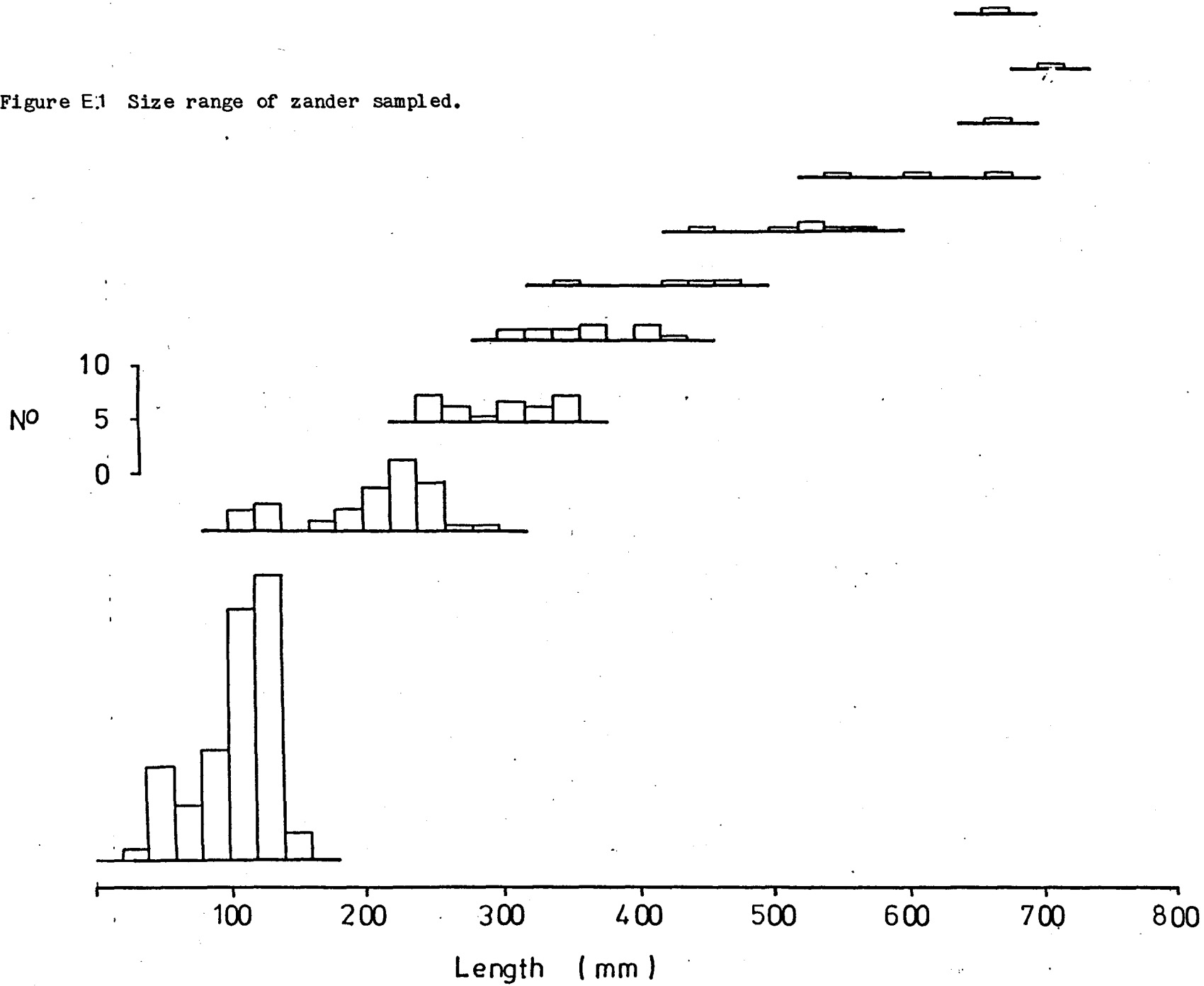


Figure E.2 Size range of pike sampled.

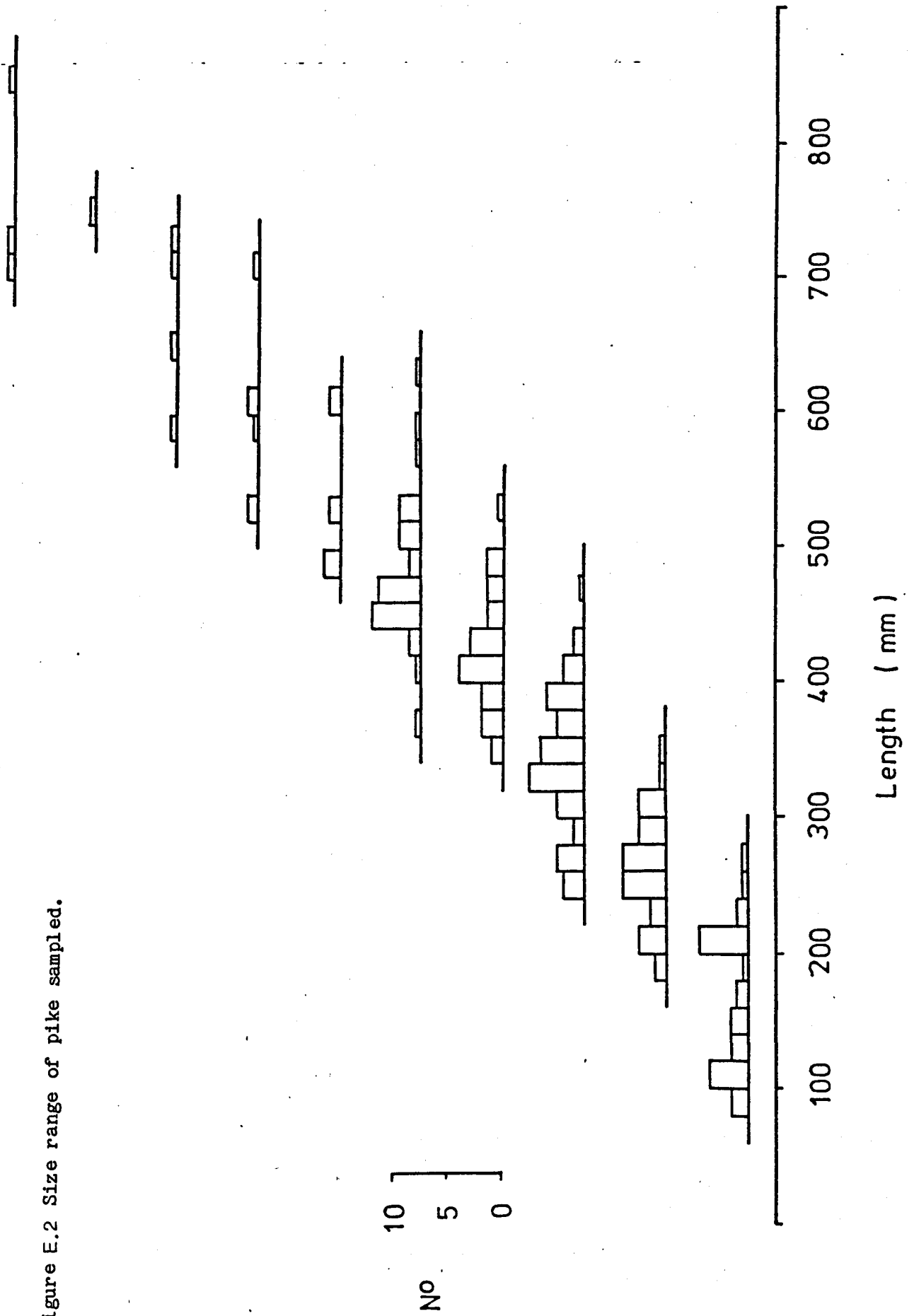


Figure E.3.1 Size of roach predated by zander, 1981-82.

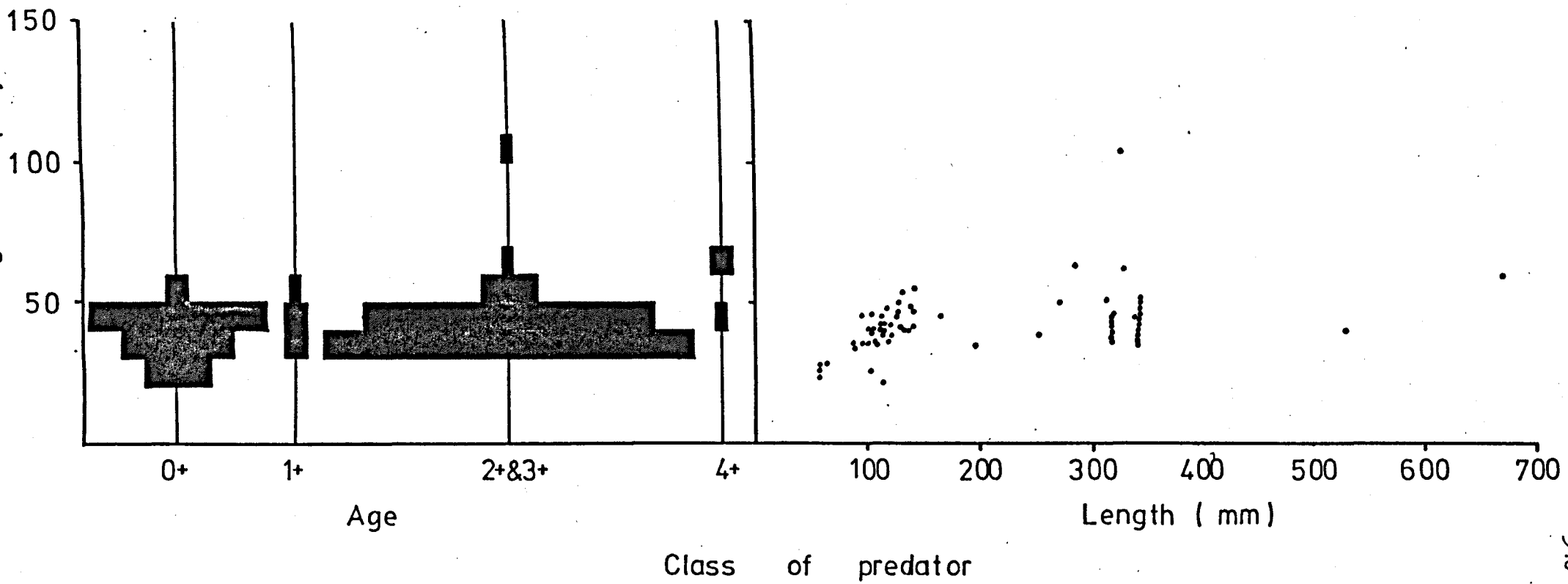


Figure E.32 Size of roach predated by zander, 1982-83.

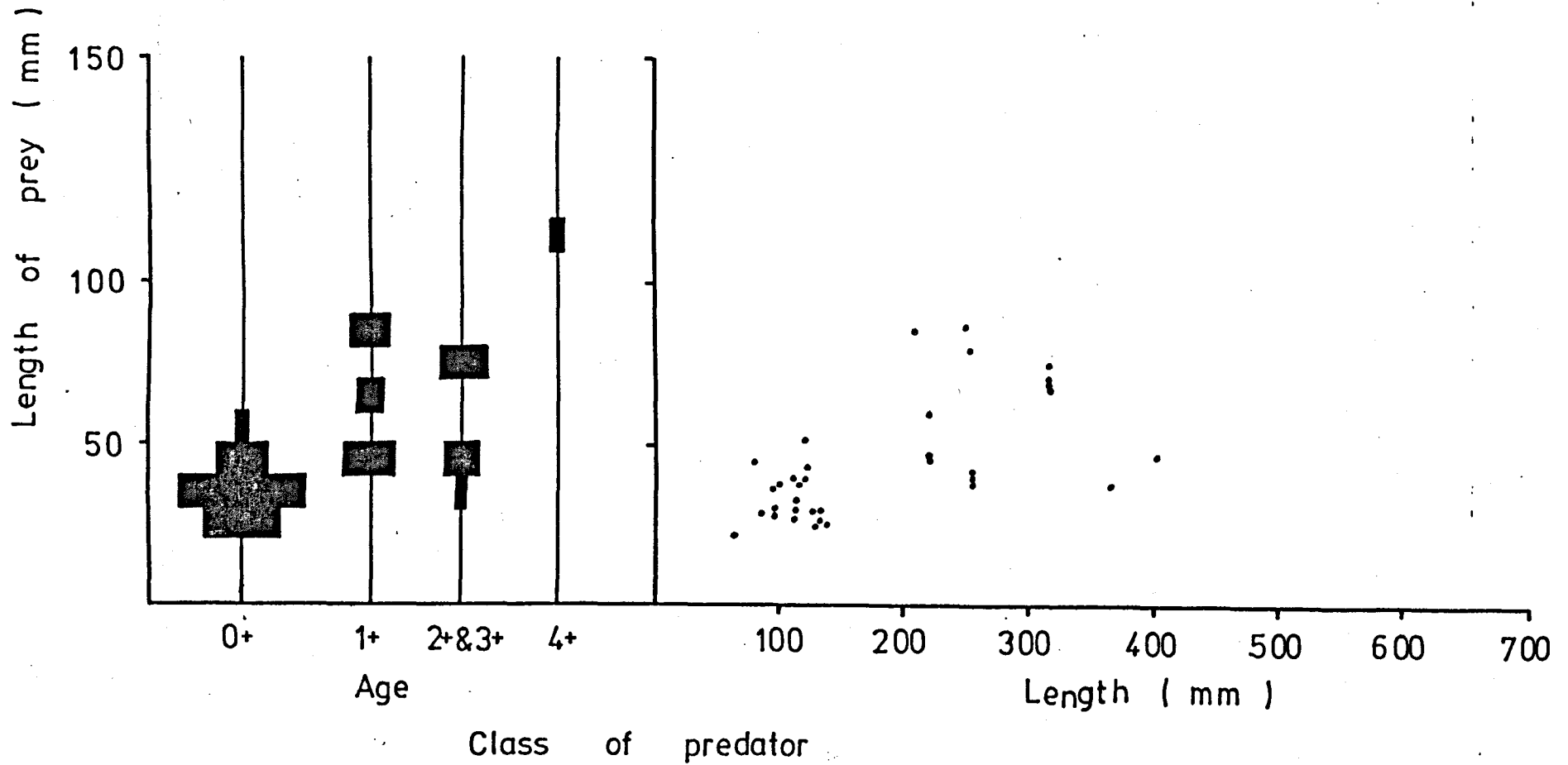


Figure E.3.3 Size of roach predated by zander, 1983-84.

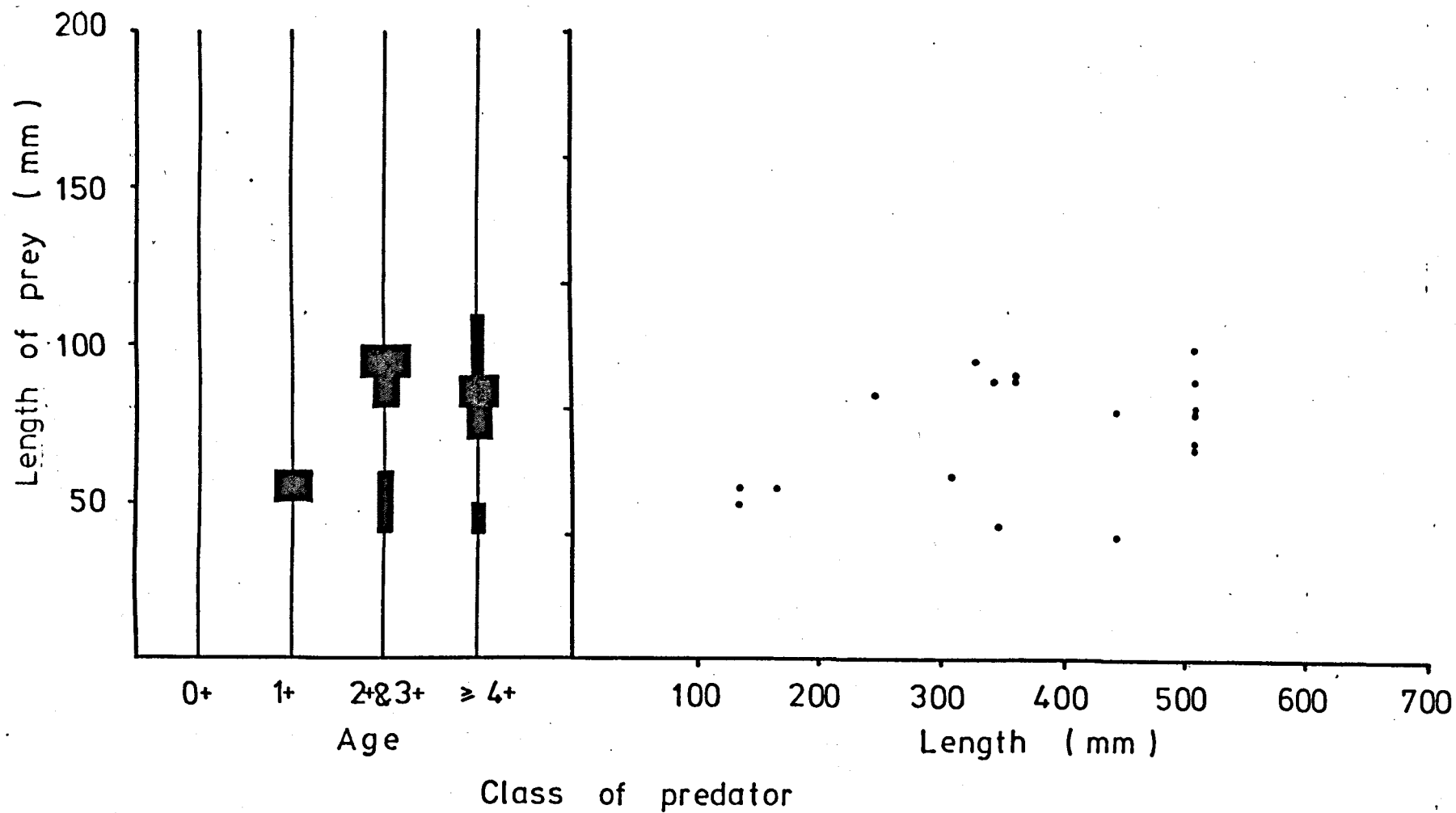


Figure E.41 Size of roach predated by pike, 1981-82.

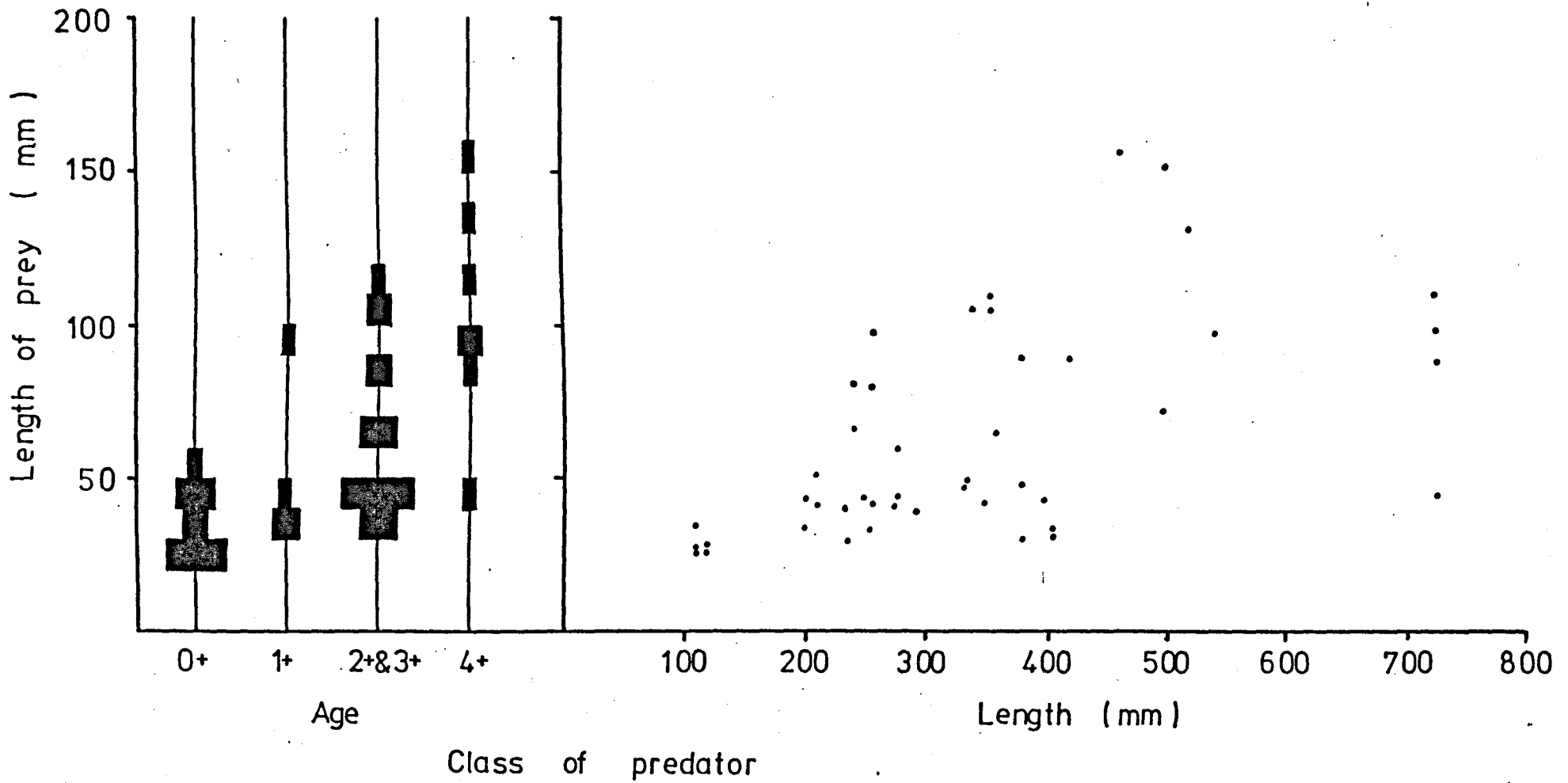


Figure E.4.2 Size of roach predated by pike, 1982-8 .

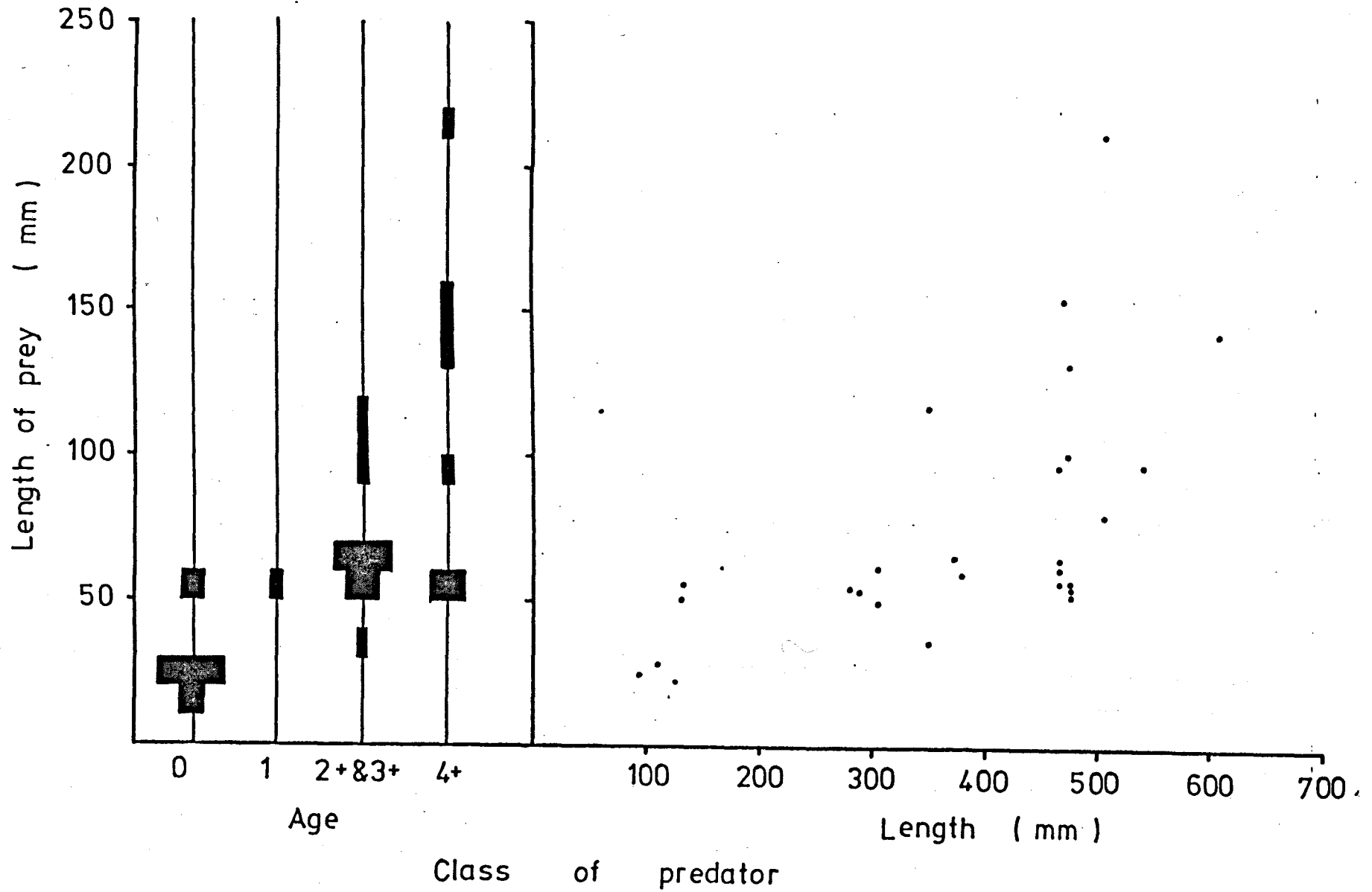
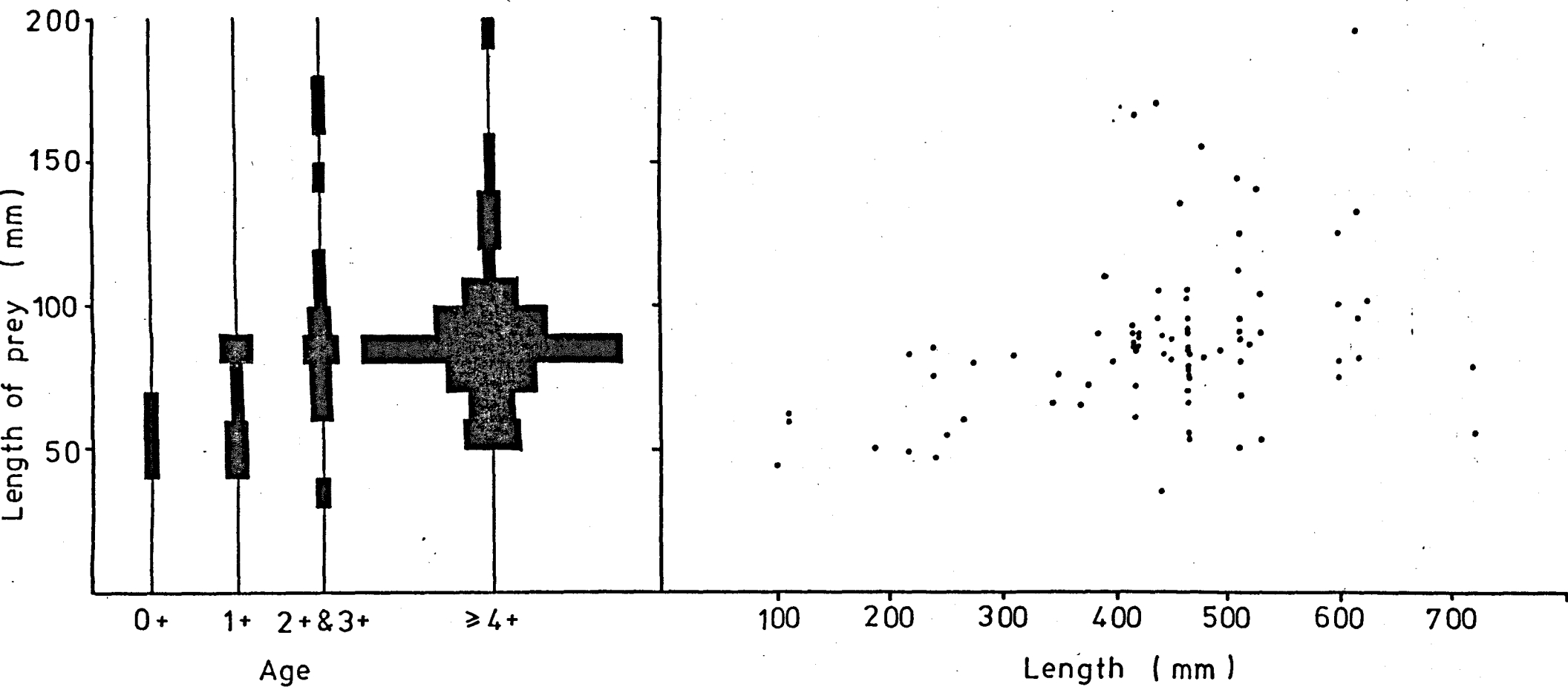


Figure E.4.3 Size of roach predated by pike, 1983-84.



Class of predator

TABLE E.1 Diet of zander by month (%wt)

	Nov to April		May to July		August to Oct	
	%wt	Rank	%wt	Rank	%wt	Rank
Roach	84.67	1	58.83	1	78.82	1
Common Bream	.63	5	10.11	4	9.82	2
Silver Bream	263	2	16.04	2		
Perch			1.71	6	4.91	3
Ruffe	6.37	3	10.34	3	4.46	4
Non Fish	.69	4	2.96	5	1.38	5
Unid Fish			.08	7	.61	6
No of Stomachs	55		61		132	

TABLE E.2 Diet of zander by month (% No)

	Nov to April		May to July		August to Oct	
	%No	Rank	%No	Rank	%No	Rank
Roach	77.61	1	4.00	2	57.76	1
Common Bream	1.49	6	.32	5	2.59	3
Silver Bream	5.97	3	.64	3		
Perch			.32	5	2.59	3
Ruffe	2.99	5	.64	3	1.72	6
Non Fish	7.47	2	93.76	1	32.76	2
Unid Fish	4.48	4	.32	5	2.59	3
No of Stomachs	55		61		132	

TABLE E.3 Diet of pike by month (%wt)

	Nov to April		May to July		August to Oct	
	%wt	Rank	%wt	Rank	%wt	Rank
Roach	85.76	1	70.78	1	78.90	1
Common Bream			3.75	3		
Silver Bream						
Perch	7.43	2	.55	7	.29	4
Ruffe	3.69	3	2.82	5	8.98	3
Sp. Loach	.29	6	.05	8	.16	5
3 Sp. Stkb	.81	5				
Eel			18.08	2		
Pike						
Zander			.84	6		
Mammals		3.11	4	11.67	2	
Non Fish	2.03	4	.004	9		
No of Stomachs	39		103		41	

TABLE E.4 Diet of pike by month (%No)

	Nov to April		May to July		August to Oct	
	%No	Rank	%No	Rank	%No	Rank
Roach	27.54	2	78.57	1	83.33	1
Common Bream			5.19	3		
Perch	4.35	3	3.25	4	2.78	3
Ruffe	1.45	5	6.49	2	5.56	2
Sp. Loach	1.45	5	.65	8	2.78	3
3 Sp. Stkb.	2.90	4				
Eel			1.95	5		
Pike						
Zander			1.30	6		
Mammals			.65	8	2.78	3
Non-Fish	60.87	1	.30	6		
Unid. Fish	1.45	5	.65	8	2.78	3
No of Stomachs	39		103		41	

TABLE E.5 Diet of zander by year (% wt)

	1980-1981		1981-1982		1982-1983		1983-1984	
	%wt	Rank	%wt	Rank	%wt	Rank	%wt	Rank
Roach	68.00	1	71.85	1	56.67	1	62.49	1
Common Bream			.44	7	4.90	4	14.07	3
Silver Bream	32.00	2	1.32	2	25.63	2	14.97	2
Perch			2.41	5			.53	5
Ruffe			6.65	3	12.04	3	7.94	4
Non-fish			6.55	4	.53	5		
Unid. fish			3.77	6	.23	6		
No of stomachs	8		172		66		21	

TABLE E.6 Diet of zander by year (%No)

	1980-1981		1981-1982		1982-1983		1983-1984	
	%No	Rank	%No	Rank	%No	Rank	%No	Rank
Roach	33.33	1	15.57	2	47.89	1	61.90	1
Common Bream			.14	7	4.23	3	9.52	3
Silver Bream	33.33	1	.69	4	1.41	6	9.52	3
Perch			.42	6			4.76	4
Ruffe			.55	5	2.82	4	14.29	2
Non fish			83.38	1	40.85	2		
Unid fish	33.33	1	1.25	3	2.82	4		
No of stomachs	8		172		66		21	

TABLE E.7 Diet of pike by year (%wt)

	1980-1981		1981-1982		1982-1983		1983-1984	
	%wt	Rank	%wt	Rank	%wt	Rank	%wt	Rank
Roach	89.78	1	69.12	1	94.70	1	45.86	1
Common Bream							3.09	4
Silver Bream								
Perch			5.64	4	1.41	3	.20	7
Ruffe			12.92	2			1.97	6
Sp. Loach	2.69	4	.09	8			.04	8
	3.76	2	.09	8			.02	9
Eel							14.88	3
Pike			4.94	5			28.38	2
Zander					3.94	2		
Mammals			6.65	3			2.56	5
Non Fish	3.71	3	.56	6			.003	10
No of stomachs	11		74		35		67	

TABLE E.8 Diet of pike by year (%No)

	1980-1981		1981-1982		1982-1983		1983-1984	
	%No	Rank	%No	Rank	%No	Rank	%No	Rank
Roach	29.17	2	46.79	1	87.80	1	73.64	1
Common Bream							7.27	3
Perch			5.50	3	4.88	2	2.73	5
Ruffe			4.59	4			8.18	2
Sp Loach	4.17	3	.92	6			.91	7
	4.17	3	1.83	5			.91	7
Eel							2.73	5
Pike			.92	6			.91	7
Zander					4.88	2		
Mammals			.92	6			.91	7
Non fish	58.33	1	37.62	2			1.82	6
Unid fish	4.17	3	.92	6	2.44	4		
No of stomachs	11		74		35		67	

TABLE E.9. Percentage of zander and pike stomachs containing fish prey in each year of the study
(only piscivorous individuals included i.e. 1+ fish and older)

		FISHING SEASON			
		1980-1981	1981-1982	1982-1983	1983-1984
Zander	No. of stomachs containing fish prey	3	23	17	5
	No. of stomachs	5	41	32	8
	% piscivores feeding on fish prey	60.0	56.1	53.1	62.5
Pike	No. of stomachs containing fish prey	6	42	24	49
	No. of stomachs	11	74	35	67
	% piscivores feeding on fish prey	45.5	56.8	68.6	73.1

APPENDIX F Derivation of age and growth

F.1 Introduction

The methods used in ageing and the calculation of growth rates are presented here.

F.2 Scales

The morphology of scales and their use in age determination has been extensively described, notably by Masterman (1923), Hartley (1947), and Jones (1953) for roach, Hofstede (1974), Goldspink (1978) and Gajdusek (1981) for common bream, Van Zalinge (1970) Brio (1970); Svardson and Molin (1973) and Fickling (1982) for Zander and Williams (1955) Frost and Kipling (1959) and Casselman 1974 for Pike.

The surface of scales used in this study are covered by ridges or circuli which are concentric and surround a focus. These circuli are often interrupted by a number of radii, of which some extend from the focus to the margin. The pattern of these rings is not uniform, a number of checks are sometimes present which, when established as of annual occurrence, correspond to the age of the fish. The main characteristics of a check are:

- a) The circuli become more closely spaced, the annuli being at the outer edge.
- b) Circuli become discontinuous or fragmented.
- c) "Cutting over" occurs whereby one or two ridges appear to cut across others.

d) The Check can be followed round the circuli pattern.

F.3 Operculae

A full description of the use of the opercular to determine age and growth, is given by Le Cren (1947). Its application to pike has been detailed by Frost and Kipling (1959) and Banks (1970) and to zander by Fickling (1982). When viewed under reflected light broad opaque zones corresponding to summer growth fade into narrow transparent winter zones. These end relatively abruptly, the annuli are located at the outer edge of the transparent zones. The patterns observable on the cleithra of pike are the same as those seen on the opercular, except that in general they appear to be more distinct.

F.4 Handling of scales

In all cases a "Key Scale" was removed from the same area on a fish. This has been shown to reduce the variation in scale size for fish of a given length (Bagenal and Tesch, 1978). This area may correspond to the location where scales were first laid down (Frost and Kipling, 1959; Priegel 1964). Zander scales were taken from just below the lateral line by the pectoral fin (Fickling, 1982), pike scales from between the dorsal fin and the lateral line (Frost and Kipling, 1959) and cyprinids scales from between the dorsal fin and lateral line (Cragg-Hine and Jones 1969). If care was taken to avoid regenerated scales, only two or three scales needed to be taken from each fish. Regenerated scales could generally be recognised in the field since the centres appear opaque.

Scales were then placed in plain envelopes bearing a unique reference number enabling subsequent collation of all the relevant data. Scales which needed cleaning before they were read were left to soak in a solution of trypsin overnight. Scales were then mounted dry between two microscope slides, so that they could be read using a "Projectina" microprojector. This was used at magnifications of x10, x20 or x30, depending on the size of the scales to be read. The distance from the centre of the scale to each annulus was measured using the graduations on the projectina screen.

F.5 Handling of opercular and cleithra

Both opercular and cleithra were dissected out in the laboratory using scalpel and tweezers. They were then placed in boiling water after which most of the surrounding tissue could be removed by rinsing under running water. These bones were most easily read after drying out, either by storing for several months or else by drying for 10 minutes at 120°C. Measurement was by an ocular microscope fitted with a micrometer. Information on growth was prepared in two main ways, back calculation and age length data. A comparison of the two techniques will enable an assessment of their validity to be made.

Annual increments in growth, obtained by subtracting the length at successive age classes the variance being given by $S^2(Y_1 - Y_2) = S^2Y_1 + S^2Y_2 - r_{12}SY_1$. SY_2 are tabulated in Table 63 and shows the correlations between successive ages for the species shown.

It is interesting to note that the correlations between size at age I and II are less than those at later ages for all species analysed, a finding also given by Kempe (1962). It is known that size at age I is important

for determining year-class strength for many species of fish (see section 2.6). A strong year-class will result when 0+ growth is good: this increased recruitment may mean that competition will be greater in later years reducing growth rates. Alternatively if there is strong size linked mortality (the smaller individuals being less fit) for 0+ fish the later growth history of a cohort may not be so strongly correlated to that of 0+ fish.

If either of these explanations are true it will mean that population structure and biomass levels will vary depending on environmental climatic conditions, since these largely determine 0+ growth rate. The result of this will be that it may often be difficult in complex ecological systems to manage fish stocks to produce consistently good angling results. Variations occurring due to climatic conditions that are largely outside the control of fishery managers (Pearce, 1983).

Significant differences in the annual growth increments and length at a particular age are summarised in Tables G4 to G8, Appendix G.

The determination of the size of individual fish at various times in its past is possible by using the checks or annuli present on a persistent hard structure (ie. back calculation) this depends on there being a mathematical relationship between the size of an individual and a particular structure which maintains a growth history in the form of yearly checks. The techniques have been reviewed by Lee (1920), Graham (1929), Lagler (1956), Hile (1970), Weatherley (1972), Bagenal (1974) and Bagenal and Tesch (1978). To use this technique the age and length of the fish must be established, and measurements made of the total radii of the hard structure and of the annuli.

F.6 Back calculation of growth rates

An algorithm describing the relationship between a persistent hard structure and fish lengths must be constructed before the back calculation of growth rate can be attempted. This relationship may take many forms, for example it may pass through the origin, it may be linear, curved, sigmoidal or a complex of such relationships (Wooland and Jones, 1975). The relationship is also sometimes shown to vary between years (Duncan, 1980) or between year classes (Carlander, 1981). The normal method of determining this relationship is to regress body length (L) and structure length (S), if necessary using a transformation to fit a curve directly, such as power series or polynomial (Thompson, 1923). The more common forms of the function $L = F(S)$ are

$$L = bS \quad \text{---(1)}$$

$$L = a + bS \quad \text{---(2)}$$

$$\text{Log } L = \log a + bs (\log S) \quad \text{---(3)}$$

$$L = a + bS + cS^2 \quad \text{---(4)}$$

(1) Lea (1910)

(2) Lee (1920)

(3) Monastyrsky (1930) log transform

(4) Mann (1973)

The regressions are fitted by means of least squares using the standard regression procedures (Sokal and Rohlf, 1969). Although Ricker (1975) recommends a G.M. regression, its use has not generally been accepted by fishery statisticians (Bagenal and Tesch, 1978).

On substituting body length (L_n) and scale radius (S_n) at age t in equations (1), (2) and (3), equations used in back calculation can then be derived.

$$L_n = \frac{S_n^2}{S} \quad -(5)$$

$$L_n = \frac{S_n}{S} (L-a) + a \quad -(6)$$

$$\text{Log } L_n = \frac{\text{Log } S_n (\text{Log } L-a)}{\text{Log } S} + a \quad -(7)$$

It is also possible to calculate a , which corresponds to the intercept, directly rather than by regression analysis. This is of benefit since in the least squares regression techniques the slope, is optimised rather than the intercept. By avoiding regression analysis and calculating a directly, this suboptimisation of a can be avoided. Duncan (1980) calculated a using the following equation for this reason.

$$L_i = a + (L_j - C) S_i/S_j \quad -(8)$$

L = Length of Fish

$L_n =$ Length of fish at age t

$S =$ Radius of Scale or hard structure

$S_n =$ Radius of n th annulus

$a, b, c,$ are constants

$L_i =$ Length of fish at age i

$L_j =$ Length of fish at age j

$S_i =$ Radius of i th annulus

$S_j =$ Radius of j th annulus

This method was not used in this work as length frequency data and back calculations all showed good agreement.

To determine the best form of the function $L_n = F(S_n, S, L)$ normally entails a process of trial and error. This is then followed by a subjective decision on which is the best form of the function. To overcome this problem, (Bartlett et al, 1984) used an analysis of covariance, (Sokal & Rohlf, 1969) to distinguish between trends in the data. This was achieved by comparing the relationship between body length and indication structure size. Regression analysis was first performed on the data as a whole. It was then performed on groups of the data divided accordingly to

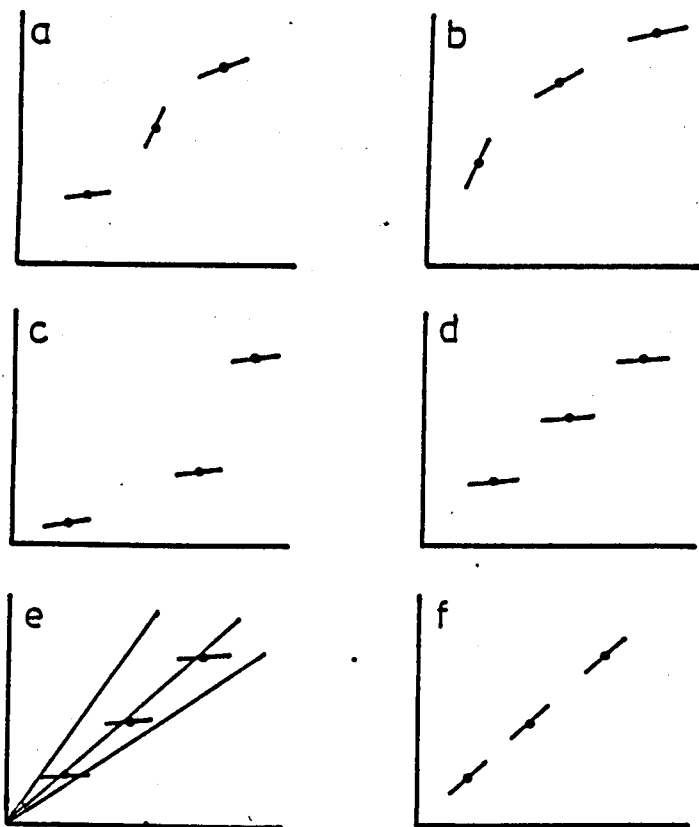
a third variable (i.e. the covariance) which was the age of fish, at capture or year - class. finally on the mean values of body length and indicator structure size for each age group on year class.

The analysis of covariance distinguishes four models as described by Bartlett et al (1984).

- a) The slopes of the lines fitted through the separate subsets of the data, differ significantly from one another (figure F.1.A). This data will need transforming or fitted to a curve before any back calculations can be performed.
- b) The slopes of the lines through individual age groups do not differ significantly, but their mean values show a significant deviation from a straight line (figure F.1.B). Back - calculation not being possible with the data of this form.
- c) If neither a) nor b) are true the slope of the means may differ significantly from the parallel slope of the lines within age group (figure F.1.C). Back calculation can be performed if such a result is due to the function for each fish deviating from the mean by a constant degree, so that the mean slope was merely a summary of all such lines.

Table F.1.1 summarises the analysis of the body length hard structure relationship.

Figure F.1 Possible mathematical relationships of body length to hard structure length (Bartlett et al, 1983).



F.7 Relationship between hard structure and body length.

Roach

A linear relationship was found between roach body length and scale radius (Table F.1.2). This is a similar result to that of Burroughs and Kennedy (1979), although Mann (1973) found the best fit to be given by a parabola of the form $Ln = a + bS + cS^2$.

The relationships between body length and scale radius are given in Table F.2.

Common Bream

The relationship between body length and scale length was found to be linear (Table F.1.3) the scale being measured along the ventral field of the scale since Goldspink (1978) had shown this to produce least variation. This was similar to the findings of Vastnetsov et al (1957), Oliva (1958) Kennedy and Fitzmaurice (1968) and Gajdusek (1981).

Zander

It was found that the relationship between body length and hard structure was linear, for both scales and opercular bones, (Table F.1.4) findings similar to those of Fickling (1982) and Van Zalinge (1970). Scales were measured along the cranial radius to the outer edge, as described by Svardson and Molin, (1973), since this gave least variation. Opercular bones were measured from the centre to the dorsal margin (Le Cren, 1974).

TABLE F.1.1 Compilation of the analysis of covariance table; relationship of hard structure to body length (after Barlett et al, 1983)

Source	Degrees of freedom	Sums of squares	Mean square	F ratio	*
Total	N-1	$S_t(y,y)$	ss/df	ms/rms	Fig. (f)
Due to the overall line (b_t)	1	$\frac{(S_t(x,y))^2}{S_t(x,x)}$	ss/df	ms/rms	
Difference of b_a and b_m	1	$1 - m - a$	ss/df	ms/rms	Fig. (d)
Deviation of the means from a straight line (b_m)	K-2	m	ss/df	ms/rms	Fig. (c)
Between slopes (b_i)	K-1	$a - i$	ss/df	ms/rms	Fig. (a)
Residual	N-2K	i	ss/df	-	-

Where N = number of fish in the sample; K = number of age groups present in the sample; ss = sum of squares; df = degrees of freedom; ms = mean square; rms = residual ms.

* Appropriate model if the F ratio is significant.

TABLE F.1.2 Analysis of covariance of relationship between roach body length and scale radius.

Source	Degrees of freedom	Sums of squares	Mean square	F ratio	*
Total	86	586,097.80	6,815.10	.013	
Due to the overall line (b_t)	1	511,892.48	511,892.48	55.77*	
Difference of b_a and b_m	1	9,178.65	9,178.65	9.24	
Deviation of the means from a straight line (b_m)	2	1,985.87	992.94	14.41	
Between slopes (b_i)	3	226.39	68.91	.08	
Residual	79	62,814.40	795.12		

TABLE F.1.3 Analysis of covariance of relationship between common bream body length and scale radius.

Source	Degrees of freedom	Sums of squares	Mean square	F ratio *
Total	63	463,203.73	7.352.44	.0158
Due to the overall line (b_t)	1	465,287.46	465,287.46	226.4363
Difference of b_a and b_m	1	2,056.15	2,056.15	0.5272
Deviation of the means from a straight line (b_m)	5	19,500	3,900	2.4799
Between slopes (b_i)	6	9,435.7	1,572.6	2.4114
Residual	50	32,607.66	652.15	-

TABLE F.1.4 Analysis of covariance of relationship between zander body length and scale radius.

Source	Degrees of freedom *	Sums of squares	Mean square	F ratio
Total	78	679,757.01	8,714.83	.02
Due to the overall line (b_t)	1	546,321.12	546,321.12	15.99* f
Difference of b_a and b_m	1	34,167.30	34,167.30	7.02
Deviation of the means from a straight line (b_m)	2	9,731.25	4,865.62	3.57
Between slopes (b_i)	3	4,087.91	1,362.64	1.13
Residual	71	85,449.43	1,203.51	-

TABLE F.1.5 Analysis of covariance of relationships between pike body length and scale radius.

Source	Degrees of freedom	Sums of squares	Mean square	F ratio *
Total	97	16,2316.15	1,673.36	.001
Due to the overall line (b_t)	1	1,249,094.82	1,249,094.82	498.50*f
Difference of b_a and b_m	1	2,505.73	2,505.73	1.23
Deviation of the means from a straight line (b_m)	3	8,129.04	2,032.26	9.39
Between slopes (b_l)	4	649.26	216.42	.15
Residual	87	129,700.74	1,483.36	-

TABLE F.2 Relationship between scale radius and body length

	body length = b.scale radius + a		correlation coef.
	a	b	r
Roach	28.0179	1.7401	.9283
Common Bream	11.1720	1.9227	.9334
Zander	-8.1325	.1866	.9382
Pike	24.9349	7.9152	.9329

body length in mm
scale radius in mm x 20

The location of the first annuli on the opercular bones was often indistinct, compared to the succeeding ones or to the corresponding ones in the scales; sometimes being obliterated by the spongy growth around the centre. This results in a greater variance in size of fish at age I calculated from operculars, than from scales. This made it difficult to compare 0+ growth using operculars. It was not thought desirable to calculate size at age I using Ford-Walford plots as done by Fickling (1982) and Mann (1976), since size at age II, although in later years there was a strong correlation between size at age of adjoining years (Table F.13).

Pike

The back-calculation of length at age I for pike using the opercular bones was not always possible, since the first annulus was often obscured by an area of spongy growth at the centre. Fish could be more easily aged when cleithra and scales were used as well as operculae. First year growth is not closely correlated to length at the end of the second year (see Table F.13) and so it was not thought desirable to calculate size at age I using Ford-Walford plots. This limits the usefulness of opercular bones since size at age I is important in that it has implications for year-class strength.

The posterior field of the scale was used in the back calculation process since this gave a linear relationship with body length (Table F.1.5) as also shown by Frost and Kipling (1959). Whilst Frost and Kipling noted "That the use of scales for the back calculation of the growth of individual fish was found in general to be unsatisfactory primarily an

account of the ill defined boundary of many of the annuli ... " it was possible that in the case of "... large numbers of fish them means of scale readings agree well with means obtained by other methods".

Since three methods were used for ageing pike it was generally possible to determine whether annuli on the scales were false or not since both operculars (Frost and Kipling, 1959; Banks, 1970; Mann 1978) and cleithra (Casselmann, 1974) had been shown to be reliable methods. The problems of overcrowding or indistinct annuli making back calculation difficult was minimal, due to the young age of most of the fish. Back calculation was performed using the posterior field of the scale.

F.8 Calculation of mean growth rates and correction for the Rosa-Lee phenomenon

Even if every effort has been made to accurately determine the body length hard structure relationship it is possible that on substituting the radius annuli into the equation for body length that an error in the back calculated lengths becomes apparent. Back calculated lengths may not agree with those measured directly from the population, in particular they may become smaller the older the fish from which they are back calculated, i.e. the Rose-Lee phenomenon [Thompson (1923) Van Oosten (1929), Graham (1929), Hile (1936) Vouk (1956), Kuznetsova (1957), Jones (1958, 1960), Taylor (1958), Bryuzgin (1961, 1963), Lapin (1969) and Ricker (1969)] although not always taken into account in investigations of growth.

The populations which are the subject of this study are known to have gradually recovered from a low level of abundance in the past few years. It would be expected that growth rates might also have changed. This means that it is not possible to establish whether the Rose-Lee phenomenon is

present by looking for trends in the lengths of the various year classes at a particular age (Duncan, 1980). However, since data exists from different growing seasons for most age classes of roach, common bream, zander and pike (Tables F3, F4, F5 and F6) it is possible to compare the size of a particular year-class at a particular age from different aged fish. This will permit the Rose-Lee phenomenon to be investigated and allowed for in any subsequent analysis. The mean size at each age for all year-classes of roach, pike and zander were compared for the 1980-81, 1982-83 and 1983-84 growing seasons by an analysis of variance. (Sokal and Rohlf (1969)) and by a test for regression since "when the means (of Y) increase or decrease slightly as X increases they (the means of Y) may not be different enough for the mean square among groups to be significant by anova yet a significant regression can be found." (Sokal and Rohlf 1969), see Table F.7. Only in the case of roach aged I was any evidence of the Rose-Lee phenomenon found. In this case reverse Rose-Lee in that the size of the older fish got smaller with time. I year old roach were therefore corrected using an average value for the percentage decrease in size per year.

Although all species and age classes were treated statistically to show whether the Rosa-Lee Phenomenon was present, data are presented only for those cases where a positive result was found. Otherwise a vast amount of data would need to be presented which would add nothing to the main objectives of the study.

This analysis permitted the pooling of the data from each sampling season to be made, after correction for the Rose-Lee phenomenon. This pooling of data is valuable since for some species' year-classes the amount of data available would not have permitted comparisons to be made.

TABLE F.3.1 Back-calculated growth of roach, 1980-1981

Year- Class	Age	Length at annulus formation (mm)						
		I	II	III	IV	V	VI	VII
1979	1+	x	55.1					
		s	7.755					
		n	111					
1978	2+	x	57.0	87.4				
		s	6.455	13.132				
		n	82	82				
1977	3+	x	57.7	88.6	117.0			
		s	5.474	10.202	10.559			
		n	22	23	23			
1976	4+	x	55.6	80.6	105.8	134.4		
		s	7.230	8.834	13.382	13.150		
		n	10	10	10	10		
1975	5+	x	62.7	85.6	106.5	126.2	150.1	
		s	2.317	7.757	11.881	10.486	12.965	
		n	6	10	10	10	10	
1974	6+	x	57.2	84.2	101.0	116.0	140.0	160.8
		s	2.317	8.886	10.658	16.769	17.321	23.173
		n	6	6	6	6	6	6

TABLE F.3.3 Back calculated growth of roach, 1982-1983

Year-class	Age		Length at annu lus formation (mm)					
			I	II	III	IV	V	VI
1982	1+	x	58.6					
		s	5.662					
		n	94					
1981	2+	x	56.9	85.9				
		s	5.626	8.097				
		n	128	127				
1980	3+	x	59.3	87.7	114.5			
		s	4.950	7.268	9.063			
		n	68	68	70			
1979	4+	x	57.7	87.6	114.6	133.7		
		s	4.920	9.156	9.093	11.151		
		n	15	15	15	15		
1978	5+	x	60.7	82.3	107.0	127.0	147.8	
		s	10.372	16.820	18.565	21.380	29.398	
		n	4	4	4	4	4	

TABLE F 4.1 Back calculated growth of Common Bream 1981-1982

Year-class	Age		Length at annulus formation (mm)										
			I	II	III	IV	V	VI	VIII	IX	X	XI	
1978	3+	x	55.3	95.7	137.2								
		s	8.321	19.531	33.902								
		n	7	6	6								
1976	5+	x	53.8	100.3	152.5	194.5	235.000						
		s	8.714	12.781	19.734	32.734	47.099						
		n	8	8	8	8	8						
1975	6+	x	64.5	107.5	153.2	197.8	240.5	294.3					
		s	11.581	17.591	19.666	20.527	27.067	24.756					
		n	29	28	28	28	28	28					
1974	7+	x	61.3	98.5	144.8	195.0	233.8	279.6	36.6				
		s	9.322	17.996	21.711	22.041	23.987	22.442	24.945				
		n	10	11	11	11	11	11	11				
1973	8+	x	58.8	97.8	150.2	196.6	234.8	271.0	309.0	340.6			
		s	6.494	7.537	10.556	23.443	20.749	25.478	27.477	32.494			
		n	19	19	19	19	19	19	19	19			
1971	10+	x	56.6	92.8	147.8	193.4	239.0	280.4	322.0	348.6	379.2	405.2	
		s	6.309	6.611	15.320	19.982	23.335	22.075	21.296	17.743	14.481	14.325	
		n	5	5	5	5	5	5	5	5	5	5	
1970	11+	x	53.1	100.6	142.3	184.3	226.6	263.9	298.7	329.1	353.6	381.1	405.1
		s	6.846	15.059	19.510	16.348	17.508	27.141	27.139	23.635	18.548	13.569	14.455
		n	9	9	9	9	9	9	9	9	9	9	9

TABLE F4.2

Back calculated growth of Common Bream 1982-1983

Year-class	Age		Length at annulus formation (mm)								
			I	II	III	IV	V	VI	VIII	IX	
1980	2+	x	54.9	104.0							
		s	14.152	18.916							
		n	36	36							
1979	3+	x	67.9	109.5	174.9						
		s	17.414	11.390	23.157						
		n	10	12	12						
1978	4+	x	67.0	115.6	165.6	209.2					
		s	10.607	11.781	26.492	31.650					
		n	5	5	5	5					
1977	5+	x	62.2	102.8	154.8	221.7	276.3				
		s	13.805	18.563	23.634	37.265	38.821				
		n	6	6	6	6	6				
1976	6+	x	70.2	109.5	154.8	202.1	249.0	300.1			
		s	11.890	16.178	23.561	27.427	32.107	33.030			
		n	11	12	12	12	12	12			
1975	7+	x	63.7	105.5	152.0	199.4	238.9	291.4	332.9		
		s	10.461	16.231	18.403	23.998	25.429	24.288	26.150		
		n	28	30	30	30	30	30	30		
1974	8+	x	59.1	91.2	139.3	189.5	237.3	282.9	326.1	357.5	
		s	9.387	9.373	19.176	21.113	27.660	27.503	30.385	22.227	
		n	10	12	13	13	13	13	13	12	
1973	9+	x	59.5	101.5	166.7	199.2	244.1	282.5	311.2	349.6	376.7
		s	14.222	16.936	33.714	37.775	46.613	41.454	41.049	28.496	36.245
		n	10	12	13	13	13	13	13	13	12

TABLE F.5.1 Back calculated growth of zander 1980-81

Year class	Age		length at annulus formation (mm)	
			I	II
1979	1+	x	109.5	
		s	11.214	
		n	4	
1978	2+	x	105.4	199.6
		s	-	-
		m	1	1

TABLE F5.2 Back calculated growth of zander 1981-82

Year class	Age		length at annulus formation (mm)					
			I	II	III	IV	V	VI
1980	1+	x	111.7					
		s	13.191					
		n	12					
1979	2+	x	109.8	213.3				
		s	11.676	19.443				
		n	12	13				
1978	3+	x	138.6	240.0	315.3			
		s	6.435	2.616	-			
		n	2	2	1			
1977	4+	x	104.0	185.9	264.2	317.5		
		s	-	-	-	-		
		n	1	1	1	1		
1976	5+	x	118.4	193.0	284.0	380.2	469.5	
		s	8.103	17.683	32.448	24.154	14.659	
		n	2	4	4	4	4	
1975	6+	x	120.9	215.9	290.2	492.9	578.7	617.8
		s	25.649	81.600	-	63.640	1.655	.941
		n	3	2	1	2	2	2

TABLE F5.3 Back calculated growth of zander, 1982-83

Year class	Age		length at annulus formation (mm)							
			I	II	III	IV	V	VI	VII	
1981	1+	x s n	122.8 12.995 14							
1980	2+	x s n	113.7 14.335 4	225.2 31.269 5						
1979	3+	x s n	109.9 .2899 2	212.9 .750 2	301.5 8.987 2					
1978	4+	x s n	99.7 - 1	195.5 - 1	288.5 - 1	337.7 - 1				
1977	5+	x s n		206.4 - 1	304.0 - 1	360.1 - 1				
1976	6+	x s n								
1975	7+	x s n	115.9 - 1	205.3 - 1	326.2 - 1	394.1 - 1	515.5 - 1	578.6 - 1	641.7 - 1	
1974	8+	x s n		145.1 - 1	297.5 - 1	449.8 - 1	519.6 - 1	614.9 - 1	678.4 - 1	

TABLE F.6.1 Back calculated growth of pike, 1980-81

Year-class	Age		Length at annulus formation (mm)		
			I	II	III
1979	1+	x	179.8		
		s	29.265		
		n	5		
1978	2+	x	156.2	253.8	
		s	-	-	
		n	1	1	
1977	3+	x	214.2	342.5	419.6
		s	-	-	-
		n	1	1	1

TABLE F.6.2 Back calculated growth of pike, 1981-82

Year class	Age		length at annulus formation						
			I	II	III	IV	V	VI	VII
1980	1+	x	193.6						
		s	28.466						
		n	17						
1979	2+	x	188.1	287.5					
		s	29.277	26.4549					
		n	21	26					
1978	4+	x	201.2	311.8	399.9				
		s	30.986	34.518	52.753				
		n	5	6	6				
1977	4+	x	174.2	321.2	384.5	454.3			
		s	14.756	32.675	43.159	62.0495			
		n	4	4	4	4			
1976	5+	x							
		s							
		n							
1975	6+	x							
		s							
		n							
1974	7+	x			331.3	433.1	549.4	636.6	680.2
		s			-	-	-	-	-
		n			1	1	1	1	1
1972	9+	x		260.8		495.8	604.2	694.5	766.8
		s		-		-	-	-	-
		n		1	1	1	1	1	1

TABLE F6.3 Back calculated growth of pike 1982-83

		length at annulus formation (mm)						
		I	II	III	IV	V	VI	
1981	1+1	x s n	186.7 35.018 6					
1980	2+	x s n	208.7 27.069 11	298.1 35.135 8				
1979	3+	x s n	181.2 17.855 6	286.6 50.605 4	374.5 22.987 5			
1978	4+	x s n	198.8 25.187 4	265.5 44.138 2	367.7 35.592 4			
1977	5+	x s n	218.7 - 1			502.7 - 1	631.0 1	
1976	6+	x s n		282.9 - 1	372.8 - 1	475.6 - 1	527.0 - 1	591.2 - 1

TABLE F7.1 Summary of analysis for Rosa-Lee Phenonemon by analysis of variance and regression.

Roach at age I

Year class	Source of variation		(Fs values)
	Amongst fish of different ages	Linear regression	Deviations from regression
1981	.210 ns	-	-
1980	.298 ns	282.322 *	128.826 ***
1979	7.730 ***	12.214 ns	1.632 ns
1978	2.584 *	.356 ns	3.290 *
1977	3.334 *	10.836 ns	.779 ns
1976	8.004 **	222.600 *	.072 ns
1975	.350 ns	1.431 ns	.288 ns
1974	2.736 *	2.203 ns	1.709 ns

TABLE F.7.2 Summary of analysis for Rosa-Lee Phenomenon by analysis of variance and regression.

Roach at age II			
Year class	Source of variation		(Fs values)
	Amongst fish of different ages	Linear regression	Deviations from regression
1980	.252 ns	-	-
1979	.245 ns	1.207 ns	.222 ns
1978	1.670 ns	.002 ns	2.503 ns
1977	.420 ns	.537 ns	.546 ns
1976	2.423 ns	2017.007 *	.002 ns
1975	37.172 ***	.005 ns	73.988 ***
1974	.249 ns	1.074 ns	.240 ns

TABLE F.8 Two tailed t-test for significant difference between a mean (Lt/Lt) and a constant, where c=1. Length of roach at age n (Lt) and age n+1 (Lt).

AGE	n	x	s	t _s
I	18	.9677	.0351	3.9043**
II	14	1.0016	.0313	.1913 ns
II	11	1.0037	.0413	.2971 ns
IV	8	.9884	.0744	.4125 ns
V	5	.9806	.0788	.5505 ns

$$H_0 : u = u$$

$$t_s = \frac{y - u}{s / n}$$

Figure F.2 Analysis of Rosa-Lee Phenomenon (Roach). Length of year-classes plotted against no of annuli after check.

- 1983
- I 1982
- ◇ 1981
- × 1980
- 1979
- + 1978
- ⊙ 1977
- * 1976
- ⊖ 1975
- ⊕ 1974

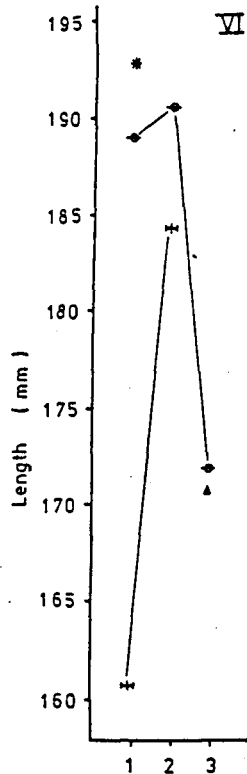
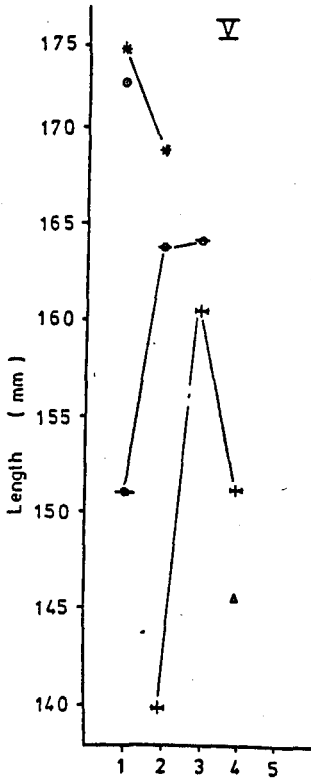
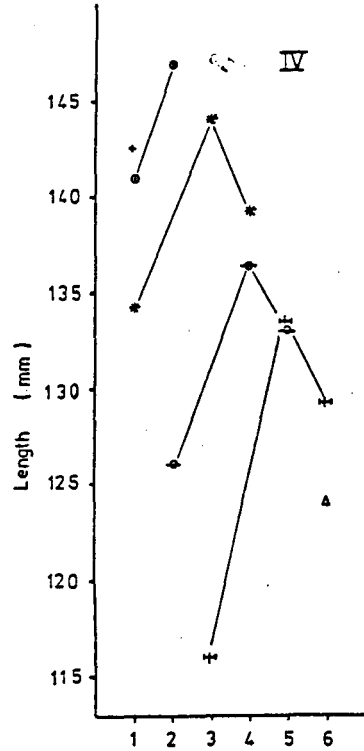
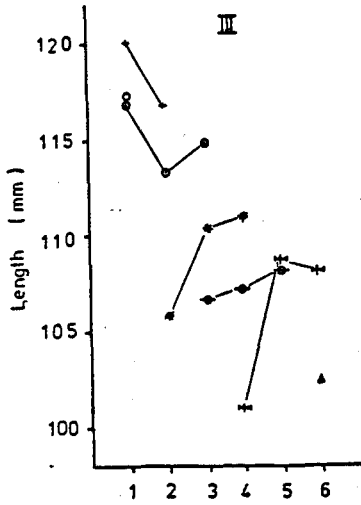
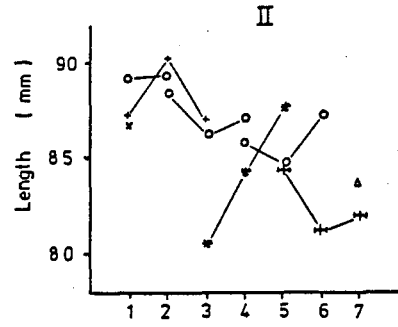
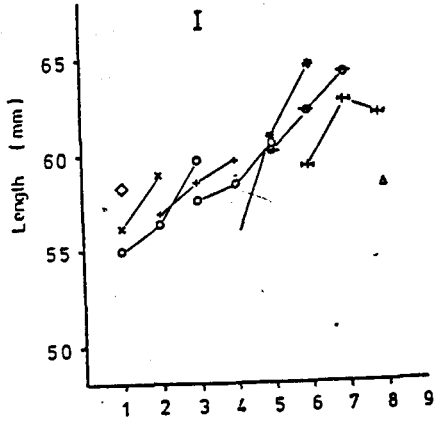
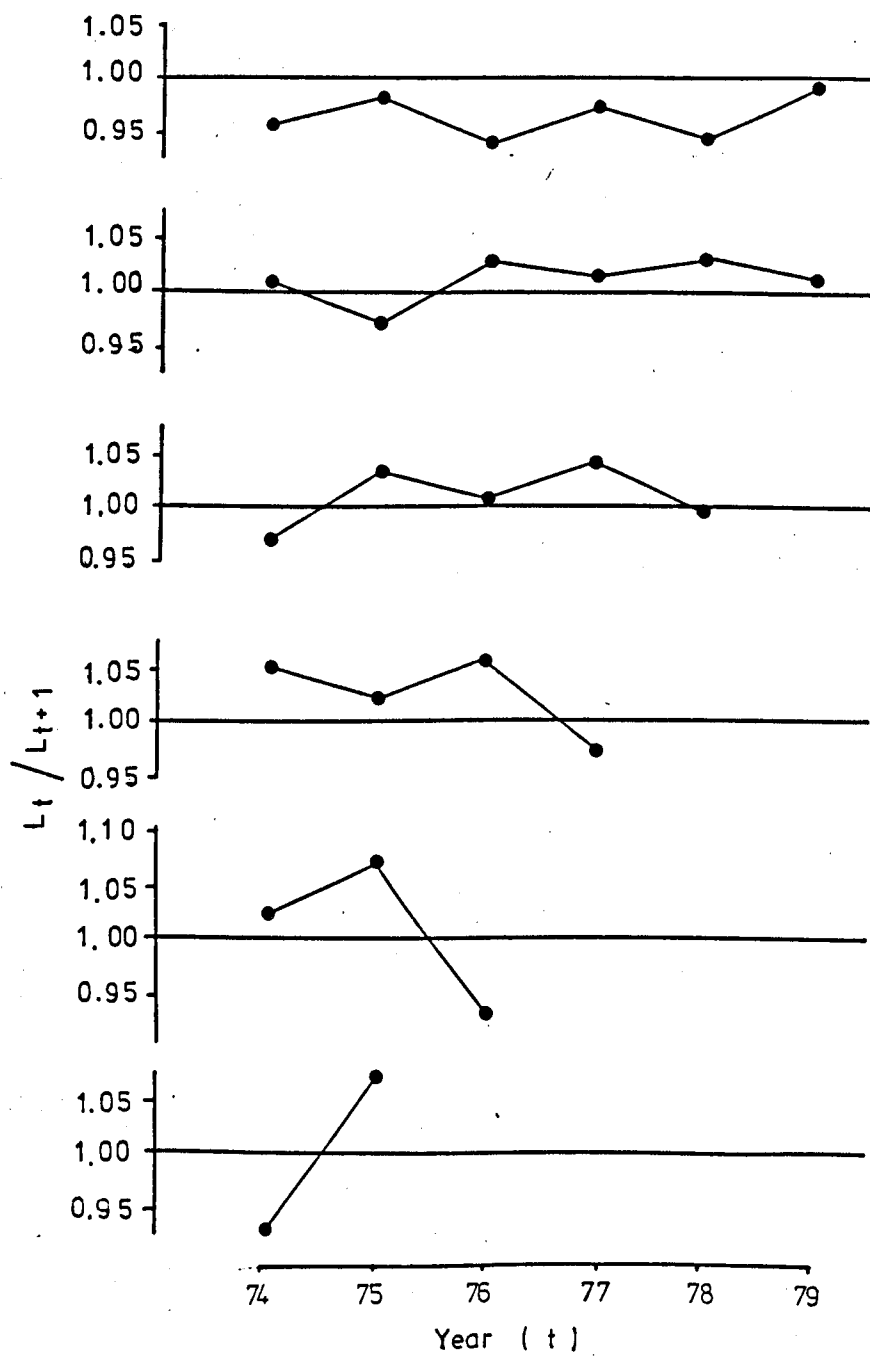


Figure F.3 Analysis of Rosa-Lee phenonemon (Roach) L_t/L_{t+1} against t .



Tables F.7.1 and F.7.2 show the summary of the Anova. Only fish of age I were corrected since a significant difference between lengths calculated from fish of different ages was only found for these fish (Table F.8). Figures F.2 and F.3 show this trend as fish lengths are calculated from older fish.

The growth rates of each year-class of roach, common bream, zander and pike are presented in Tables F.9, F.10, F.11 and F.12.

TABLE F9 Back Calculated length (mm) roach obtained from measurements of scales (I corrected for Rosa-Lee)

Year Class		Length at age							
		I	II	III	IV	V	VI	VII	VIII
1982	x	58.6							
	95% CI	57.4-59.8							
	n	94							
1981	x	56.2	85.9						
	95% CI	55.2-57.2	84.5-87.4						
	n	219	127						
1980	x	56.6	87.2	114.5					
	95% CI	55.9-57.3	86.1-88.3	112.3-116.6					
	n	267	212	70					
1979	x	55.0	89.3	117.3	133.7				
	95% CI	54.3-55.7	88.2-90.3	115.7-118.8	127.6-139.9				
	n	445	351	227	15				
1978	x	54.8	88.6	118.8	141.0	147.8			
	95% CI	54.2-55.4	87.1-90.1	116.3-121.5	136.6-145.3	101.0-194.5			
	n	234	238	159	70	4			
1977	x	53.8	87.2	115.3	143.8	172.4			
	95% CI	52.6-55.0	85.1-89.3	112.4-118.1	139.6-147.9	165.9-178.9			
	n	76	77	79	56	26			
1976	x	53.5	85.6	109.4	138.6	169.9	192.9		
	95% CI	51.5-55.5	83.1-88.1	106.2-112.6	134.7-142.5	165.8-174.0	187.7-198.1		
	n	50	59	54	55	48	33		
1975	x	53.2	86.2	107.5	132.6	161.2	190.2	215.1	
	95% CI	51.5-54.9	83.6-88.8	103.7-111.3	128.2-137.0	155.7-166.7	182.5-197.9	205.8-224.5	
	n	45	48	48	48	48	38	23	
1974	x	49.6	82.5	106.2	126.4	150.1	171.7	194.7	214.7
	95% CI	47.2-51.3	79.1-85.8	101.8-110.5	119.7-133.1	142.3-157.8	162.8-180.6	186.6-202.8	204.2-225.2
	n	20	20	20	20	20	20	14	9
1973	x		81.1	101.3	121.0	141.0	170.8	197.7	216.2
	95% CI		71.6-90.7	92.9-109.7	109.0-133.0	123.6-158.4	154.9-186.8	178.3-217.1	196.7-236.7
	n		7	7	7	7	6	6	6
Mean		54.6	86.0	111.3	133.9	157.1	181.4	202.5	215.5

TABLE F 10 Back calculated lengths (mm) of common bream obtained from measurement scales

Year	Class	Length at age									
		I	II	III	IV	V	VI	VII	VII	IX	X
1981	x	62.9									
	95% CI	59.9-65.9									
	n	96									
1980	x	54.5	105.5								
	95% CI	52.2-56.7	101.0-109.8								
	n	43	45								
1979	x	61.9	109.5	174.9							
	95% CI	56.6-67.3	102.3-116.7	160.2-189.6							
	n	8	12	12							
1978	x	56.8	99.8	150.4	209.2						
	95% CI	52.2-61.4	86.9-112.6	128.0-172.1	169.9-248.5						
	n	10	9	11	5						
1977	x	62.2	102.8	154.8	221.7	276.3					
	95% CI	53.9-70.4	83.4-122.3	130.0-179.6	182.6-260.8	235.6-317.1					
	n	6	6	6	6	6					
1976	x	59.3	105.8	153.9	199.1	243.4	300.1				
	95% CI	55.0-63.7	83.2-128.4	143.8-163.9	185.5-219.6	225.5-261.3	279.1-321.1				
	n	12	20	20	20	20	12				
1975	x	64.1	106.6	152.6	198.6	239.7	292.8	332.9			
	95% CI	61.1-67.0	102.2-111.1	147.6-157.6	192.8-204.5	232.8-246.6	286.3-199.2	323.1-342.7			
	n	57	58	58	58	58	58	30			
1974	x	60.3	94.5	141.8	192.0	235.7	281.4	322.0	357.5		
	95% CI	55.8-64.9	88.6-100.5	133.3-150.3	183.1-201.0	224.9-246.5	270.9-291.9	309.9-334.0	344.0-370.9		
	n	18	24	24	24	24	24	23	13		
1973	x	59.0	99.3	152.9	197.6	238.5	275.7	309.9	347.9	376.7	
	95% CI	55.4-62.7	94.9-103.6	145.8-159.9	187.0-208.3	226.5-250.7	263.9-287.5	298.0-321.8	333.6-362.1	353.6-399.7	
	n	29	31	32	32	32	32	32	30	12	
1972	x	73.5	111.5	166.3	215.8	263.5	295.3	327.5	348.6	384.8	415.5
	95% CI	51.6-95.4	65.4-157.6	127.4-205.1	171.9-259.6	226.4-300.6	267.9-322.6	306.2-348.8	326.5-370.7	368.1-401.4	396.4-434
	n	4	4	4	4	4	4	4	4	4	4

TABLE F.10(ctd)

Year Class	Length at age										
	I	II	III	IV	V	VI	VII	VII	IX	X	
1971	x	56.6	92.8	147.8	193.4	239.0	280.4	322.0	356.0	379.2	405.2
	95% CI	48.8-64.4	84.6-101.0	128.8-166.8	168.6-218.2	210.0-268.0	253.0-307.8	295.5-348.5	335.7-376.3	361.2-397.2	387.4-423
	n	5	5	5	5	5	5	5	5	5	5
1970	x	53.1	100.6	142.6	184.3	226.8	263.9	298.7	329.1	353.6	381.1
	95% CI	47.8-58.4	89.0-112.2	126.5-158.6	171.7-196.9	213.0-240.6	243.0-284.8	277.8-319.6	310.9-347.3	339.3-367.8	370.7-391
	n	9	9	9	9	9	9	9	9	9	9
Mean	60.4	102.6	153.8	201.3	245.4	284.2	318.8	347.8	373.6	400.6	

TABLE F.11 Back calculated lengths (mm) of zander obtained from measurements of scales

Year Class	Length at age								
	I	II	III	IV	V	VI	VII	VII	IX
1981	x 95% CI n	122.3 116.8-127.8 21	229.2 198.0-260.4 4						
1980	x 95% CI n	112.4 107.3-117.5 24	211.5 196.9-226.0 13	310.5 296.2-324.9 7					
1979	x 95% CI n	111.3 106.9-115.8 23	214.8 206.3-223.3 18	325.5 293.3-357.8 5	417.2 359.7-474.7 3				
1978	x 95% CI n	114.2 90.0-138.3 4	218.8 179.6-257.9 4	301.9 131.3-472.5 2	337.7 - 1				
1977	x 95% CI n	98.1 88.0-108.2 4	185.7 160.4-211.1 4	268.8 224.2-313.3 4	359.8 296.9-422.8 4	479.7 292.3-667.0 2	531.1 374.6-687.6 2		
1976	x 95% CI n	118.4 45.6-191.3 2	193.0 164.9-221.1 4	284.0 224.4-343.5 4	380.2 341.8-418.6 4	469.5 446.2-492.8 4			
1975	x 95% CI n	119.7 86.1-153.2 4	212.3 68.3-356.4 3	308.2 79.0-537.3 2	460.0 - 3	557.6 467.0-648.3 3	604.8 548.5-661.0 3	669.6 315.6-1023.5 2	
1974	x 95% CI n		145.1 - 1	297.5 - 1	450.0 - 1	494.9 181.1-808.8 2	574.9 66.6-1083.2 2	630.6 23.7-1237.5 2	614.1 - 1
Mean		113.8	201.3	299.5	400.8	500.4	570.3	650.1	614.1
									647.5

TABLE F.12 Back calculated lengths (mm) of pike obtained from measurements of scales.

Year Class	Length at age						
	I	II	III	IV	V	VI	
1982	x 95% CI n	195.5 184.2-206.9 18					
1981	x 95% CI n	192.2 163.5-220.9 8					
1980	x 95% CI n	194.5 185.2-203.7 39	287.4 270.6-304.1 18	381.3 360.5-402.1 12			
1979	x 95% CI n	190.0 172.3-189.7 46	283.0 274.3-291.8 44	354.5 339.7-369.3 25	424.0 406.5-441.5 19		
1978	x 95% CI n	203.4 189.7-217.2 16	300.5 280.6-320.4 16	396.4 374.9-417.9 17	476.0 430.3-521.7 6	528.8 458.9-598.7 6	
1977	x 95% CI n	191.4 168.2-214.6 9	273.6 300.8-346.9 7	367.2 327.1-407.3 6	465.6 425.5-505.7 8	590.3 78.7-701.9 3	613.8 264.8-962.8 2
1976	x 95% CI n		290.5 144.8-402.4 3	342.1 151.2-533.0 3	432.5 241.6-623.4 2	522.1 376.9-767.3 3	593.3 541.6-645.0 3
Mean		194.5	287.0	368.3	449.5	547.1	603.6

TABLE F.13 Correlation (r) between length at successive ages

Species	I v II	II v III	III v IV	IV v V	V v VI	VI v VII	VII v VIII	VIII v IX
Roach	.5644	.8988	.8223	.8902	.8992	.8794	.6368	
Common Bream	.4882	.7186	.7508	.8375	.8215	.8674	.8603	.9260
Pike	.6588	.7581	.7504	.8884				
Zander	.4253	.8116	.7887	.5857				

TABLE F.14 Growth in length (mm) of roach between successive annuli

Year	Class	I-II	II-III	III-IV	IV-V	V-VI
1981	x	29.7281				
	n	127				
	s ²	52.7480				
1980	x	30.6736	27.2118			
	n	212	70			
	s ²	51.3491	15.9653			
1979	x	34.3013	27.9955	16.4548		
	n	351	227	15		
	s ²	70.1131	27.4384	47.4105		
1978	x	33.8078	30.2252	22.1664	6.7786	
	n	238	159	70	4	
	s ²	96.8823	61.4984	109.4612	243.000	
1977	x	33.3627	28.0837	28.4893	28.6168	
	n	76	79	56	26	
	s ²	56.9431	38.7866	76.6832	54.5681	
1976	x	32.1125	23.8142	29.2290	31.2595	22.9830
	n	50	54	54	48	33
	s ²	64.0229	26.9892	66.3303	44.2179	41.5775
1975	x	32.9798	21.2917	25.1458	28.5625	28.9967
	n	48	48	48	48	38
	s ²	55.7286	40.1852	74.5196	28.5625	110.7510
1974	x		24.3000	20.2500	23.6500	21.6500
	n		20	20	20	20
	s ²		18.0798	72.7012	56.6048	69.6428
1973	x		20.1429	19.7143	20.000	29.8333
	n		7	7	7	6
	s ²		20.6680	57.1723	87.6367	70.7591

TABLE F.15 Growth in length (mm) of common bream between successive annuli.

Year- Class		I-II	II-III	III-IV	IV-V	V-VI	VI-VII	VII-VIII
1980	x	51.0227						
	n	43						
	s ²	163.6516						
1979	x	47.5625	65.4167					
	n	8	12					
	s ²	99.8925	286.9361					
1978	x	42.8778	50.3131	59.109				
	n	9	9	5				
	s ²	215.3123	567.3268	518.8136				
1977	x	40.6667	52.0000	66.8333	54.6667			
	n	6	12	6	6			
	s ²	263.8239	272.6506	624.8187	472.6137			
1976	x	46.4667	48.0500	45.2000	44.3500	45.6593		
	n	12	20	20	20	12		
	s ²	178.0921	225.506	365.9433	447.3506	478.9863		
1975	x	43.4298	45.94828	46.0690	41.0172	53.1207	40.0908	
	n	57	58	58	58	58	30	
	s ²	223.4578	182.9150	219.7329	202.2192	228.7863	172.0682	
1974	x	38.1212	47.2917	50.2083	43.6667	45.7083	40.5399	35.5050
	n	18	24	24	24	24	23	13
	s ²	157.4411	195.8140	214.3591	194.8569	226.8594	193.7713	206.2182
1973	x	40.2236	53.61690	44.7500	40.87500	37.1875	34.2188	37.9604
	n	29	31	32	32	32	32	30
	s ²	123.2384	190.0513	387.7664	334.957	390.8019	605.4694	374.859
1972	x	38.000	54.7500	49.5000	47.7500	31.7500	32.2500	21.1000
	n	4	4	4	4	4	4	4
	s ²	640.1775	419.3067	345.3410	229.4644	149.8133	75.6796	85.2948
1971	x	36.200	55.0000	45.6000	45.6000	41.4000	41.6000	34.000
	n	5	5	5	5	5	5	4
	s ²	42.7781	132.8553	174.3394	162.7871	185.4386	125.2675	148.8701
1970	x	47.9944	42.000	41.77778	42.4444	37.1111	34.7778	30.4444
	n	9	9	9	9	9	9	9
	s ²	172.9800	187.927	171.279	97.4678	258.8389	195.3898	191.5514

TABLE F.16 Growth in length (mm) of zander between successive annuli (scales).

Year- Class		I-II	II-III	III-IV	IV-V	V-VI	VI-VII	VII-VIII
1981	x	106.9						
	n	4						
	s ²	419.3713						
1980	x	99.1	99.0					
	n	13	7					
	s ²	252.0483	243.7154	112.8972				
1978	x	104.6	83.1					
	n	4	2					
	s ²	519.0222	207.9664					
1977	x	87.6	83.1	91.0	120.7	51.4		
	n	4	4	4	2	2		
	s ²	208.6963	214.9706	402.3300				
1976	x	74.6	91.0	96.2	89.3			
	n	2	4	4	4			
	s ²	256.4724	434.2166	205.3437	110.4001			
1975	x	92.7	95.9			47.1	64.7867	
	n	3	2			3	2	
	s ²	2770.5137	1615.3610					
1974	x					79.9	55.7	
	n					2	2	
	s ²							

TABLE F.17 Growth in length (mm) of pike between successive annuli

Year Class		I-II	II-III	III-IV	IV-V	V-VI
1982	x	195.5				
	n	18				
	s ²	524.4383				
1981	x	192.2				
	n	8				
	s ²	1179.0646				
1980	x	194.5	92.9	94.0		
	n	39	18	12		
	s ²	807.2718	679.7766	533.6350		
1979	x	181.0	102.0	71.5	69.5	
	n	46	44	25	19	
	s ²	853.0555	572.3146	548.9964	291.6879	
1978	x	203.4	97.0	92.3	83.3	152.8
	n	16	16	16	6	6
	s ²	668.9887	790.1119	775.1954	409.2054	
1977	x	191.4	132.4	72.6	69.2	124.7
	n	9	7	6	8	3
	s ²	911.2437	541.5773	638.3130	921.3718	
1976	x			93.6	110.9	89.6
	n			3	2	2
	s ²			2553.2952	5442.4819	

APPENDIX G Growth Data

G.1 Growth from age data

Growth from age data is also presented, for assessing the accuracy of back-calculated lengths. This was prepared by ageing a sample of fish. All the older fish were aged but only a proportion of the more abundant younger age classes. An age-length key was then used to calculate from the length frequency data the mean size of each year-class. Bagenal and Tesch (1978) states that the calculation of mean length at particular age using just the sub-sample produced unacceptable errors.

Growth curves obtained by ageing and lengthening fish on each sampling occasion have been prepared (Figures 28, 29, 30 and 31). These are less useful than the back calculated data, since they are confined to the years of the study. It is therefore, not possible to show any trends in growth rate linked to changes in environmental conditions of population densities. they are useful, however, in that they can be used to judge the accuracy of the back calculated data.

Figure G.1 Growth curves from age/length data, roach.

Figure G.2 Growth curves from age length data, common bream.

- 1983
- I 1982
- ◇ 1981
- x 1980
- 1979
- + 1978
- ⊙ 1977
- * 1976
- ⊖ 1975
- † 1974

Figure G.2

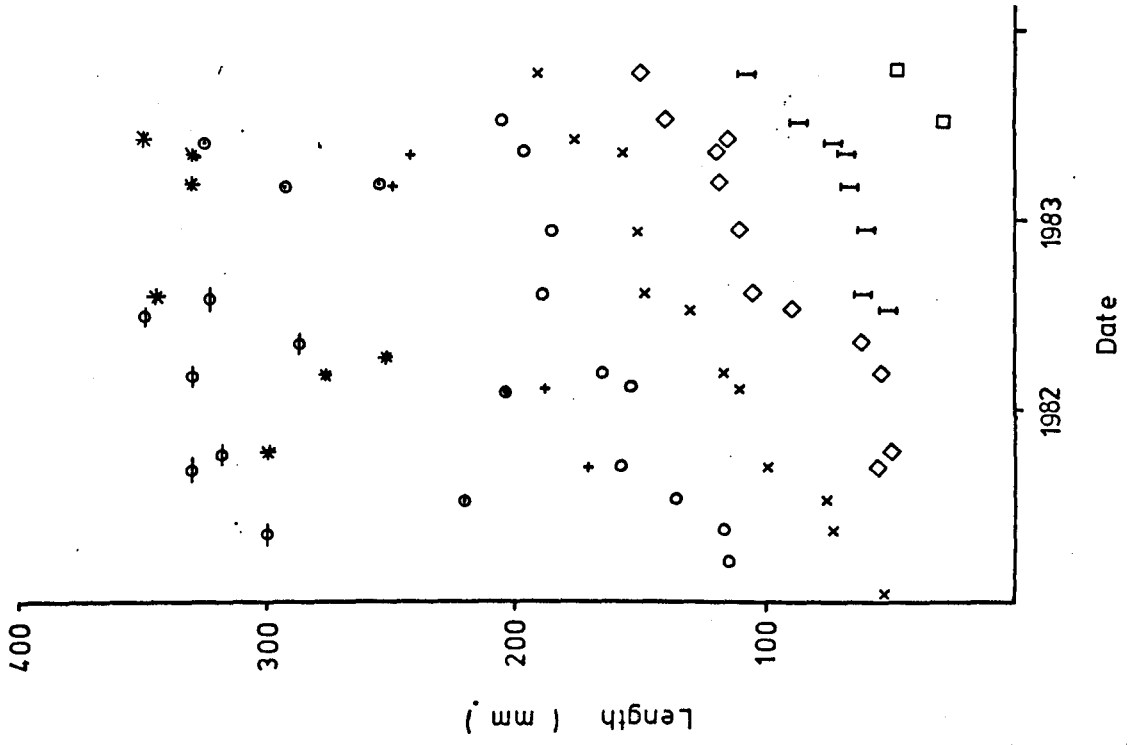


Figure G.1

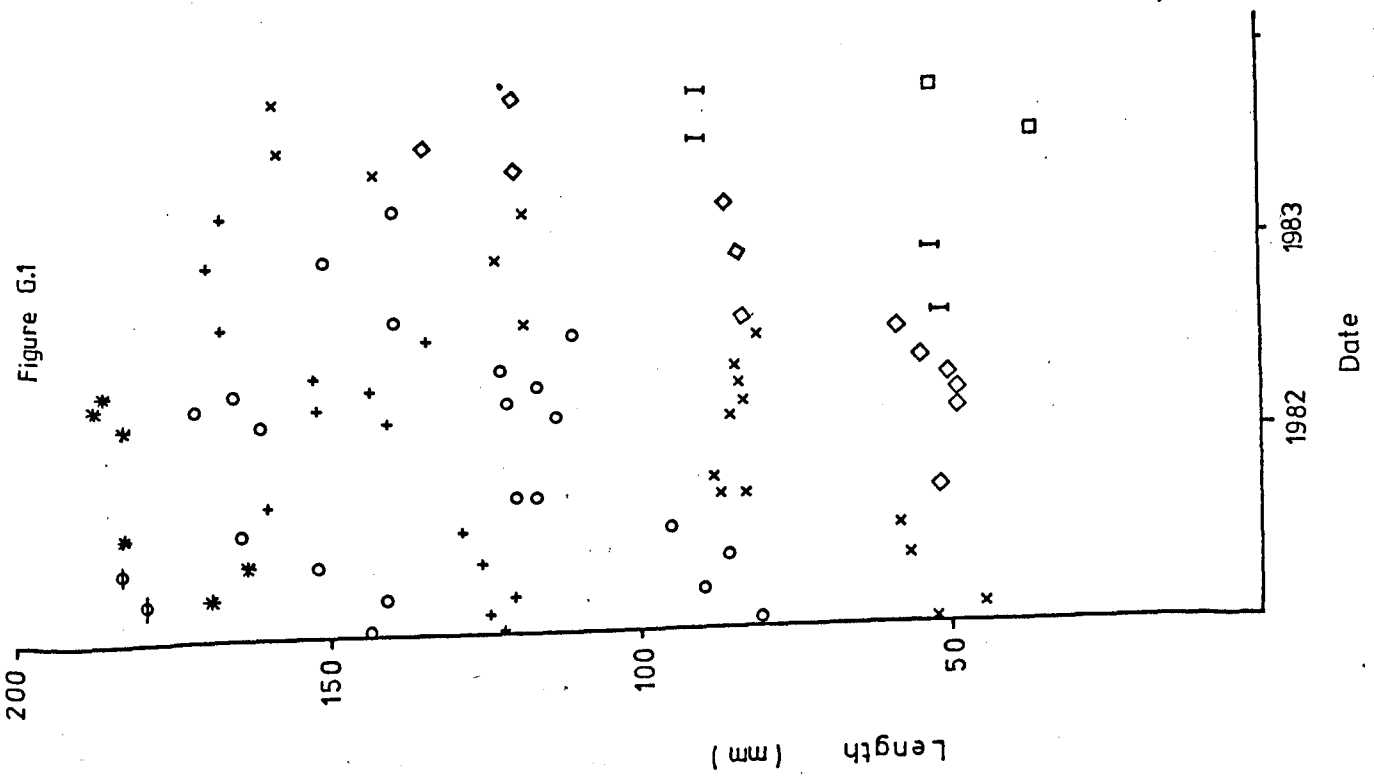


Figure G.3 Growth curves from age/length data, zander.

Figure G.4 Growth curves from age/length data, pike.

- 1983
- I 1982
- ◇ 1981
- × 1980
- 1979
- ⋄ 1978
- ⊙ 1977
- * 1976
- ⊖ 1975
- ⊕ 1974

Figure G.3

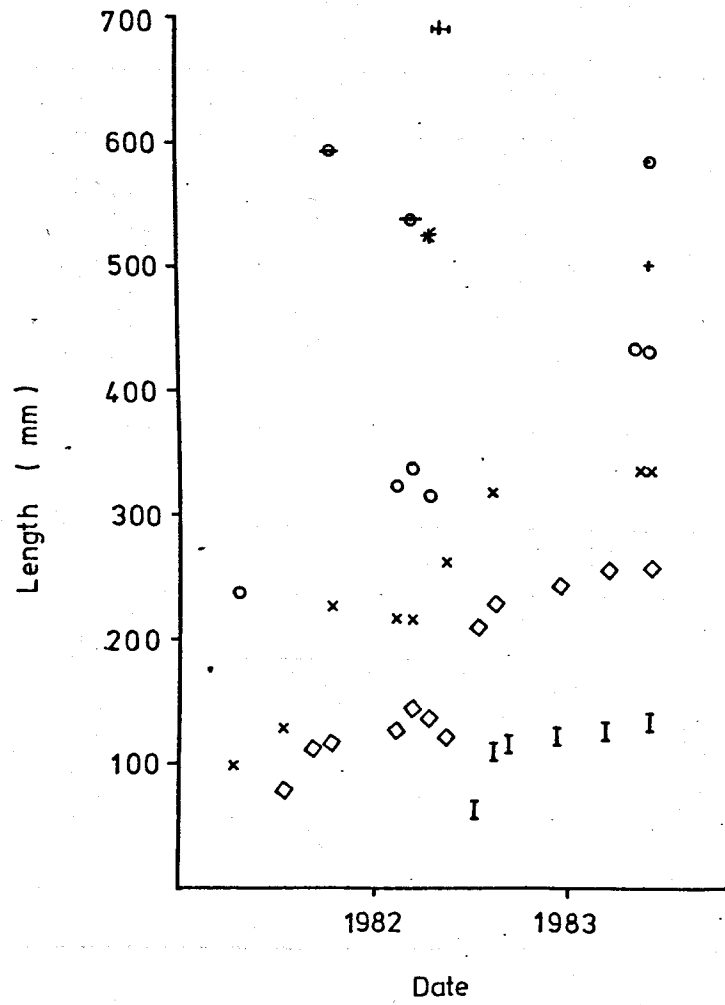


Figure G.4

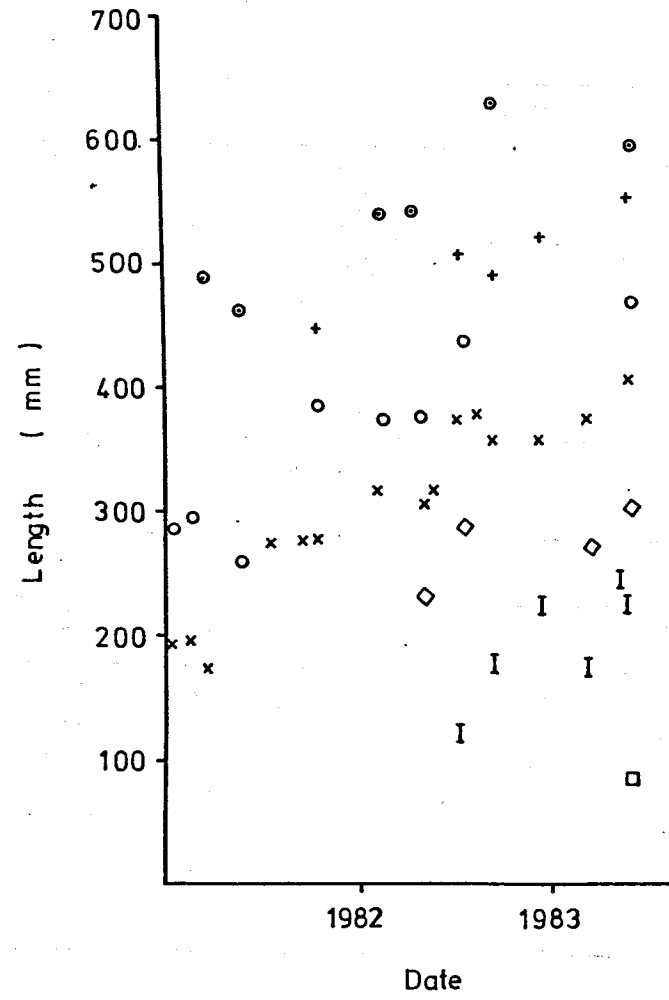


TABLE G.1 A comparison of roach growth using the growth standard of Hickley and Dexter

AGE	Length (mm)											
	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	Mean	
I	50.0		49.6	53.2	53.5	53.8	54.8	55.0	56.6	56.2	58.6	54.6
II	91.9	81.1	82.5	86.2	85.6	87.2	88.6	89.3	87.2	85.9		86.0
III	127.0	101.3	106.2	107.5	109.4	115.3	118.8	117.3	114.5			111.3
IV	156.4	121.0	126.4	132.6	138.6	144.8	141.0	133.7				133.9
V	181.1	141.0	150.1	161.2	169.9	172.4						158.9
VI	201.7	170.8	171.7	190.2	192.9							181.4
VII	219.0	197.7	194.7	215.1								202.5
VIII	233.5	216.7	214.7									215.5

Percentage of growth standard											
AGE	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	
I	50.0		99.2	106.4	107.0	107.6	109.6	110.0	113.2	112.4	117.2
II	91.9	88.2	89.8	93.8	93.1	94.9	96.4	97.2	94.9	93.5	
III	127.0	79.8	83.6	84.6	86.1	90.8	93.5	92.4	90.2		
IV	156.4	77.4	80.8	84.8	88.6	91.9	90.2	86.1			
V	181.1	77.9	82.9	89.0	93.8	95.2					
VI	201.7	84.7	85.1	94.3	95.6						
VII	219.0	90.3	88.9	98.2							
VIII	233.5	92.6	91.9								

TABLE G.2 A comparison of common bream growth using the growth standard of Hickley and Dexter (19)

AGE	Length (mm)													
	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	MEAN	
I	50.0	53.1	56.6	73.5	59.0	60.3	64.1	59.3	62.2	56.8	61.9	54.5	62.9	60.4
II	97.2	100.6	92.8	111.5	99.3	94.5	106.6	105.8	102.8	99.8	109.5	105.5		102.6
III	142.0	142.6	147.8	166.3	152.9	141.8	152.6	153.9	154.8	150.4	174.9			153.8
IV	184.3	184.3	193.4	215.8	197.6	192.0	198.6	199.1	221.7	209.2				201.3
V	224.3	226.8	239.0	263.5	238.5	235.7	239.7	243.4	276.3					245.4
VI	262.2	263.9	280.4	295.3	275.7	281.4	292.8	300.1						284.2
VII	298.1	298.7	322.0	327.5	309.9	322.0	332.9							318.8
VIII	332.0	329.1	356.0	348.6	347.9	357.5								347.8
IX	364.1	353.6	379.2	384.8	376.7									373.6
X	390.6	381.1	405.2	415.5										400.6

AGE	PERCENTAGE OF GROWTH STANDARD												
	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	
I	50.0	106.2	113.2	147.0	118.0	120.6	128.2	118.6	124.4	113.6	123.8	109.0	125.8
II	97.2	103.5	95.5	114.7	102.2	97.2	109.7	108.8	105.8	102.7	112.7	108.5	
III	142.0	100.4	104.1	117.1	107.7	99.9	107.5	108.4	109.0	105.7	123.2		
IV	184.3	100.0	104.9	117.1	107.2	104.2	107.8	108.0	120.3	113.5			
V	224.5	101.1	106.6	117.5	106.3	105.1	106.9	108.5	123.2				
VI	262.2	100.6	106.9	112.6	105.1	107.3	111.6	114.4					
VII	298.1	100.2	108.0	109.9	104.0	108.0	111.7						
VIII	332.0	99.1	107.2	105.0	104.8	107.7							
IX	364.1	97.1	104.1	105.7	103.5								
X	390.6	97.6	103.7	106.4									

TABLE G.3 A comparison of pike growth using the growth standard of Hickley and Sutton(1984)

AGE	Length (mm)								
	1976	1977	1978	1979	1980	1981	1982	Mean	
I	199		191	203	190	195	192	196	95
II	357	291	274	301	283	287			287
III	483	342	367	396	355	381			368
IV	584	433	466	476	424				450
V	664	522	590	529					547
VI	728	593	614						570

AGE	Percentage of growth standard								
	1976	1977	1978	1979	1980	1981	1982		
I	199		96.0	102.0	95.5	98.0	96.5	98.5	
II	357	81.5	76.8	84.3	79.3	80.4			
III	483	70.8	76.0	82.0	73.5	78.9			
IV	584	74.1	79.8	81.5	72.6				
V	664	78.6	88.9	79.7					
VI	728	81.5	84.3						

TABLE G.4.1 . Comparison between lengths by Tukey-Kramer method

loach age I, all Fish combined

Ranked lengths of year classes	Ranked length of year classes							
	1975	1976	1977	1978	1979	1981	1980	1982
975	-	4.0330	3.6918	3.1948	3.0702	3.2124	3.1628	3.5579
976	.2730	-	3.5739	3.0579	2.9275	3.0763	3.0244	3.4355
977	.6244	.6244	-	2.5913	2.4360	2.6130	2.5517	3.0277
978	1.5643	1.5643	.9399	-	1.5849	1.8453	1.5193	2.3967
979	1.7731	1.7731	1.1487	1.2088	-	1.6201	1.5193	2.2279
981	3.0012	3.0012	2.3768*	1.4369	1.2281	-	1.7893	2.4201
980	3.3640*	3.3640*	2.7396*	1.7997*	1.5909*	.3628	-	2.3539
982	5.4412*	5.4412*	4.8168*	3.8769*	3.6681*	2.4400*	2.0772	-

TABLE G.4.2 Comparisons between lengths by Tukey-Kramer method

Roach age II, all Fish combined									
Ranked lengths of year classes	Ranked length of year classes								
	1973	1974	1976	1981	1975	1977	1980	1978	1979
1973	-	13.5136	12.3013	11.9469	12.4498	12.1478	11.8211	11.8004	11.7460
1974	1.3071	-	7.9621	7.4027	8.1898	7.7229	7.1980	7.1641	7.0741
1976	4.4504	3.1432	-	4.8482	5.9813	5.3242	4.5294	4.4752	4.3298
1981	4.7941	3.4870	.3438	-	5.2137	4.4444	3.4529	3.3815	3.1865
1975	5.0446	3.7375	.5943	.2505	-	5.6590	4.9187	4.8689	4.7355
1977	6.0520	4.7448	1.6016	1.2578	1.0073	-	4.0944	4.0344	3.8724
1980	6.1024	4.7953	1.6521	1.3083	1.0578	.0505	-	2.9060	2.6766
1978	7.4370	6.1298	2.9866	2.6428	2.3923	1.3850	1.3346	-	2.5839
1979	8.1392	6.8321	3.6888	3.3451*	3.09455	2.0872	2.0368	.7022	-

TABLE G.4.3 Comparisons between lengths by Tukey-Kramer method

Roach age III, all Fish combined								
Ranked lengths of year classes	Ranked length of year classes							
	1973	1974	1975	1976	1980	1977	1979	1978
1973	-	17.3396	15.9747	15.8614	15.6520	15.5707	15.1519	15.2486
1974	4.8643	-	10.5085	10.3353	10.0110	9.8835	9.2096	9.3677
1975	6.1935	1.3292	-	7.8326	7.3994	7.2259	6.2727	6.5026
1976	8.1217	3.2574	1.9282	-	7.1513	6.9717	5.9781	6.2189
1980	13.1714	8.3071	6.9779	5.0497	-	6.4812	5.3981	5.6636
1977	13.9928	9.1285	7.7993*	5.8711	.8214	-	5.1577	5.4350
1979	15.9918*	11.1275*	9.7983*	7.8701*	2.8204	1.9990	-	4.0332
1978	17.5193*	12.6550*	11.3259*	9.3976*	4.3479	3.5265	1.5275	-

TABLE G.4.4 Comparisons between lengths by Tukey-Kramer method

Roach age IV, all Fish combined							
Ranked lengths of year classes	Ranked length of year classes						
	1973	1974	1975	1979	1976	1978	1977
1973	-	18.8301	17.3479	19.6269	17.2068	16.9974	17.1894
1974	5.4000	-	11.4118	14.6456	11.1962	10.8116	11.1695
1975	11.6250	6.2250	-	12.6835	8.4694	8.0354	8.4341
1979	12.7323	7.3323	1.1073	-	12.4898	12.1997	12.4659
1976	17.6364*	12.2364*	6.0114	4.9041	-	7.7261	8.1399
1978	19.9714*	14.5714*	8.3464	7.2391	2.3351	-	7.6874
1977	22.7678*	17.3678*	11.1428	10.0356	5.1314	2.7964	-

TABLE G.4.5 Comparisons between lengths by Tukey-Kramer method

Roach age V, combined						
Ranked lengths of year classes	Ranked length of year classes					
	1973	1978	1974	1975	1976	1977
1973	-	30.6461	21.4721	19.7819	19.7819	20.8199
1978	6.7500	-	26.7805	25.4453	25.4453	26.2604
1974	9.0500	2.3000	-	13.0130	13.0130	14.5423
1975	20.1875*	13.4375	11.1375	-	9.9805	11.9060
1976	28.8958*	22.1458	19.8458*	8.7083	-	11.9060
1977	31.3846*	24.6346	22.3346*	11.1971	2.4888	-

TABLE G.4.6 Comparisons between lengths by Tukey-Kramer method

Roach age VI, combined				
Ranked lengths of year classes	Ranked length of year classes			
	1973	1974	1975	1976
1973	-	23.6828	22.3511	22.5808
1974	.8667	-	14.0555	14.4180
1975	19.3509	18.4821*	-	12.1065
1976	22.0455	21.1788*	2.6916	-

TABLE G.4.7 Comparisons between lengths by Tukey-Kramer method

Roach age VII, combined			
Ranked lengths of year classes	Ranked length of year classes		
	1974	1973	1975
1974	-	22.6929	15.7647
1973	2.9524	-	21.3193
1975	17.4637*	17.4637	-

TABLE G5.1 Comparisons between mean lengths of common bream by Tukey Kramer method

Common Bream age I												
Ranked length of year classes	Ranked length of year-classes											
	1972	1975	1981	1977	1979	1974	1976	1973	1978	1971	1980	1970
1972	-	19.4593	19.1984	24.2842	23.0381	20.7958	21.7205	20.0659	22.2569	25.2369	19.6659	22.6073
1975	9.42980	-	6.2908	16.1468	14.2037	10.171	11.948	8.5811	12.80823	17.5470	7.5990	13.494
1981	10.6042	1.1744	-	15.8314	13.8442	9.6630	11.5190	7.9717	12.5011	17.2572	6.9035	13.1150
1977	11.3333	1.9035	.7292	-	20.3177	17.7347	18.8105	15.0241	19.4274	22.7806	16.3953	19.8280
1979	11.5625	2.1326	.95833	.2292	-	15.9858	17.1716	15.0241	17.8452	21.4473	14.4856	18.2805
1974	13.1667	3.7368	2.5625	1.8333	1.6042	-	14.0205	11.1039	14.8380	19.0184	10.5615	15.3587
1976	14.1667	4.7369	3.5625	2.8333	2.6042	1.0000	-	12.9132	16.1083	20.0253	12.2825	16.5893
1973	14.4655	5.0357	3.8614	3.1322	2.9030	1.2989	.2988	-	13.7963	18.2174	9.0399	14.3550
1978	16.6000	7.1702	5.9958	5.2667	5.0375	3.4333	2.4333	2.1345	-	20.6059	13.2079	17.2857
1971	16.9000	7.4702	6.2958	5.5667	5.3375	3.7335	2.7333	2.4345	.3000	-	17.7759	20.9840
1980	19.0116	9.5818	8.4075*	7.6783	7.4491	5.84	4.8449	4.54611	2.4116	2.1116	-	13.7904
1970	31.8457*	22.4160*	21.2415*	20.5124*	20.2832*	18.6790*	17.3801*	17.3801*	15.2457	14.9457	12.8341	-

TABLE G5.2 Comparisons between mean lengths of common bream by Tukey Kramer method

Common Bream age II												
Ranked length of year classes	Ranked length of year-classes											
	1972	1979	1975	1976	1980	1977	1970	1978	1973	1974	1971	
1972	-	28.5615	25.5737	27.0958	25.8109	31.9327	29.7277	29.7277	26.2823	26.7168	33.1854	
1979	2.0000	-	15.68864	18.06385	16.07243	24.73494	21.81417	21.81417	16.81914	17.49025	26.33236	
1975	4.8793	2.8793	-	12.8280	9.8274	21.2149	17.7232	17.7232	11.0063	12.0068	23.0575	
1976	5.7000	3.7000	.8201	-	13.2946	23.0261	19.8566	19.8566	14.1883	14.9778	24.7349	
1980	5.9889	3.9889	1.1096	.2889	-	21.5003	18.0639	18.0639	11.5468	12.5041	23.3203	
1977	8.66667	6.66667	3.78736	3.78736	2.67778	-	26.0729	26.0729	22.06405	22.5798	29.9555	
1970	10.9444	8.9444	6.0651	6.0651	4.95555	2.27778	-	23.3203	18.7313	19.33619	27.59298	
1978	11.7222	9.7222	6.8429	6.0222	5.7333	3.0556	.77778	-	18.7313	19.33619	27.59298	
1973	12.2419	10.24194	7.36263	6.54194	6.25305	3.57527	1.2975	.51972	-	13.45041	23.8411	
1974	16.9583	14.9583	12.0790*	11.2583	10.9694	8.29166	6.01389	5.2361	4.71639	-	24.3192	
1971	18.7000	16.7000	13.8207	13.000	12.7111	10.0333	7.7556	6.9778	6.45806	1.74167	-	

TABLE G.5.3 Comparisons between mean lengths of common bream by Tukey Kramer method

Common Bream age III										
Ranked length of year classes	Ranked length of year-classes									
	1979	1972	1977	1976	1973	1975	1978	1971	1970	1974
1979	-	38.914	33.7006	24.611	22.8154	21.3753	28.1349	35.8771	29.7212	23.8291
1972	8.6667	-	43.5073	36.9172	35.7444	34.8434	39.3539	45.2141	40.5031	36.4009
1977	20.0833	11.416	-	31.373	29.985	28.9047	34.2075	40.8135	35.5236	30.7649
1976	21.066	12.4000	.9833	-	19.2123	17.4778	25.3010	33.7006	27.0540	20.4088
1973	22.0417	13.3750	1.9583	.9750	-	14.8423	23.5576	32.4122	25.4310	18.3004
1975	22.3477*	13.6810	2.2644	2.2644	.30603	-	22.1658	31.4152	24.1474	16.35
1978	24.8258*	16.1591	4.7424	4.7424	2.7841	2.4781	-	36.3536	30.2946	24.5415
1971	27.1167	18.4500	7.0333	13.0833	5.0750	4.7690	2.2909	-	37.5946	33.1342
1970	32.3611	23.6944	12.27787	11.2944	10.3194	10.0134	7.5354	5.2444	-	26.3450
1976	33.0833*	24.4167	13.0000	12.0167	11.0417	10.7356	8.2576	5.9667	.7222	-

TABLE G.5.4. Comparisons between mean lengths of common bream by Tukey Kramer method

Common Bream age VII						
Ranked length of year classes	Ranked length of year-classes					
	1975	1972	1971	1974	1973	1970
1975	-	44.4177	40.3084	23.1271	21.2064	31.7145
1972	5.3667	-	55.9776	45.2060	44.2541	50.1451
1971	10.8667	5.5000	-	41.1754	40.1281	46.5442
1974	10.9102	5.5435	.0435	-	22.8113	32.8093
1973	22.9604*	17.5938	12.0938	12.0503	-	31.4850
1970	34.2000*	28.8333	23.3333	23.2899	11.2396	-

TABLE G.6.1 Comparisons between mean lengths of zander by Tukey-Kramer method

Zander age I							
Ranked length of year classes	Ranked length of year-classes						
	1977	1979	1980	1978	1976	1975	1981
1977	-	18.1828	18.1266	23.7333	29.067	23.7333	18.310
1979	13.224	-	9.7938	18.1828	24.7437	18.1828	10.1030
1980	14.3074	1.083	-	18.1266	24.7024	18.12662	10.029
1978	16.0820	2.8578	1.774	-	29.0672	23.73332	18.3107
1976	20.3420	7.1178	6.034	4.2600	-	29.067	24.837
1975	21.5550	8.3308	7.247	5.4730	1.2130	-	18.310
1981	24.1900*	10.9658*	9.882	8.1080	3.8480	2.6350	-

TABLE G.6.2 Comparisons between mean lengths of zander by Tukey-Kramer method

Zander age II								
Ranked length of year classes	Ranked length of year-classes							
	1974	1977	1976	1980	1975	1979	1978	1981
1974	-	72.6863	72.6863	67.4668	75.0701	66.7941	72.6863	72.6863
1977	40.6525	-	45.9708	37.1724	49.6542	35.9374	45.9708	45.9708
1976	47.9100	7.2575	-	37.1724	49.6542	35.9371	45.9708	45.9708
1980	66.4000	25.7475	18.4900	-	41.6414	23.6630	37.1724	37.1724
1975	67.2400	26.5875	19.3300	0.8400	-	40.5425	49.6542	49.6542
1979	69.6994*	29.04694	21.7894	3.29944	2.45944	-	35.9371	35.9371
1978	73.6750*	33.0225	25.7650	7.275	6.4350	3.9756	-	45.9708
1981	84.07250*	43.4200	36.1625	17.6725	16.8325	14.37306	10.3995	-

TABLE G.7.1 Comparisons between growth seasons for Roach by Tukey-Kramer method

Roach growth between ages I and II								
Season	Year Class	Growth between successive annuli ranked						
		80-81 1979	79-80 1978	78-79 1977	76-77 1975	77-78 1976	81-82 1980	82-83 1981
80-81	1979	-	2.0630	3.0927	3.8705	3.6950	2.1263	2.5313
79-80	1978	0.4934	-	3.2274	3.9790	3.8085	2.3178	2.6942
78-79	1977	0.9385	0.4451	-	4.5979	4.4512	3.2682	3.5451
76-77	1975	1.3215	0.8280	0.3829	-	5.0229	4.0121	4.2407
77-78	1976	2.1887	1.6953	1.2502	0.8673	-	3.8431	4.0812
81-82	1980	3.3277*	3.1343*	2.6891	2.3062	1.4389	-	2.7429
82-83	1981	4.5732*	4.0797*	3.6346*	3.2517	2.3844	0.9455	-

TABLE G.7.2 Comparisons between growth seasons for Roach by Tukey-Kramer method

Roach growth between ages II and III									
Season	Year Class	Growth between successive annuli ranked							
		80-81 1978	79-80 1977	81-82 1979	82-83 1980	76-77 1974	78-79 1976	77-78 1975	75-76 1973
80-81	1978	-	2.5447	1.9118	2.6517	4.3861	2.9118	3.0446	7.1395
79-80	1977	2.1415	-	2.4149	3.0345	4.6275	3.2642	3.3832	7.2903
81-82	1979	2.2298*	0.0882	-	2.5274	4.3120	2.7990	2.9369	7.0943
82-83	1980	3.0134*	0.8719	0.7836	-	4.6873	3.3483	3.4644	7.3284
76-77	1974	5.9252*	3.7837	3.6955	2.9118	-	4.8391	4.9202	8.1186
78-79	1976	6.4110*	4.2695*	4.1813*	3.3976*	0.4858	-	3.6673	7.4264
77-78	1975	8.9335*	6.7920*	6.7038*	5.9202*	3.0083	2.5225	-	7.4795
75-76	1973	10.0824*	7.9408*	7.8526*	7.0690	4.1572	3.6713	1.1488	-

TABLE G.7.3 Comparisons between growth seasons for Roach by Tukey-Kramer method

Roach growth between ages III and IV		Growth between successive annuli ranked						
Season	Year Class	79-80 1976	80-81 1977	78-79 1975	81-82 1978	77-78 1974	76-77 1983	82-83 1979
77-78	1976	-	5.1010	5.3056	4.8442	7.0009	10.7441	7.8061
78-79	1977	0.7396	-	5.2608	4.7951	6.9671	10.7221	7.7757
76-77	1975	4.0831	3.3435	-	5.0122	7.1182	10.8209	7.9115
79-80	1978	7.0626*	6.3229*	2.9794	-	6.7813	10.6023	7.6097
75-76	1974	8.9790*	8.2393*	4.8958	1.9164	-	11.7455	9.1354
74-75	1973	9.5147	8.7750	5.4315	2.4521	0.5357	-	12.2425
80-81	1979	12.7742*	12.0345*	8.6910*	5.7116	3.7952	3.2595	-

TABLE G.7.4 Comparisons between growth seasons for roach by Tukey-Kramer method

Roach growth between ages IV and V		Growth between successive annuli ranked					
Season	Year Class	80-81 1976	81-82 1977	79-80 1975	78-79 1974	77-78 1973	82-83 1978
80-81	1976	-	5.6014	4.6955	6.1221	9.3067	11.9712
81-82	1977	2.6427	-	5.6014	6.8417	9.7950	12.3546
79-80	1975	2.6970	0.5430	-	6.1221	9.3067	11.9712
78-79	1974	7.6095*	4.9668	4.9125	-	10.1019	12.5993
77-78	1973	11.2595*	8.6168	8.5625	3.6500	-	14.4179
82-83	1978	24.4809*	21.8382*	21.7839*	16.8714*	13.2214	-

TABLE G.7.5 Comparisons between growth seasons for roach by Tukey-Kramer method

Roach growth between ages V and VI

Season	Year Class	Growth between successive annuli ranked			
		78-79 1973	80-81 1975	81-82 1976	79-80 1974
78-79	1973	-	9.4138	9.5105	9.9747
80-81	1975	0.8366	-	5.0990	5.9199
81-82	1976	6.8503	6.0137*	-	6.0725
79-80	1974	8.1833	7.3467*	1.3330	-

TABLE G.8.1 Comparisons between growth seasons for common bream by Tukey-Kramer method

Common Bream growth between ages I and II

Season	Year Class	Growth between successive annuli, ranked										
		81-82 1980	80-81 1979	71-72 1970	77-78 1976	76-77 1975	79-80 1978	78-79 1977	74-75 1973	72-73 1971	75-76 1974	73-74 1972
81-82	1980	-	16.9989	16.1830	14.4135	8.9175	16.1830	19.2399	10.6083	12.3939	23.0780	20.8601
30-81	1979	3.4602	-	21.4522	20.1509	16.6682	21.4522	23.8428	17.6308	18.7594	27.0352	25.1684
71-72	1970	3.5783	.1181	-	19.4676	15.8353	20.8117	23.2682	16.8456	18.0235	26.5298	24.6247
77-78	1976	4.5561	1.0958	.9778	-	14.0220	19.4676	22.0742	15.1536	16.4531	25.4890	23.49999
76-77	1975	7.5929	4.1327	4.01462	3.036	-	15.8353	18.9483	10.0699	11.9363	22.8356	20.5915
79-80	1978	8.1450	4.6847	4.5667	3.5889	6.3520	-	23.2682	16.8456	18.0235	26.5298	24.6247
78-79	1977	10.3564	6.8958	6.7778	5.8000	2.7632	2.2111	-	19.8004	20.8117	28.4976	26.7331
74-75	1973	10.7992*	7.3389	7.2209	6.2431	3.2062	2.6542	.4431	-	13.2470	23.5473	21.3781
72-73	1971	12.9015*	9.4413	9.3232	8.3455	5.3086	4.7566	2.5455	2.1024	-	24.4039	22.3181
75-76	1974	13.0227	9.5625	9.4444	8.4667	5.4298	4.8778	2.6667	2.2236	.1212	-	29.6156
73-74	1972	14.8227	11.3625	11.2444	10.2667	7.2298	6.6778	4.46667	4.0236	4.0236	1.8000	-

TABLE G.8.2 Comparisons between growth seasons for common bream by Tukey-Kramer method

Common Bream growth between ages II and III

Season	Year Class	Growth between successive annuli, ranked									
		81-82 1979	72-73 1971	74-75 1972	75-76 1973	79-80 1977	80-81 1978	78-79 1976	76-77 1974	77-78 1975	72-73 1970
81-82	1979	-	25.5132	27.6730	16.2959	19.5678	21.1356	17.5019	16.9461	15.2006	21.1356
72-73	1971	10.4167	-	32.1531	23.0995	25.5132	26.7346	23.9655	23.5627	22.3402	26.7346
74-75	1972	10.6667	.2500	-	25.4648	27.6730	28.8030	26.2530	25.8857	24.7781	28.8030
75-76	1973	11.7997	1.3831	1.1334	-	16.2959	18.1487	13.7469	13.0326	10.6639	18.1487
79-80	1977	13.4167	3.0000	2.75000	1.6169	-	21.1356	17.5019	16.946	15.2006	21.1356
80-81	1978	15.1035	4.6869	4.4369	3.3038	1.6869	-	19.2389	18.7347	17.1719	22.5949
78-79	1976	17.3667	6.9500	6.7000	5.5669	3.9500	2.2631	-	14.51183	12.4290	19.2390
76-77	1974	18.1250*	7.7083	7.4583	6.3253	4.7083	3.0215	.7583	-	11.6333	18.7347
77-78	1975	19.4684*	9.0518	8.8018	7.6687	6.0518	4.3649	2.1017	1.3434	-	17.1719
72-73	1970	23.4167	13.0000	12.7500	11.6169	10.0000	8.3131	6.0500	5.2917	3.9483	-

TABLE G.8.3 Comparisons between growth seasons for common bream by Tukey-Kramer method

Common Bream growth between ages V and VI								
Season	Year Class	Growth between successive annuli, ranked						
		80-81 1975	79-80 1974	81-82 1976	76-77 1971	78-79 1973	75-76 1970	77-78 1972
80-81	1975	-	12.2398	15.9931	23.5050	11.1050	18.0672	26.0700
79-80	1974	7.4123	-	17.8297	24.7912	13.6176	19.7114	27.2353
81-82	1976	7.5275	.1152	-	26.8434	17.0706	22.2375	29.1157
76-77	1971	11.7206	4.3083	4.1931	-	24.2510	28.1285	33.8294
78-79	1973	15.9331*	8.5208	8.4056	4.2125	-	19.6276	26.7445
75-76	1970	16.0095	8.5972	8.4819	4.2888	.0763	-	30.3046
77-78	1972	21.3706	13.9583	13.8431	9.6500	5.4375	5.3611	-

APPENDIX H Year class data

TABLE H.1 Relative year-class strengths of roach in seasons 1980 to 1984, trawl catches

Season		1+	2+	3+	4+	5+	6+	7+	8+
1980-81	Yr-class	'79	'78	'77	'76	'75	'74	'73	
	No	704	134	20	30	9	3	1	
	%	78.14	14.87	2.22	3.33	1.00	.33	.11	
1981-82	Yr-class	'80	'79	'78	'77	'76	'75	'74	'73
	No	227	453	116	53	36	30	12	5
	%	24.36	48.61	12.45	5.69	3.86	3.22	1.29	.54
1982-83	Yr-class	'81	'80	'79	'78	'77	'76	'75	'74
	No	1028	121	159	44	16	13	11	6
	%	73.53	8.66	11.37	3.15	1.14	.93	.79	.43
1983-84	Yr-class	'82	'81	'80	'79	'78			
	No	11	83	29	19	3			
	%	6.11	46.11	16.11	10.56	1.67			
	% Standard	45.54	29.56	10.54	5.68	1.92	1.12	.60	.25

TABLE H.2 Relative year-class strength of common bream between 1980 and 1984, trawl catches

Season		1+	2+	3+	4+	5+	6+	7+	8+	9+	10+	11+	12+	13+	14+	15+	16+	17+
1980-81	Yr-class	79	78		76	75		73	72		70							
	No	23	1		1	2		2	1		2							
	%	71.88	3.13		3.13	6.25		6.25	3.13		6.25							
1981-82	Yr-class	80	79	78	77	76	75	74	73	72	71	70	69	68			66	
	No	18	6	10	15	7	32	9	18	3	10	9	2	1			1	
	%	12.77	4.26	7.09	10.64	4.96	22.70	6.38	12.71	2.13	7.09	6.38	1.42	.71			.71	
1982-83	Yr-class	81	80	79	78	77	76	75	74	73	72	71						
	No	486	17	13	4		1	21	3	6	3	1						
	%	87.57	3.06	2.34	.72		.18	3.78	.54	1.08	.54	.18						
1983-84	Yr-class	82	81	80							75							
	No	41	18	5							2							
	%	62.12	27.27	7.58							3.03							
	% Std.	58.58	9.43	4.25	3.62	2.80	5.72	4.10	4.19	.80	3.47	1.04	.36	.18			.18	

TABLE H.3 Relative year-class strengths of pike between 1980 and 1984, trawl catches

Season		0+	1+	2+	3+	4+	5+	6+	7+
1980-81	Yr-class	80	79						
	No	3	2						
	%	60.00	40.00						
1981-82	Yr-class	81	80	79	78	77			74
	No	5	17	24	4	6			1
	%	8.77	29.82	42.11	7.02	10.53			1.75
1982-83	Yr-class	82	81	80	79	78			
	No	7	5	10	1	2			
	%	28.00	20.00	40.00	4.00	8.00			
1983-84	Yr-class	83	82		80				
	No	6	3		1				
	%	60.00	30.00		10.00				
Mean	%	39.19	29.96	20.53	5.26	4.63			.44

APPENDIX I Impact of piscivores on the fish community: data

TABLE I.1. Relative biomass of a roach cohort over its life span (calculated from growth and mortality data)

	I	II	III	IV	V	VI	VII	VIII
Length (mm)	55	86	111	134	159	181	203	216
Weight (g)	2	9	21.5	40	70	109	157	193
Survival	% of individuals surviving at age t							
70%	100	70	49.0	34.3	24.0	16.8	11.8	8.2
60%	100	60	36.0	21.6	13.0	7.8	4.7	2.8
50%	100	50	25.0	12.5	6.3	3.1	1.6	0.8
40%	100	40	16.0	6.4	2.6	1.0	0.4	
30%	100	30	9.0	2.7	0.8			
20%	100	20	4.0	0.8				
	Relative biomass of a cohort over its life span							
70%	1	3.2	5.3	6.8	8.4	9.2	9.3	7.9
60%	1	2.7	3.9	4.3	4.6	4.3	3.7	0.3
50%	1	2.3	2.7	2.5	2.2	1.7	1.3	0.8
40%	1	1.8	1.7	1.3	0.9	0.5	0.3	
30%	1	1.4	1.0	0.5	0.3			
20%	1	0.9	0.4	0.1				

TABLE I.3 Relative biomass of a zander cohort over its life span
(calculated from growth and mortality data)

	I	II	III	IV	V	VI	VII	VIII
Length (mm)	124	215	291	403	511	619	640	690
Weight (g)	30.7	85.5	240.3	634.9	1,349	1,600	1,758	2,175
Survival	% of individuals surviving at age t							
Boiko (1968)	100	100	100	99.3	95.6	82.0	60.7	41.9
65%	100	65	42.3	27.5	17.9	11.6	7.5	4.9
60%	100	60	36.0	21.6	13.0	7.8	4.7	2.8
50%	100	50	25.0	12.5	6.3	3.1	1.6	0.8
40%	100	40	16.0	6.4	2.6	1.0	0.4	
30%	100	30	9.0	2.7	0.8			
20%	100	20	4.0	0.8				
Relative biomass of a cohort over its life span								
Boiko (1968)	1	2.8	7.8	20.5	42.0	42.8	34.8	29.7
65%	1	1.8	3.3	5.7	7.9	6.0	4.3	3.5
60%	1	1.7	2.8	4.5	5.7	4.1	2.7	2.0
50%	1	1.4	2.0	2.6	2.8	1.6	0.9	0.6
40%	1	1.1	1.3	1.3	1.1	0.3	0.2	
30%	1	0.8	0.7	0.6	0.4			
20%	1	0.6	0.3	0.2				

TABLE I.4 Relative biomass of a pike cohort over its life span (calculated from growth and mortality data)

	I	II	III	IV	V	VI
Length (mm)	95	287	368	450	547	570
Weight (g)	6.2	183	419	705	1,358	1,557
Survival	% of individuals surviving at age t					
70%	100	70	49.0	34.3	24.0	16.8
60%	100	60	36.0	21.6	13.0	7.8
50%	100	50	25.0	12.5	6.3	3.1
40%	100	40	16.0	6.4	2.6	1.0
30%	100	30	9.0	2.7	0.8	
20%	100	20	4.0	0.8		
Relative biomass of a cohort over its lifespan						
70%	1	20.7	33.1	39.0	52.6	41.4
60%	1	17.7	24.3	24.6	28.5	19.6
50%	1	14.8	16.9	14.2	13.8	7.8
40%	1	11.8	10.8	7.3	5.7	2.5
30%	1	8.9	6.1	3.1	1.8	
20%	1	5.9	2.7	0.9		

TABLE I.5 Relative annual consumption of roach by the zander population assuming Boiko's (1964) estimate of mortality

Age	Biomass (relative)	Potential annual consumption of roach (relative to biomass of 0+ zander)			
		0+	1+	2+	Combined
0					
	1	2.50			2.50
I					
	2.8	4.31	2.69		7.00
II					
	7.8	12.01	7.49		19.50
III					
	20.5	31.57	19.68		51.25
IV					
	42.0	2.52	45.36	57.54	105.00
V					
	42.8	2.57	46.22	58.64	107.00
VI					
	34.8	2.09	37.58	47.68	87.00
VII					
	29.7	1.78	32.08	40.69	74.25
Total	181.40	59.35	191.11	204.55	453.5
Percentage of total consumption		13.04	42.00	44.96	

TABLE I.6

Relative annual consumption of roach by the zander population assuming mortality to be 35%

Age	Biomass (relative)	Potential annual consumption of roach (relative to biomass of 0+ zander)			
		0+	1+	2+	Combined
0	1	2.50			2.50
I	1.8	2.77	1.73		4.50
II	3.3	5.08	3.17		8.25
III	5.7	8.7	5.47		14.25
IV	7.9	0.47	8.53	10.82	19.75
V	6.0	0.36	6.48	8.22	15.00
VI	4.3	0.26	4.64	5.89	10.75
VII	3.5	0.21	3.78	4.80	8.75
Total	33.50	12.93	33.80	29.73	83.75
Percentage of total consumption		23.88	40.50	35.62	

TABLE I.7 Relative annual consumption of roach by the zander population assuming mortality to be 40%.

Age	Biomass (relative)	Potential annual consumption of roach (relative to biomass of 0+ zander)			
		0+	1+	2+	Combined
0	1	2.50			2.50
I	1.7	2.62	1.63		4.25
II	2.8	4.31	2.69		7.00
III	4.5	6.93	4.32		11.25
IV	5.7	0.34	6.16	7.81	14.25
V	4.1	0.25	4.43	5.62	10.25
VI	2.7	0.16	2.92	3.70	6.75
VII	2.0	0.12	2.16	2.74	5.00
Total	24.50	17.23	24.31	19.87	61.25
Percentage of total consumption		28.06	39.57	32.36	

TABLE I.8 Relative annual consumption of roach by the zander population assuming mortality to be 50%.

Age	Biomass (relative)	Potential annual consumption of roach (relative to biomass of 0+ zander)			
		0+	1+	2+	Combined
0					
	1	2.50			2.50
I					
	1.4	2.16	1.34		3.50
II					
	2.0	3.08	1.92		5.00
III					
	2.6	4.00	2.50		6.50
IV					
	2.8	0.17	3.02	3.84	7.00
V					
	1.6	0.10	1.73	2.19	4.00
VI					
	0.9	0.05	0.97	1.23	2.25
VII					
	0.6	0.04	0.65	0.82	1.50
Total	12.90	12.10	12.13	8.08	32.25
Percentage of total consumption		37.45	36.54	25.01	

TABLE I.9 Relative annual consumption of roach by the zander population assuming mortality to be 60%.

Age	Biomass (relative)	Potential annual consumption of roach (relative to biomass of 0+ zander)			
		0+	1+	2+	Combined
0					
	1	2.50			2.50
I					
	1.1	1.69	1.06		2.75
II					
	1.3	2.00	1.25		3.25
III					
	1.3	2.00	1.25		3.25
IV					
	1.1	0.07	1.19	1.51	2.75
V					
	0.5	0.03	0.54	0.69	1.25
VI					
	0.2	0.01	0.22	0.27	0.50
Total	6.50	8.36	5.51	2.47	16.25
Percentage of total consumption		51.16	33.72	15.12	

TABLE I.10 Relative annual consumption of roach by the zander population assuming mortality to be 70%.

Age	Biomass (relative)	Potential annual consumption of roach (relative to biomass of 0+ zander)			
		0+	1+	2+	Combined
0	1	2.50			2.50
I	0.8	1.23	0.77		2.00
II	0.7	1.08	0.67		1.75
III	0.6	0.92	0.58		1.50
IV	0.4	0.02	0.43	0.55	1.00
Total	3.50	5.75	2.45	0.55	8.75
Percentage of total consumption		65.71	28.00	6.29	

TABLE I.11 Relative annual consumption of roach by the zander population assuming mortality to be 80%.

Age	Biomass (relative)	Potential annual consumption of roach (relative to biomass of 0+ zander)			
		0+	1+	2+	Combined
0	1	2.50			2.50
I	0.6	0.92	0.58		1.50
II	0.3	0.46	0.29		0.75
III	0.2	0.31	0.19		0.50
Total	2.10	4.19	1.06		5.25
Percentage of total consumption		78.81	20.19		

TABLE I.12 Relative annual consumption of roach by the pike population assuming mortality to be 30%.

Age	Biomass (relative)	Potential annual consumption of roach (relative to biomass of 0+ pike)					Combined
		0+	1+	2+	3+	>4+	
0							
1	1.97	0.53					2.50
I	20.7	10.39	41.36				51.75
II	33.1	2.99	21.35	16.05		42.37	82.75
III	39.0	3.52	25.16	18.92		49.92	97.50
IV	52.6	1.04	23.68	8.71	13.81	84.27	131.50
V	41.4	0.82	18.64	6.85	10.87	66.32	103.50
Total	187.80	20.73	130.72	50.53	24.68	242.88	469.50
Percentage of total consumption		4.41	27.84	10.76	5.26	51.73	

TABLE I.13 Relative annual consumption of roach by the pike population assuming mortality to be 40%.

Age	Biomass (relative)	Potential annual consumption of roach (relative to biomass of 0+ pike)					Combined
		0+	1+	2+	3+	>4+	
0	1	1.97	0.53				2.50
I	17.7	8.88	35.37				44.25
II	24.3	2.19	15.67	11.79		31.10	60.75
III	24.6	2.22	15.87	11.93		31.49	61.50
IV	28.5	0.56	12.83	4.72	7.48	45.66	71.25
V	19.6	0.39	8.82	3.24	5.15	31.40	49.00
Total	115.70	16.21	89.09	31.68	12.63	139.65	289.25
Percentage of total consumption		5.60	30.80	10.95	4.37	48.28	

TABLE I.14 Relative annual consumption of roach by the pike population assuming mortality to be 50%.

Age	Biomass (relative)	Potential annual consumption of roach (relative to biomass of 0+ pike)					Combined
		0+	1+	2+	3+	>4+	
0							
1	1.97	0.53					2.50
I	14.8	7.43	29.57				37.00
II	16.9	1.53	10.90	8.20		21.62	42.25
III	14.2	1.28	9.16	6.89		18.18	35.50
IV	13.8	0.37	6.21	2.28	3.62	22.11	34.50
V	7.8	0.15	3.51	1.29	2.05	12.50	19.50
Total	68.50	12.63	59.88	18.66	5.67	74.42	171.25
Percentage of total consumption		7.37	34.96	10.90	3.31	43.45	

TABLE I.15 Relative annual consumption of roach by the pike population assuming mortality to be 60%.

Age	Biomass (relative)	Potential annual consumption of roach (relative to biomass of 0+ pike)					Combined
		0+	1+	2+	3+	4+	
0							
1	1.97	0.53					2.50
I	11.8	5.92	23.58				29.50
II	10.8	0.97	6.97	5.24		13.82	27.00
III	7.28	0.66	4.70	3.53		9.32	18.20
IV	5.7	0.11	2.57	0.94	1.50	9.13	14.25
V	2.5	0.05	1.13	0.41	0.66	4.01	6.25
Total	39.08	9.68	39.48	10.02	2.16	36.28	97.70
Percentage of total consumption		9.92	40.44	10.26	2.21	37.17	

TABLE I.16 Relative annual consumption of roach by the pike population assuming mortality to be 70%.

Age	Biomass (relative)	Potential annual consumption of roach (relative to biomass of 0+ pike)					Combined
		0+	1+	2+	3+	>4+	
0							
1	1.97	0.53					2.50
I	8.9	4.47	17.78				22.25
II	6.1	0.55	3.93	2.96		7.81	15.25
III	3.1	0.28	2.00	1.50		3.97	7.75
IV	1.8	0.04	0.81	0.30	0.47	2.88	4.50
Total	20.90	7.31	25.05	4.76	0.47	14.66	52.25
Percentage of total consumption		13.99	47.94	9.11	0.90	28.06	

TABLE I.17 Relative annual consumption of roach by the pike population assuming mortality to be 80%.

Age	Biomass (relative)	Potential annual consumption of roach (relative to biomass of 0+ pike)					Combined
		0+	1+	2+	3+	4+	
0							
1	1.97	0.53					2.50
I	9.9	2.96	11.79				14.75
II	2.7	0.24	1.74	1.31		3.46	6.75
III	0.9	0.08	0.58	0.44		1.15	2.25
Total	10.50	5.25	14.64	1.75		4.61	26.25
Percentage of total consumption		20.00	55.77	6.67		17.56	

APPENDIX J Temperature data

Probably nearest degree only.

W.D.U. 22 (Revised. 1979)

Calendar Day River Water Temperatures: 19.78..

IN DEGREES CELSIUS

HYDROMETRIC AREA NO.
OR GAUGING STATION NO.

RIVER. CAM
LOCATION. BOTTISHAM

Annual Summary				
Mean Max.	Mean Min.	Mean of Max. & Min.	Highest	Lowest

Day	JAN.		FEB		MAR		APR		MAY		JUN		JUL		AUG		SEP		OCT		NOV		DEC			
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.		
1	6	5	4	4			9	9	10	10	19	17	15	14	19	18	14	14	12	11	13	12	3	3	1	
2	6	5	5	5	8	8	10	9	10	10	19	17	15	15	18	17	15	14	12	11	13	12	3	2	2	
3	5	5	5	5	8	7	10	9	12	10	20	18	16	15	18	17	15	14		11	12	12	3	3	3	
4	5	4	5	5	7	7	9	8	12	10	20	18	15	14	17	16	15	14	12	11	12	11	4	3	4	
5	5	4	6	5	7	6	9	8	12	11	19	18	14	14	17	16	14	14	12	11	12	11	4	3	5	
6	5	4	6	5	7	6	8	7	11	9	18	17	14	13	17	16	15	14	12	12	12	11	4	4	6	
7	5	4	6	6			9	7	12	10	17	16	14	13	17	16	15	14	13	12	12	11	4	3	7	
8	5	4	6	5	7	7	8	8	12	11	17	16	14	13	17	16	16	14	14	12	12	11	5	4	8	
9	5	4	5	4	7	7	8		12	10	17	16	15	13	16	16	16	15	13	12	11	10	6	5	9	
10	5	4	4	3	8	8	8	7	12	11	15	15	16	14	16	15	18	15	14	13	11	10	7	5	10	
11	5	4	3	2	9	9	7	6	11	11	17	14	17	15	17	15	17	16	15	13	11	10	7	7	11	
12		4	3	2	10	9	7	6	11	10	16	14	16	15	16	16	16	15	15	14	11	10	8	8	12	
13			3	3	9	9	6	6	11	10	14	13	17	15	17	15	16	15	14	14	10	10	8	8	13	
14			4	3	9	8	6	6	10	10	14	13	17	16	17	16	16	15	14	13	10	9	8	7	14	
15			4	4	8	7	7	6	11	10	14	13	17	16	17	16	16	15	14	13	10	10	8	7	15	
16			5	4	7	7	8	6	12	10	14	13	17	16	17	16	17	15	13	13	9	9	7	6	16	
17			5	4	6	5	8	7	13	11	15	13	18	16	17	16	16	15	12	11	9	9	6	6	17	
18			4	4	6	5	8	8	12	12	16	14	17	17	18	16	16	14	11	10			6	5	18	
19			4	3	7	6	9	8	12	11	17	14	17	16	18	16	15	14	11	10			5	5	19	
20			3	2	7	6	9	8	13	11	18	16	16	15	18	17	15	14	11	11	10	10	5	4	20	
21			3	3	7	7	9	9	13	12	17	16	16	15	19	18	16	14	11	11	10	9	4	4	21	
22			5	3	7	7	10	9	13	12	16	16	17	15	19	18	16	15	12	11	11	10	4	3	22	
23			7	5	7	7	11	9	13	12	16	15	16	16	18	18	16	15	12	10	11	10	3	3	23	
24			8	7	7	7	12	10	13	12	15	14	17	15	18	17	17	15	12	10	10	10	4	3	24	
25	4	4	9	8	7	6	11	11	14	12	14	13	18	16	19	17	16	15	12	11	10	9	4	4	25	
26	4	4	9	9	7	6	11	9	14	12	13	13	17	17	17	16	15	14	13	12	8	7	5	4	26	
27	4	4	9	9	7	7	9	8	16	13	13	12	18	17	16	16	15	14	13	12	6	5	6	4	27	
28	5	5			9	8	9	8	17	14	14	13	19	18	16	16	14	13	13	12	4	4	7	6	28	
29	5	4			9	9	9	8	17	15	15	14	20	18	16	15	14	13	13	12	4	4	7	6	29	
30	5	5					10	9	18	16	15	14	19	19	15	14	12	12	13	12	4	3	6	5	30	
31	4	4			9	9			19	17			19	18	14	14			13	12			4	3	31	
TOTAL																										
Monthly Means			5.19	4.52	7.56	7.07	8.80	7.90	12.84	11.45	16.13	14.83	16.55	15.45	17.10	16.16	15.47	14.33	12.70	11.71	9.93	9.25	5.32	4.61		
Monthly Mean of Max. & Min.																										

NOTES:-

1. The daily maximum and minimum temperatures should be entered to the nearest degree.
2. The mean temperatures should be computed to one place of decimals.
3. The highest and lowest temperatures recorded each month should be prefixed with the letters "H" and "L" respectively.
4. Entries to be in black ink or type.

COMMENTS:-

Copied from Cambridge data. (via A. Atciolan).

W.D.U. 221 (Revised 1979)

Calendar Day River Water Temperatures: 1979

IN DEGREES CELSIUS

HYDROMETRIC AREA NO. RIVER: CAM
 OR GAUGING STATION NO. LOCATION: BOTTISHAM LOCK

Annual Summary				
Mean Max.	Mean Min.	Mean of Max. & Min.	Highest	Lowest

Day	JAN		FEB		MAR		APR		MAY		JUN		JUL		AUG		SEP		OCT		NOV		DEC			
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.		
1	2	2	4	3	4	3	7	5	10	9	13	14	17	15	19.5	18.5	18.5	17	15	14	9.7	8.7	8.5	8.1	1	
2	2	1	4	3	5	4	7	6	9	7	12	14	16	15	19	18	18.5	17.5	15	14	9.3	8.4	8.9	8.3	2	
3	1	1			6	5	7	6	9	6	17	14	16	15	19	8	17.5	17	15.5	14	9.6	8.4	8.9	8.3	3	
4	1	1			7	6	7	6	9	7	17	15	18	15.5	19	18	17.5	16	15.5	15	9.9	9.7	8.5	7.9	4	
5	1	1			5	5	8	6	10	7	17	16	19	17	19.5	18	18	16	15	14.5	9.7	9.0	8.9	8.4	5	
6	1	1	4	3	5	4	7	6	10	8	17	16	19.5	17	20	18.5	18.5	17	15	13.5	9.0	8.7	8.9	8.2	6	
7	2	1	4	3	5	4	6	5	10	10	17	16	19	18.5	19.5	19	18.5	17	16	14	9.1	8.5	9.0	8.5	7	
8	2	2	4	3	5	4	7	6	11	10	16	15	19.5	18	19	18.5	18.5	17	15.5	14.5	9.0	8.4	9.1	8.8	8	
9	3	2	3	3	5	5	7	6	12	11	16	15	19	18.5	19	17.5	19	17.5	15.5	14	8.5	7.9	9.2	8.6	9	
10	3	3	3	3	5	4	9	7	12	11	17	15	19	17.5	18	16.5	19	17.5	15	14.5	7.8	6.9	8.7	7.8	10	
11	3	3	3	2	5	4	11	9	12	11	17	16	19.5	18	19	17.5	16.5	17.5	15	14	7.3	6.6	7.8	7.7	11	
12	3	2	3	2	6	5	11	9	14	11	16	15	20	18	19	18	19	17.5	15	14	7.3	5.8			12	
13	2	2	3	2	6	5	11	9	16	13	16	15	20	18.5	19	19	18	17.5	14.5	14	6.8	6.0			13	
14	2	2	3	2	5	5	12	10	17	15	15	15	20	19	19	18.5	17	16	14	14	5.9	5.2			14	
15	2	2	2	1	4	3	13	11	18	16	14	14	20	19	18.5	17.5	16	15	14.5	13	5.3	5.0			15	
16	3	2	2	1	3	3	12	11	18	17	15	14	19.5	18.5	18.5	17.5	16	15	14	13.5	5.4	5.1			16	
17	4	3	2	2	3	3	11	9	17	15	15	14	20	18.5	17.5	17	16	14.5	13.5	12.5	5.1	4.9			17	
18	4	3	3	2	4	3			15	13	17	15	19.5	19	17.5	17	15.5	15	13.5	12.5	5.8	5.0			18	
19	3	2	3	2	4	4			16	13	19	16	19	18	17.5	17	15.5	15	13	12	5.2	5.2			19	
20	3	2	3	3					14	13	20	18	19	17.5	17.5	17	16	15.5	12.4	11.5	5.7	5.1	4	4-	20	
21	3	3	3	3					13	13	19	18	18.5	17.5	17.5	17	15	13.5	12.0	10.9	5.9	5.3	4	3.5	21	
22	3	3	4	3					13	12	19	18	17.5	17	17	16	13.5	13	10.8	9.8	6.3	5.5	3.5+	3.5	22	
23	3	3	4	3					14	12	19	18	17	16	16	15.5	13	12.5	10.3	9.3	6.8	6.2	4-	4-	23	
24	2	2	3	3					13	12	18	17	17.5	16	15.5	15	14.5	12.5	9.6	9.1	6.6	5.8	4	4-	24	
25	2	2	4	3			9	9	14	13	17	16	18.5	17	16	14.5	14.5	13	9.8	9.0	6.1	5.5	4+	3.5+	25	
26	3	2	3	3			9	8	13	12	17	16	19	17.5	16	15	15.5	14	10.1	9.5	7.6	6.3	4-	3.5	26	
27	3	2	4	3	6	5	10	8	13	12	18	16	20.5	18	16	15	16	15	9.7	9.2	8.0	7.3	4.5+	4-	27	
28	2	1	4	3	5	4	10	9	13	12	18	16	21	19.5	16.5	14.5	16	14.5	8.8	8.5	8.0	7.6	5	4+	28	
29	2	1			5	4	9	9	14	13	17	17	20.5	20	17	15	14.5	14	9.6	8.5	7.6	7.2	4+	4-	29	
30	3	2			5	4	10	8	15	14	17	16	20.5	19.5	18	15.5	14	13.5	9.1	8.3	8.2	7.4	4	4-	30	
31	3	3			5	5			16	15					18	16.5			10.1	9.1			4-	3.5	31	
TOTAL																										
Monthly Means	2.45	2.00	3.28	2.56					13.2	11.7	17.1	15.7	19.0	17.6	18.0	17.0	16.6	15.5	13.0	12.1	7.4	6.8				
	0		0		0				6		30		31		31		25		13							

- NOTES:-
1. The daily maximum and minimum temperatures should be entered to the nearest degree.
 2. The mean temperatures should be computed to one place of decimals
 3. The highest and lowest temperatures recorded each month should be prefixed with the letters "H" and "L" respectively.
 4. Entries to be in black ink or type.

COMMENTS:-

408

Calendar Day River Water Temperatures: 1980..

IN DEGREES CELSIUS

Annual Summary				
Mean Max.	Mean Min.	Mean of Max. & Min.	Highest	Lowest

HYDROMETRIC AREA NO. RIVER..... CAM

OR GAUGING STATION NO. LOCATION..... BOTTISHAM LOCK

Day	JAN		FEB		MAR		APR		MAY		JUN		JUL		AUG		SEP		OCT		NOV		DEC	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
1	3+	3	5.5-	5	7.5+	7	8	7.5	11+	9.5-	13.5+	12.5+	15-	14+	20.5-	19-	17	14.5-	14.5+	13.5+	9+	8.5-	4	3.5
2	3+	2.5+	5+	5-	8+	7+	9	8	12+	10	14+	12.5+	15.5+	14-	20.5-	19-	18-	15	14+	13+	8.5	8-	4+	3.5
3	3+	2.5	5	5	8	7	9	8	12+	10.5-	16.5	14-	16	14+	20.5	19+	18	15.5	14-	13-	7.5+	7-	4-	3.5+
4	N.D.	3	5	5	7+	6+	9+	8+	12.5	10.5-	18+	16-	16-	15+	20-	19	17.5+	15+	13.5+	13-	6.5+	6.5-	4-	3
5	N.D.	N.D.	6+	5	6.5	6	10-	8-	12+	10.5	19.5+	17.5+	16-	15+	19-	18+	17	16	13	12	6	6-	5	4-
6	N.D.	N.D.	6.5	6+	6+	6	10	9+	11.5-	10-	20-	18.5	16-	15+	18.5-	17.5	17.5	15.5-	12.5	12-	5.5	5+	5	4+
7	N.D.	N.D.	6.5	6+	7	7-	10	9	11.5	10	20-	19-	16+	15.5	18.5+	17.5-	18-	15.5	12	11.5	5+	5	4+	3.5
8	5.5	5+	7+	6	7+	7-	9.5	8+	10.5+	10	19+	18.5-	15.5	15-	18-	17.5+	17.5-	16-	11.5	10.5	5.5-	5+	4-	3
9	5.5-	5+	7.5+	7+	7.5	7-	9-	8-	11.5	9+	19.5-	18+	14+	14	18-	17-	16.5	15+	10.5+	9.5+	6-	5+	4-	3
10	5+	5	7.5+	7	7	6.5+	9-	8	12.5-	9.5+	19.5-	18+	13.5-	13+	19+	16.5+	15.5+	15	10	9.5-	6-	5+	5-	3.5
11	5	5-	7+	6.5+	7.5+	7-	9.5	8	13+	10.5+	18.5	18-	14.5	13-	18	17.5	15+	14.5-	10.5-	9.5	6	5.5+	5.5+	5
12	5-	4.5	7.5-	6.5+	8-	7.5+	11-	9	14.5-	12-	19-	17+	14+	14-	17.5	17-	15.5-	14+	10+	9+	5.5+	5+	6.5	5.5
13	4.5	3+	7.5	7-	8	7.5	12	10-	16-	13+	19	17.5-	15-	13.5	17+	16+	14.5-	13.5+	10.5-	9-	6-	5+	7+	6.5
14	4	3.5	7.5	7	7	6+	13	11	16+	14+	18	18-	14.5+	14-	18+	17-	15-	13.5-	10.5	9+	6.5+	6-	7.5+	7-
15	4-	3.5	8-	7.5	6	5+	13.5	12-	16	14.5-	18.5	16.5	14.5+	13+	19-	17.5	15+	14-	10	9+	8	7-	7	6.5
16	4+	4-	8	8-	5.5-	5.5-	14-	12+	16-	14.5	17.5	17	15.5+	13.5+	19+	17+	15.5-	14.5-	10+	9.5-	9+	8	6+	6-
17	4.5	4+	8	7.5+	6-	5+	14-	13-	16	14+	17+	16.5-	15.5	14.5	19-	18-	15.5	14.5-	9.5+	9.5-	10-	9-	7-	6-
18	4.5+	4.5-	8-	7+	6-	5+	13.5	12+	16.5	14.5+	18-	16	15.5+	15-	19+	17.5	15.5	14.5	9+	8.5	9+	8.5	6+	5
19	4.5-	4+	7+	7-	5+	5-	13-	12+	17	15	17+	17	16+	15	18+	17+	16-	14.5	8.5	7.5+	9-	8+	5	4.5
20	4.5	4.5-	7-	6+	5	4+	10.5	10+	15.5	15	16	15.5	16	15.5	19+	16.5+	16	15	8.5-	7.5+	9+	9-	5	4+
21	5-	4.5-	7	6.5-	5	4+	10-	9	15-	15.5	14.5	15	14+	19	18-	17-	15.5-	10-	8+	9.5	9-	5-	4	21
22	5-	4.5+	7+	7-	6-	4+	9.5-	9	16-	14.5	17.5	15-	17.5+	16.5	16.5-	15.5-	10+	9	10	9.5	6	5	22	
23	5	5-	8-	7-	6+	5+	9.5	8.5	15.5	14.5	18	16+	17+	16	16	15+	10.5+	9.5+	11	10	7	6	23	
24	5	5-	7+	7-	6+	5.5-	10+	9	15	14.5	19+	17-	17-	15+	16	15-	10.5	9+	11+	11-	7.5-	7-	24	
25	5-	4.5	7	7-	7.5	6+	11	10-	15.5	14.5	20	17.5	17+	15-	16+	14.5	10+	9.5	10+	10	7.5+	7	25	
26	5	4.5	7-	6+	8+	7+	10+	10-	16	15	20	19-	18-	15.5-	16-	14+	10+	9.5	9	9-	6.5	6	26	
27	4.5-	4-	7-	7-	9	8-	10.5+	9.5+	20	18.5	18-	15.5+	16-	14.5+	12	10-	8	7.5+	6	5	27			
28	4.5-	4	7-	6.5-	9.5	8.5+	10-	9.5+	21	18.5+	17.5+	16+	15+	15-	12+	12	7	5+	5+	5-	28			
29	5-	4+	7.5-	7-	9	8	10+	9+	21	19.5	16.5+	16.5-	15	14.5	11.5	11+	5-	4.5+	5.5	5+	29			
30	5.5+	5	8.5	7.5	10.5	9.5	14.5	13-	16	15-	20.5+	20-	16.5	16-	15+	14+	11-	10-	4.5	4+	6	5.5	30	
31	5.5	5	8.5	7.5	13+	13	20.5+	19	16	14.5+	10-	9-	6.5-	5.5+	31									
TOTAL																								
Monthly Means			6.95	6.48	7.05	6.29	10.58	9.45					16.68	15.45	18.26	16.95	16.15	14.77	10.97	10.06	7.62	7.05	5.61	4.89
Monthly Mean of Max & Min																								

- NOTES:-
- The daily maximum and minimum temperatures should be entered to the nearest degree.
 - The mean temperatures should be computed to one place of decimals.
 - The highest and lowest temperatures recorded each month should be prefixed with the letters "H" and "L" respectively.
 - Entries to be in black ink or type.

COMMENTS:-

Calendar Day River Water Temperatures: 19.81..

IN DEGREES CELSIUS

Annual Summary				
Mean Max.	Mean Min.	Mean of Max. & Min.	Highest	Lowest

HYDROMETRIC AREA NO. RIVER. CAM
 OR GAUGING STATION NO. LOCATION. BOTTISHAM LOCK

Day	JAN		FEB		MAR		APR		MAY		JUN		JUL		AUG		SEP		OCT		NOV		DEC				
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.			
1	5.5+	5.5-	7-	6+	5	4			11.5	10.5+	17.5+	15-	16.5-	15+			N.D.	N.D.	16-	15-	10.5	9+	6.5-	6+	1		
2	6r	5.5-	6	5.5	6	5			12-	10.5	18.5	16.5-	17-	15.5			N.D.	N.D.	15-	14-	11.5-	10.5	5.5+	5.5-	2		
3	7-	6.5-	6.5+	6	6	5.5			10	9.5+	19-	17	17+	16+			N.D.	N.D.	14-	13.5-	12-	11+	6+	5+	3		
4	6-	5+	6	5+	5	5			9.5+	9+	18	17+	18	16+	2.5r	19.5-	N.D.	N.D.	13.5+	12.5	11.5+	11+	6.5	6	4		
5	5	4.5-	6-	5-	5+	5			10	8.5-	17.5	16	18.5	17+	2.2-	19+	N.D.	N.D.	14-	13+	11-	10+	6.5-	6-	5		
6	4.5	4+	7-	6-	5	5			11.5+	10-	17+	15.5+	19+	17+	2.1	20-	N.D.	N.D.	13.5+	12.5+	10.5	10	6+	6-	6		
7	4.5	4+	7.5+	7-	5	5			13+	11.5-	16	15	20.5-	18-	18.5	18	N.D.	N.D.	12.5	12-	10	9.5	6	5.5+	7		
8	5	4+	7.5+	7	5	5			14.5	13	16.5+	15.5	21.5-	19.5+	18+	18-	N.D.	N.D.	13-	11.5+	9-	8+	6-	5	8		
9	5	4.5+	8-	7	5	5	12	12	14.5	14	16.5	15.5+	20.5+	19.5+	17.5+	17	N.D.	N.D.	13-	12+	8+	8-	4.5+	4.5-	9		
10	5	4	7+	6			14+	11.5-	14.5	14	16	15	19.5+	19.5-	18.5-	16.5	N.D.	N.D.	11.5+	11	8-	7.5-	4-	3.5-	10		
11	4.5-	4-	6.5-	5.5		?	15	13-	15-	12.5+	16.5-	15.5-	20	19-	19-	16.5+	N.D.	N.D.	11+	10.5	8-	7	3+	3-	11		
12	4.5-	3.5+	5.5+	5.5			14.5+	13	15	13.5+	16+	15.5	19.5+	19-	20-	18-	N.D.	N.D.	11	10.5-	8+	7.5	2.5	2+	12		
13	4-	2.5+	5.5-	5-		INVALID	15-	13	15	14+	18-	15.5	20-	18.5	20-	17.5	N.D.	N.D.	10	9.5	8-	7+	1.5+	1+	13		
14	4+	3+	5	4-		DATA?	15.5	11.5+	15.5+	14.5	19-	17-	19-	19-	20.5+	19-	N.D.	N.D.	10+	9+	8-	7	2	1+	14		
15	4	3+	4.5	3.5-		SEE TRACE	15	11-	16-	14+	19.5	18.5	19	18	21-	19.5+	N.D.	N.D.	10-	9.5-	8-	7.5	2.5+	2	15		
16	3.5	3-	4.5-	3.5			13.5	11.5-	15+	14.5	18-	17.5	18.5	18	20.5	19+	N.D.	N.D.	10+	8.5+	8+	7.5+	1.5+	1+	16		
17	4-	3.5	5	4	7-	6	13	11+	14.5	14-	16.5-	16+	18	17-	20.5+	18+	17.5	N.D.	9	8+	8	8-	1.5	1+	17		
18	4	3+	5-	3.5+	6.5	5.5	13-	11-	13.5	13	16.5-	15.5	17.5	16.5+	19.5+	18.5+	17.5	16.5	10-	8.5	8.5	8-	1.5	1+	18		
19	4.9+	4+	4+	4-	7.5-	6	11.5-	10.5+	14	13	16-	15.5-	17.5	16.5	19	18+	17.5	15.5+	9.5+	8.5-	8+	8-	1.5+	1+	19		
20	4.5+	4.5	4.5+	4-	8.3	7	10.5+	9.5+	14.5	13+	16	15	18.5+	17-	18	17.5	16-	15+	10.5-	9.5+	9.5+	8	1.5	1.5	20		
21	5r	4.5	5-	4	9	8.5-	10	9.5-	15	13.5+	16.5	15+	20-	18-	17+	16.5	16-	15-	10-	9-	9.5	9-	2r	1.5	21		
22	6r	5+	3.5+	3.5	9+	8.5+	9	9-	16-	14.5-	17.5	15+			17.5-	16+	16.5-	15	9	8.5	10.5-	9.5	2+	2-	22		
23	7.5r	6+	3.5+	3.5-	8.5+	7.5+	9.5	8+	15+	14.5	18-	16.5+		SEE NOTE	18-	16	16+	14.5-	9-	8+	10.5	10+	2-	1.5	23		
24	8-	7.5+	4+	3.5-	8.5	8+	8+	8-	15.5+	13.5+	17+	17					14.5	9.5	8.5	9-	8-	8-	2+	1.5+	24		
25	7.5+	7	4	3.5-	10	8.5-	8+	7.5	14.5+	14-	17-	16					14.5+	9.5+	9	8	7-	7-	2	2-	25		
26	7+	7	4-	3+	11	9.5	7.5+	7.5-	14.5+	13-	16-	15+					19.5	15	15-	9+	8+	7	6+	2	1.5	26	
27	7.5	7	4.5-	3-	11	10+	7.5	7-	14.5	13.5	16-	14.5					20+	18-	15	14-	9.5-	8+	8-	7	2+	2-	27
28	7.5+	7-	4.5	3.5	11.5+	10-	N.D.	N.D.	14.5	13.5-	15.5-	14.5					19.5	18+	15-	13.5	9	8+	7-	5.5	2.5-	2	28
29	7.5+	7.5			10.5	10+	9.5	8.5	14.5	14-	15+	14					19.5+	18-	15-	13.5-	9	8.5+	6-	5.5-	3-	3.5-	29
30	8	7.5			11+	11+	9.5	8.5	15.5+	14-	15.5	14.5-					N.D.	18-	15+	14-	9	8+	7-	5.5+	N.D.	2.5	30
31	7+	6.5							16+	14.5							N.D.	N.D.	10	9			3	3	31		
TOTAL																											
Monthly Means	5.60	4.95	5.41	4.66					14.05	12.87	16.95	15.72							10.95	10.05	8.88	8.13	3.30	2.89			
Monthly Mean of Max & Min																											

- NOTES:-
- The daily maximum and minimum temperatures should be entered to the nearest degree.
 - The mean temperatures should be computed to one place of decimals
 - The highest and lowest temperatures recorded each month should be prefixed with the letters "H" and "L" respectively.
 - Entries to be in black ink or type.

COMMENTS:-

Calendar Day River Water Temperatures: 1982.

IN DEGREES CELSIUS

RECEIVED

HYDROMETRIC AREA NO.
OR GAUGING STATION NO.

RIVER CAM
LOCATION BOTTISHAM LOCK

Annual Summary				
Mean Max.	Mean Min.	Mean of Max. & Min.	Highest	Lowest

Day	JAN		FEB		MAR		APR		MAY		JUN		JUL		AUG		SEP		OCT		NOV		DEC			
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.		
1	35+	3+	8	8-	8	8-	8.5-	7	12-	11	20+	18.5+			21.5-	20-	16-	15	17.5+	13+	12+	11.5			1	
2	45+	35+	8	8-	8	7.5-	9-	8-	11+	10.5-	21+	19.5+			22.5	20	17	15-	14.5-	14-	12.5	12+			2	
3	N.D.	N.D.	8.5	6-	8-	7.5	10	8	11+	10-	21.5-	20-			22.5+	20.5-	17+	15-	14-	13.5-	13-	12.5+			3	
4	N.D.	N.D.	6	5.5	7+	6.5	11	9			22-	20-			21.5+	N.D.	18-	15.5	13	13-	13-	13-	13-		4	
5	N.D.	N.D.	6.5+	5.5	7+	6	10+	10-			22+	20.5-			20.5+	19.5+	18-	16+	13	12.5	13-	12+			5	
6	5	4+	7.5+	6.5	6.5+	6-	11.5+	11-			22+	20.5			21.5	19.5	17+	17-	13	12+	12	11.5-			6	
7	4+	3	8-	7.5	7+	6	12	11			21.5+	19.5	20-	19-	20.5	19.5+	18	16.5	12.5+	12	11+	10.5			7	
8	3	2+	8-	7+	7-	6-	11.5	10.5			22	19.5+	21+	19-	21.5	19.5	18-	16+	12.5-	12-	11+	10.5			8	
9	2+	1.5	7.5+	7+	7.5-	6+	10+	9.5			21.5-	20-	22	19.5+	22-	20-	18+	16.5-	13+	12-	11.5-	11-			9	
10	1.5	1-	7.5+	7	8-	7-	10	9			21-	20-	22.5-	20+	21.5+	19.5+	19-	16.5	12+	11.5+	11+	10.5	6.5		10	
11	1.5	1	8-	7.5	7+	6.5-	9+	8.5+			19.5+	19.5-	23-	21-	21.5+	19.5+	19	17	11.5+	11.5	11.5+	10.5	5.5+	4.5	11	
12	1.5	1+	7.5+	7-	7	6	9-	8			19+	18.5+	21-	19.5+	21	19.5+	18.5-	16.5+	12-	11+	11.5-	11	5	4.5	12	
13	1.5	1	7.5+	7.5	7-	5.5+	9	7.5+	16.5	15-	18.5	17+	21.5+	19+	19	18.5-	18.5+	17-	12	11	10.5	9.5+	5.5-	5	13	
14	1.5+	1	7.5	7-	7	6	10+	8-	16.5-	14.5-	18-	16.5+	21	20-	19.5-	17.5-	12.5	16.5	11+	10.5+	9	9-	5+	5-	14	
15	1.5	1	7	6.5-	7+	7-	11-	8.5+	17	15+	17	16.5	20.5-	19	19.5+	17.5	12.5+	16.5	11+	10+	N.D.	N.D.	8	5+	15	
16	2	1.5	6+	5.5	7+	6	11.5-	9.5	18+	16.5-	15.5+	19	18	19-	18	19	17-	11-	10+	N.D.	N.D.	8	7-	16		
17	2	2-	5.5+	5	6	6-	12	10	18+	17.5-			20	17+	19-	17.5	19-	17.5	11.5+	10.5-	N.D.	N.D.	7-	5	17	
18	3.5+	2	5+	5-			12.5	10.5	18.5	16.5			20	19-	18	17+	19.5-	17.5	11.5-	10.5	9	8	5	4	18	
19	3.5+	3+	5+	5-			13-	10.5+	18	17-			20.5+	19-	18-	16	12.5+	12-	11.5	10.5+	8.5+	8+	5-	4-	19	
20	5	4-	5	4.5+			12.5+	11-	17.5+	17+			19+	18+	16.5	15.5-	12.5	18-	12+	11.5	7.5+	7.5-	5+	4.5+	20	
21	5+	5-	5	4			13+	11.5-	17.5-	16.5+			19-	18	17-	15	18-	16+	12.5-	12-	8+	7.5-			21	
22	5	5	4+	3.5+			13.5-	12-	17+	16.5-	17+	17	18.5	17.5	17-	15.5-	16.5-	15.5-			9-	8			22	
23	5+	5-	4	4-	8.5+	7	13.5-	12.5-	17-	16	18	16.5-	18-	17.5	17	15.5	15.5+	14.5			8.5	8-			23	
24	5	4+	4	3.5+	9.5+	8	13+	12	16+	15.5-	18-	17+	18-	17	16+	15.5	15.5+	14.5-			8.5+	8.5			24	
25	6-	4.5	4	3.5-	10	8.5	14-	12	17+	15.5	18-	17+	19.5	17	16.5	15+	16	14.5+			8+	8			25	
26	7-	6	4	3.5+	10.5-	9	13-	12+	17.5+	16-	17.5-	16.5-	19.5-	18-	16.5	15	16+	15				7.5			26	
27	7-	5-	N.D.		10	9	13.5-	12-	17	15.5	18-	16.5-	18	17.5-	17	15+	15-	14+	11.5-	10.5+					27	
28	5-	4+	N.D.		9.5+	9-	13.5-	12	17-	15-	17.5+	16+	19	16.5	17.5-	15.5-	14.5+	13.5-	11+	10.5					28	
29	6	4.5-			9	8	12+	12-	18+	15.5	17.5+	16-	19.5+	17.5+	17.5+	15.5	14+	13.5+	10.5+	10.5-					29	
30	7.5	6			8+	7.5+	11.5+	11+	18.5	16.5-	N.D.	16	20.5	17.5+	17+	16+	15	13.5-	11+	10.5					30	
31	8	7.5			8.5	7.5			19.5-	17.5-			21.5-	19-	17-	16-			11+	10.5+					31	
TOTAL																										
Monthly Means			6.35	5.79			11.45	10.13							19.15	17.47	17.32	15.83								
Monthly Mean of Max & Min																										

- NOTES:-
- The daily maximum and minimum temperatures should be entered to the nearest degree.
 - The mean temperatures should be computed to one place of decimals.
 - The highest and lowest temperatures recorded each month should be prefixed with the letters "H" and "L" respectively.
 - Entries to be in black ink or type.

COMMENTS:-

4-171

AIR
Calendar Day River Water Temperatures: 19.83.
IN DEGREES CELSIUS

HYDROMETRIC AREA NO.
OR GAUGING STATION NO.

RIVER
LOCATION RAF WYTON

Annual Summary				
Mean Max.	Mean Min.	Mean of Max. & Min.	Highest	Lowest

Day	JAN		FEB		MAR		APR		MAY		JUN		JUL		AUG		SEP		OCT		NOV		DEC		
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	
1	10.8	6.6	6.8	5.1	7.5	0.4	7.2	-0.4	13.0	7.7	22.2	10.7	20.9	6.6	19.0	12.1	21.5	14.4							1
2	6.9	1.5	6.5	0.3	6.8	3.2	8.2	1.3	9.0	6.6	18.0	11.2	21.6	13.0	18.0	9.0	21.1	11.5							2
3	12.0	5.2	4.0	0.8	11.0	5.5	7.1	-3.2	10.4	6.7	17.3	9.7	25.4	9.4	20.9	7.5	18.5	13.1							3
4	9.5	9.5	3.1	-4.6	7.4	3.4	8.5	-0.5	14.2	1.1	19.5	13.2	26.0	12.1	23.5	11.0	21.9	10.9							4
5	13.9	5.9	5.7	2.6	10.7	1.0	9.6	1.2	16.6	8.2	18.6	11.5	27.0	13.5	23.1	11.8	20.2	12.5							5
6	12.2	11.7	4.6	2.8	10.9	4.7	9.1	1.7	18.1	10.0	18.1	7.0	23.7	12.2	21.1	10.7	18.1	10.5							6
7	7.8	2.8	3.5	0.5	12.4	2.5	11.1	1.4	16.2	9.9	22.4	8.9	24.0	13.5	21.0	10.7	20.7	7.2							7
8	6.5	2.0	2.9	-0.2	12.7	1.7	9.4	3.7	15.9	10.0	23.8	15.9	25.7	14.0	23.1	13.0	17.8	11.0							8
9	9.7	6.0	-0.1	-2.5	10.7	5.0	12.4	0.2	12.9	7.2	20.2	12.6	26.5	14.0	23.6	13.8	18.8	13.0							9
10	11.2	2.7	0.5	4.4	14.0	2.4	13.5	4.6	13.5	3.6	19.0	9.6	22.6	14.0	21.3	14.0	16.1	10.2							10
11	9.9	7.4	2.1	-0.1	9.0	4.0	5.9	4.9	14.0	4.8	17.5	10.5	25.5	13.2	20.3	14.4	13.0	9.2							11
12	10.4	6.4	2.6	0.6	10.2	4.5	8.8	0.7	13.2	6.6	19.0	12.5	26.1	12.7	24.2	11.2	13.3	9.1							12
13	5.0	2.4	1.8	-4.5	14.8	5.0	11.5	0.6	14.9	6.9	19.0	7.3	24.5	13.5	22.5	10.3	13.8	7.1							13
14	9.0	1.0	2.7	-4.8	10.7	8.4	12.0	2.2	16.2	7.2	17.8	10.7	30.2	13.2	29.0	12.9	18.2	11.1							14
15	11.3	7.0	3.1	-1.6	10.9	0.4	16.4	2.5	13.8	6.1	17.2	6.6	32.0	18.2	27.8	15.4	13.2	13.3							15
16	11.0	9.0	3.2	-0.5	10.7	2.3	18.0	3.7	17.0	4.5	16.5	6.0	30.2	17.5	24.2	14.0	17.0	11.9							16
17	9.6	5.6	4.0	-2.5	14.3	8.6	8.6	7.8	15.9	7.4	18.1	10.4	29.4	14.9	21.5	16.1	17.9	11.0							17
18	5.8	2.5	5.9	-5.0	13.5	8.5	4.2	4.2	13.7	8.9	19.6	8.3	26.0	16.5	26.2	15.5	17.5	11.1							18
19	4.5	0.2	3.0	-5.0	10.7	9.4	6.2	2.5	13.5	4.7	20.8	5.9	22.2	13.5	28.9	12.5	16.8	10.7							19
20	4.3	-2.4	2.4	-0.4	11.8	4.4	9.5	0.2	13.5	6.1	22.2	10.3	18.4	12.2	25.0	15.1	16.1	8.0							20
21	7.3	3.5	4.3	0.0	9.7	1.9	12.5	4.6	13.0	7.1	19.0	11.2	24.0	10.8	25.1	15.7	12.1	9.9							21
22	5.8	4.9	3.3	-5.0	8.6	1.2	14.0	3.8	14.5	6.7	19.5	9.8	26.7	9.3	25.7	15.2	17.2	6.1							22
23	4.9	0.4	5.2	-4.0	11.2	7.9	14.0	7.5	14.6	6.5	17.7	12.9	21.2	14.7	26.7	14.6	20.7	10.1							23
24	9.8	0.5	5.1	-1.7	6.3	3.5	14.8	2.6	15.6	8.7	15.0	11.6	22.0	14.1	18.6	14.0	20.3	14.4							24
25	10.0	7.5	6.9	3.2	8.9	0.1	14.2	7.1	16.9	3.5	21.0	10.0	24.1	14.0	23.0	12.0	19.0	6.3							25
26	11.5	4.4	11.2	3.2	7.7	0.7	16.3	5.6	13.2	5.6	22.0	10.7	26.4	13.0	25.3	11.2	22.0	11.3							26
27	14.0	11.0	8.5	4.7	7.9	3.6	13.0	5.3	13.8	5.6	15.9	9.0	24.1	14.3	24.7	12.1	17.8	15.2							27
28	11.1	8.3	8.7	2.9	8.3	-1.5	15.1	4.2	10.0	7.5	19.6	7.1	25.2	14.2	14.2	13.5	19.0	14.1							28
29	9.4	6.0			8.8	1.5	14.6	4.6	12.4	8.2	20.0	14.0	30.1	14.1	18.6	12.2	17.5	13.6							29
30	3.9	2.8			9.4	3.3	15.3	6.0	14.0	7.8	16.2	11.4	24.1	13.6	21.7	7.0	15.0	13.0							30
31	12.0	0.9			9.8	2.1			20.6	9.3			27.7	16.5	25.6	10.9									31
TOTAL	280.0	143.2			115	104.6	341.0	90.6	446.1	210.7	571.7	306.5	787.4	416.3	718.4	384.4	557.1	330.8							
Monthly Means	9.0	4.6			10.2	3.4	11.3	3.0	14.4	6.8	19.1	10.2	25.4	13.4	23.2	12.6	17.9	11.0							
Monthly Mean of Max. & Min.																									

NOTES:-

1. The daily maximum and minimum temperatures should be entered to the nearest degree.
2. The mean temperatures should be computed to one place of decimals.
3. The highest and lowest temperatures recorded each month should be prefixed with the letters "H" and "L" respectively.
4. Entries to be in black ink or type.

COMMENTS:-