Factors Affecting Coarse Fish Recruitment

Phase II - Examination and Analysis of Existing Environment Agency Data

R&D Technical Report W2-048/TR

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This report summarises the results attained and conclusions derived from examination and analysis of the Agency's fish population survey data as identified in Phase 1 of this research project. The information will be useful for staff wishing to compare local trends in coarse fish recruitment and focus on factors to aid fisheries management. These results may assist in reviewing the monitoring of coarse fish populations.
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EXECUTIVE SUMMARY

The coarse fish populations of England and Wales are of great social and economic importance. In many areas of the country there is concern about large-scale variations in the performance of coarse fisheries within major river systems. Although natural fluctuations may account for some of the variability, these fisheries are under pressure from a range of factors. The importance of these coarse fisheries make it imperative that the interactions between the fish and their environment are properly understood, so that management strategies can be formulated based on sound technical and scientific knowledge. The aim of this project was to determine whether or not the data held by the Environment Agency are adequate to elucidate the main factors affecting coarse fish recruitment. This entailed primary analysis of the fisheries data and environmental information, such as water temperature, that are available within the Agency. In addition, the data were used to assess the most appropriate method of quantifying year class strength for subsequent analysis.

Data on surveys of coarse fish populations and associated habitats were collected from all 26 Areas of the Agency and assessed for their utility in examining aspects of fish population dynamics, specifically relating to numbers of fish recruiting to the populations at the age of first spawning. Collation of the data sets provided an appreciation of the type, quantity and quality of coarse fish survey data gathered over a period of years in each Area, its accessibility, storage formats and locations. Many shortfalls in the data were found with respect to quality and quantity to support assessment of the factors affecting coarse fish recruitment in rivers. This was mainly because the data were not collected for the purpose of understanding these processes.

Several methods for determining relative year class strength were tested and it was concluded that the method proposed by Cowx was the most appropriate for further statistical analysis of the factors affecting coarse fish recruitment in rivers.

All species displayed a period of good recruitment and stronger year classes during 1975-76, especially for roach and chub. A period of weaker year classes was observed during 1977-80 for all species except bream, the latter possibly because of errors in age determination.

Year class strength (YCS) of both roach and dace increased in 1982, with an even stronger roach year class present in 1983. Their YCSs remained relatively weak during 1984-87 and then increased again in 1988-90. Roach YCS was again relatively poor until 1995. Dace YCS increased in 1992, but responded less well than roach in the mid-1990s. A strong 1981 year class was observed in chub, a year before roach and dace, but it was followed by a series of weak year classes until 1995.

The analyses indicated that the strong roach and chub, and to a lesser extent bream and dace, year classes of 1975-76 have not been repeated in recent years and only roach appeared to be recruiting in a “consistently” cyclical pattern since this period. The relative strengths of the 1980-83 bream year classes are reflected in the relatively low YCS of many cohorts since this period, with 1987 and 1994 being the only two year classes that were prominent. Dace have not expressed a very strong year class since 1982 and may reflect considerable variation in YCS between rivers after this period. Chub also appear to exhibit a similar degree of variability in YCS between rivers in recent years, although ageing drift may account for some of this lack of complementarity.

It appears that higher than average ambient water temperature in the first year of life may be a major factor in the production of strong cohorts of adult cyprinid fish. However, whilst temperature explains much of the variation in year-class strength (YCS), it is not the only influential factor, since high temperature does not necessarily yield strong year classes. Furthermore, years in which a strong year-class is prevalent in one species do not necessarily result in strong year-classes in other coexisting species, suggesting other biotic and abiotic factors are important in regulating recruitment success.

The relationships between water temperature, river discharge, the position of the Gulf Stream, and 0-group fish growth and recruitment success (YCS) were examined for roach, bream, chub and dace in the Yorkshire River Ouse and River Thames. Mean length of 0-group fish at the end of the summer was positively correlated with water temperature (cumulative degree-days >12°C) and negatively correlated with river discharge (cumulative discharge-days above basal discharge rate). Year class strength was positively correlated with mean 0-group fish length at the end of the summer and with the latitude of the North Wall of the Gulf Stream. 'Critical periods' (i.e. periods in the first summer of life when fish may be more susceptible to increases in river discharge) were difficult to discern due to inter-annual variations in river discharge relative to the timing of fish hatching. YCS of roach was strongly negatively correlated with discharge in the period from June to September inclusive. River discharge (rather than water temperature) may be the key factor in determining YCS. It could be that, in effect, water temperature determines potential YCS while discharge determines realised YCS.

Recommendations for future work, both in terms of data collection by the Agency and projects to be undertaken by the Agency or in collaboration with external institutions are presented.

1. INTRODUCTION

1.1 Background

The coarse fish populations of England and Wales are of great social and economic importance since they provide a vast and valuable recreational resource, enjoyed by over 1 million coarse fish anglers. In many areas of the country there is concern about large-scale variations in performance of coarse fisheries within major river systems, as anglers' perceptions are that many rivers experienced marked decline in their status in the late 1980s and early 1990s (NFA 1999). Although natural fluctuations may account for some of the variability, these fisheries are under pressure from a range of factors. Unless these can be identified and strategies formulated to ameliorate their effects, riverine coarse fish resources may exhibit long-term decline. The importance of these coarse fisheries make it imperative that the interactions between the fish and their environment are properly understood, so that management strategies can be formulated based on sound technical and scientific knowledge.

During the early 1990s a research programme was undertaken, on behalf of the National Rivers Authority, to investigate the perceived major declines in coarse fish populations, particularly in the larger lowland river fisheries in England and Wales. The work produced three outputs. These were: NRA R&D Note 459, *Factors Influencing Coarse Fish Populations in Rivers: a Literature Review* (Cowx *et al*. 1993) an in-depth review of the literature; R&D Note 460, *Factors Influencing Coarse Fish Populations in Rivers* (Cowx *et al*. 1995), which summarised the current level of understanding of the natural factors affecting recruitment in coarse fish populations; and *Modelling Habitat Requirements of Coarse Fish in Lowland Rivers* NRA R&D Report 429/10/N&Y (Pitts *et al*. 1994). All these were updated and amalgamated in 2001 (R&D Publication 18). Pertinent conclusions from these studies were:

- Little is known about the early life history of coarse fish and the factors affecting individuals at this life stage, which have profound implications for recruitment to adult fish populations and subsequent year class strength.
- Temperature may exert an overriding influence on the growth of 0-group fish, but the way it does this has not yet been ascertained. It is possible that three consecutive months of high temperature are required to stimulate a strong year class, or that there is a threshold level of degree days above which a strong year-class will result.
- The supply of food and its variability at critical stages of development has been recognised as a significant factor in the growth of 0-group fish, which in turn influences subsequent year-class strength. However, there appears to be little or no empirical (Environment Agency) data available to justify this hypothesis and further work is required to clarify this situation.
- The growth of coarse fish in their first year of life is important in determining year class strength. However, in rivers, years of good growth do not always convert to strong year-classes, suggesting that other factors are responsible.

Under Section 114 of the Water Resources Act 1991, the Environment Agency has a statutory duty to maintain, improve and develop freshwater (i.e. including coarse) fisheries. For the Environment Agency to manage coarse fisheries effectively there is a requirement to understand the factors, both biological and environmental, that affect the abundance of fish populations and the mechanisms by which these factors operate. The previous studies showed that much of this understanding was still lacking. To resolve the situation, the Agency contracted four research institutions to scope a study to identify factors affecting recruitment in riverine coarse fish populations, quantify their impact and the mechanisms by which they operate. This work is reported in the Environment Agency Technical Report W75, *Factors Affecting Coarse Fish Recruitment* (Pinder *et al.* 1997).

The main species recommended for study varied among the contractors, but based on a scoring system, the order of priority of the top five was roach (*Rutilus rutilus* (L.)), common bream (*Abramis brama* (L.)), chub (*Leuciscus cephalus* (L.)), dace (*Leuciscus leuciscus* (L.)) and barbel (*Barbus barbus* (L.)). Recommended locations for study largely reflected the backgrounds of the contractors, but the Great Ouse, Yorkshire Ouse, Severn and Trent were all mentioned by two different contractors, and it is clear that there were significant data sets relating to the Thames and Dee. The main components suggested for study also varied, but habitat was suggested by all, and movement, dispersal, growth, diet and mortality were each suggested by three out of four.

Although the previous research highlighted the factors influencing coarse fish recruitment, it also concluded that data from the Environment Agency and its predecessors had not been critically analysed. Potentially there is a large volume of Agency data to contribute to research. NRA R&D Note 460 (Cowx *et al.* 1995) did, in part, instigate the process of examining data held by the NRA, but identification of suitable data sets for this purpose was primarily limited to regions that held habitat data, had evidence of anthropogenic effects upon fish stocks or held 0-group fish growth information. This potential source of valuable information prompted the EA to commission a project to review existing fisheries data in the Agency's domain. The aim was to determine whether sufficient quantity and quality of data were available within the Agency to detect variations in recruitment and then to explore factors influencing recruitment in coarse fish populations in England and Wales. The data review carried out by S. Axford was reported in an internal report - *Assessment and Collation of Existing Fisheries Data* held by the Coarse Fisheries Science Group (Axford 1999). In addition to the data review, the report drew attention to two Agency projects, the *Survey of the Coarse Fish of the River Tees – Effect of a Barrage* (Welton *et al*. 1999) and the *River Thames Juvenile Fish Surveys 1992-98* (Bark & Ball 2000) that are complementary to this area of research.

The potentially large volume of data available across the Agency, over very different geographical regions and river types, provides a unique opportunity to compare and contrast trends in fish populations subjected to different ecological conditions within their natural range. The differences in such a demographic study would be invaluable in determining factors influencing fish stocks, initially at a national level. Consequently the project was moved into a further phase of data analysis to identify whether the existing data sets were appropriate for understanding the processes of coarse fish recruitment, and where inadequacies, if any, in the data lay.

Also as a result of the recommendations of the early studies, the National Rivers Authority (the predecessor of the EA) and NERC jointly funded a post-doctoral fellowship study focusing on perch and pike in Lake Windermere. The work is reported in R&D Technical Report W222, *Population Dynamics of Underyearling Coarse Fish* (Paxton & Winfield 2000).

1.2 Project Aims and Objectives

The aim of the current project was to determine whether or not the data sources within the Agency identified by Axford (1999) were adequate to elucidate the main factors affecting coarse fish recruitment. This entailed primary analysis of the fisheries data and environmental information, such as water temperature records, that were available within the Agency.

Specific objectives of the study were to:

- collate and critically examine national data sets within the Agency domain to determine which are suitable for analysis to elucidate riverine coarse fish recruitment;

- determine which methods for determining year class strength and population structure are most suitable for evaluating Agency data;

- identify the likely factors affecting recruitment in different waters and species from Phase 1 and the NRA Coarse Fish Project Phase 1 outputs, and identify any additional data requirements and sources to enable study of these;

- examine the variation in year class strength and mortality between rivers and identify the factors responsible for any such variations;

- identify shortfalls and limitations of Agency data with respect to understanding the factors influencing recruitment process and to identify options for future research.

1.3 Definitions

Recruitment: This was defined by the project board as 'all autecological processes up to and including the age of first spawning' that relate to the addition of new fish to the population. (For the purposes of this investigation, no data were available on the age at first spawning and thus levels of recruitment were related to catches in surveys of fish beyond their first year of life).

Year class: All the fish in a population that were spawned in the same year, e.g. the 1998 cohort. The strength of a year class is a relative measure and indicates the abundance of one year class or cohort relative to others. A strong year class is one where that cohort is very abundant in the population taking into account its age and expected mortality rate.

Mortality (Z): The death of organisms; in fisheries it is usually expressed as an instantaneous rate (Z), comprising natural mortality (M) and fishing mortality (F) according to $Z = M + F$. In recreational fisheries, fishing mortality is usually assumed to be negligible and the total mortality is due to natural causes, i.e. the proportion of the population killed each year by predation, starvation, disease and old age. Instantaneous mortality rates can be calculated for particular time periods by determining the decline in the number of fish on a natural log scale between two periods such that $Z = \ln N_{t+1} - \ln N_t$

Survival (S): The survival rate represents the ratio of the number of fish alive at the end of a time period relative to the number in the same group alive at the beginning of that time period. It is related to the instantaneous mortality rate for the same time period according to the expression $S = e^{-Z}$

Degree days: The product of the time in days and the difference in the prevailing mean daily temperature and a threshold temperature, e.g. product of the number of days and the difference between the prevailing water temperature greater than 12°C is termed degree days above 12°C. (i.e. the sum of the number of degrees above a threshold temperature each day within a period of time). For example, if the mean monthly temperature for April is 12.5°C, there are 15 day-degrees above 12°C (30 days x 0.5°C), but there may be a short hot spell of say, 10 days at 18°C, and a cold spell below 12°C, so only those days above 12°C are counted which is equivalent to 10 days x 6 degrees or 60 day-degrees.

2. MATERIALS AND METHODS

2.1 Data Retrieval

2.1.1 Fisheries data

Data on surveys of coarse fish populations and associated habitats identified in Phase I of the project (Axford 1999) were collected from all 26 Areas of the Agency and assessed for their utility in examining aspects of fish population dynamics, specifically relating to numbers of fish recruiting to the populations at the age of first spawning (Table 2.1). Collation of the data sets provided an appreciation of the type, quantity and quality of coarse fish survey data gathered over a period of years in each Area, its accessibility, storage formats and locations. It also provided an appreciation of the main drivers that have shaped the type of data collected and formats of reports. Phase I of the project recommended that the study should concentrate on roach, bream, chub, dace and barbel. Unfortunately, insufficient data were available for barbel and it was excluded from the analysis.

Reports obtained during the data review, held at the National Coarse Fisheries Centre, were examined, data extracted and entered onto a pro forma Excel spreadsheet. Several additional reports, unavailable during the initial review, were found and used during Phase II.

All age frequency data identified as being worthy of further study were retrieved from the archive of EA / NRA fish age and length survey data held at Brampton Fish Ageing Unit and by the Coarse Fisheries Science Group. These data comprise predominantly age data by species, with sub-directories holding other parameters such as temperature, flow and water quality data. Age frequency data were extracted and loaded into the Excel pro-forma. Brampton archive data were available in an Excel format back to 1993, so data prior to this were retrieved from hard copy reports sourced during the data review. All hard copy reports were archived at the National Coarse Fish Centre for further use and reference.

All age data retrieved from population survey reports were assumed to be correct for the purposes of year class strength analysis. Although they had been subjected to analytical quality controls, changes to methods and personnel may have introduced errors. Apparent anomalies in data sets shown up by the analyses have been described, but no checks of accuracy of the original age determinations have been carried out.

Only two Regions, Thames and North East, held specific juvenile (0- and 1-age class) coarse fish data with sufficient temporal coverage to be considered suitable for including in the initial stages of the project. In the Thames Region, extensive juvenile growth, abundance and meso-habitat data were collected and analysed in relation to the Thames Water Abingdon Reservoir Project (TWARP) and these data were made available for this project. A summary of data collection and results are described *in River Thames Juvenile Fish Survey 1996 vol. 3 – Five Year Review* (Bark 1997). In brief, 0- and 1-age class fish were sampled quantitatively during the last week in July or first week in August at 14 sites on the River Thames between Oxford (Binsey, NGR: SP 495075) and Shillingford (below Day's Weir, NGR: SU 591929) from 1993-1998. A total of 16 species was recorded, of which 8, roach, dace, chub, bream, bleak (*Alburnus alburnus* (L.)), gudgeon (*Gobio gobio* (L.)), pike (*Esox lucius* L.) and perch (*Perca fluviatilis* (L.)) were caught in sufficient numbers to be included in further analysis. For the purpose of this project, roach, dace, chub and bream were initially considered so that direct comparisons to the adult data could be made. In the North East Region, data from

Table 2.1. Fish Population Survey Reports - Data Set Summary

River & Region	Reports	Species (approximate sample sizes)	Ageing	Supporting Juvenile Data	Comments
Ancholme (Main river) (Anglian)	1979, 1989, 1993, 1996	Roach (4k-11k) Bream (300-500)	Non-stratified in early surveys Age:length keys	No fry data	Temporal variation in survey programme until '89 Continuous temp monitors.
Witham (Bardney-Boston) (Anglian)	1981, 1985, 1988, 1991, 1994, 1997	Roach (3k-12k) Bream (250-3k) Dace (600-6k) no dace age data 1991 & 1997 variable site selection)	Non-stratified in early surveys Age:length keys	No fry data	Minimal temporal sampling variation Some changing YC observed.
Chelmer & Blackwater Canal (Anglian)	1986, 1989, 1992, 1995, 1998 (Two surveys per year spring & autumn)	Roach (200-3k) Dace (60-800) Bream (60-150) Chub (20-70)*	Age:length keys.	No fry data	Some editing of Brampton age data may be required. Fluctuations in some YC noted.
Colne (Anglian)	1984, 1987, 1990, 1993, 1996	Roach (500-2k) Dace (250-650) Bream(100-316) Chub (150-300)	Age:length keys.	No fry data	Some editing of Brampton age data may be required. Fluctuations in some YC noted.
Blackwater (Anglian)	1984, 1987, 1990, 1993, 1996	Roach (400-1.3k) Dace (250-650) Bream(100-316) Chub (250-800)	Age:length keys.	No fry data	Some editing of Brampton age data may be required. Fluctuations in some YC noted.
Suffolk Stour (Anglian)	1985, 1988, 1991, 1994, 1997 (Discrete samples of upper, middle and lower river)	Roach (1k-4k) Dace (400-1.2k) Chub (200-600) Combined site numbers.	Age:length keys.	No fry data	Some editing of Brampton age data may be required. Fluctuations in some YC noted.
Thames (Thames)	Annual surveys 1993-98	Roach (400-3k) Bream (30-60)* Chub (50-90)*	Scale samples non-stratified. Age:length keys. n=small	Quantitative fry data and associated habitat information. Some fry disease data.	Weakness in ageing data from relatively small scale sample size. Inter/intra temporal sampling variability
Hampshire Avon (South West)	1987 & 1991	Roach (250-300) Chub (250-400) Dace (1k-2k)	Age:length keys	Short run of fry and habitat data	Although short run of data, chosen due to lack of chalk stream examples. Large dace samples.
Dorset Stour (South West)	1992 & 1998	Roach (1.4-2.9k) Chub (100-200) Dace (200-400)	Age:length keys	Short run of fry and habitat data	Although short run of data, chosen due to lack of chalk stream examples. Large dace samples.
Ouse (North East)	1984, 1987, 1990, 1993, 1996, 1997, 1998	Roach (70-300) Dace (10-80)* Chub (18-60)* Bream (2-100)*	Scale samples from N.	Relative species abundance and growth from 1981. Some fry disease data.	Qualitative data, standard methods. Minor temporal variation. All fish aged from scales.
Wharfe (North East)	1984, 1987, 1990, 1993, 1996, 1997, 1998	Roach (10-127) Dace (30-100) Chub (10-180)	Scale samples from N.	Relative species abundance and growth from 1981. Some fry disease data.	Qualitative data, standard methods. All fish aged from scales.

* samples not considered for analysis of YCS due to either sample size or gaps in data.

qualitative fry surveys (1981-1998), representing 16 species from up to 19 sites and 11 river catchments, were available for inclusion in the project. Key survey data, from 1981, were identified from 8 sites representing 8 river catchments. Sampling was undertaken during the second and third week in September.

Coarse fish fry disease data produced and analysed by CEFAS and its predecessors since 1984, but more routinely since 1993, were formatted into an Excel spreadsheet. These data were then examined by year, types of disease organisms infecting fry, species of fish affected and by incidence of infection. For the purposes of this report, these data are restricted to some of the coarse fish fry monitoring sites in the North East Region from 1993-1997.

2.1.2 Environmental data

Flow

Flow data were readily available for most of the river systems under study in the form of daily and monthly mean flows. These data were supplied courtesy of Area Hydrometry staff. All data were transposed to Excel spreadsheets and are held by the Coarse Fisheries Science Group at Kidderminster. These were retained in their daily mean format to show rates of change, initially to examine flows that could be responsible for controlling wash-out of both juvenile fishes and food items (Pinder *et al*. 1992).

Temperature

Temperature data that were adequate to describe the temperature regime in different rivers were difficult to find, primarily due to their paucity, but also as a result of the manner in which some were archived. Some Regions have collected temperature data for considerable periods (>10years), but it would seem that very few of these data were kept or could be made readily available. Temperature data were recovered from either Environmental Protection or Water Resources departments. Data from Environmental Protection related to specific water quality studies and were often in short runs that were not suited to this project.

Three Regions, Thames, Midlands and Anglian had temperature data available that were recorded simultaneously with flow data at gauging stations and were most suitable for this study. In the Thames Region daily mean water temperatures from 15 minute continuous recorders were available for 1989-1998 at Northmoor (NGR: SP 436030) and Cleve (NGR: SU 600814), although large gaps exist in the latter. In the Midlands Region, data were available for the River Severn and Warwickshire River Avon between 1994 and 1999. Early data (starting c. 1980) had been archived, but their retrieval was not pursued due to time constraints on the project. Hydrolog data were available for 27 sites for water temperature and 8 sites for air temperature in the Anglian Region. Data remain available for up to 15 months, after which they are archived. The archive material ran from 1995 and the project was advised that an Information Systems Request procedure would be required to retrieve these data at a cost of £4.5k. These data were not requested for use in the project.

Some paper records were available from the Fisheries Department, South West Region, for local rivers, but time constraints of the project ruled out their use. North East Region held daily spot water temperature data (09.00 am) for the R. Ouse near York, from 1991-1998 (1993 missing), which were supplied courtesy of the local water company. Complementary to these NE Region data, mean daily air temperatures for Linton-on-Ouse near York, from 1980-1998, were available, which were correlated against the daily water temperature data to extend the data series. (To derive water temperatures a one day lag (t-1) of air temperature was used as *Water temperature* (*day i*) = *air temperature* (*day i* - 1) + 2.6154; r^2 = 0.7428, $P < 0.05$.) Daily mean water temperature data, recorded on Orion Tiny Talk loggers, were available for the River Tees from 1995, primarily to study the effects of temperature on fry in fish havens. Several gaps occur in these data and they were considered unsuitable for the project.

The daily mean data were formatted in two distinct ways. Cumulative degree days above thresholds of 5, 9, 12, 14, 18 and 20°C were calculated examine the relationships between degree days and fish growth and year class strength and assess whether Agency data are suitable for such analysis. Further analysis was carried out to ascertain which The total number of degree days in each month were also examined to determine whether variability and rate of change in temperature at different times of the year affects recruitment. Missing data were replaced using regression data from associated sites.

All data retrieved were transposed to Excel spreadsheets and are held at the Coarse Fisheries Science Group at Kidderminster.

2.2 Data Analysis

For the derivation of mortality rates and year class strengths, age frequency data from all sites on any given river were initially pooled to reduce effects of spatial variations in age structure within a catchment. This, in turn, increased sample size. No lower limit to sample size was set, instead the output was used to decide whether the data were appropriate.

2.2.1 Young of the year data

Fry data were gathered and compiled into mean length (mm) by species, by site and pooled sites. Where raw data were available combining both 0+ and older fish (NE Region), validation of 0+ fish was undertaken by examining the length frequency data and carrying out some scale analysis.

2.2.2 Instantaneous rate of mortality (*Z*) and survival (*S*)

From the age data the number of fish in each cohort was used to calculate the instantaneous rate of mortality (*Z*) using the regression between ln number in each age class (N_t) against age in years (*t*). Survival (*S*) was calculated as $S = e^{-Z}$, representing the mean annual survival rate over the period of years considered.

2.2.3 Year class strength

Three methods are currently available for assessing relative year class strength in coarse fish populations. These are those described by Mann (1973), Linfield (1981) and Cowx (Cowx & Frear - submitted). The three methods are described below and compared using appropriate data to evaluate the most suitable for future applications.

Relative year class strength (RYCS) (Mann 1973)

The calculation of RYCS is achieved by being able to monitor the contribution of cohorts between successive sampling periods, normally between periods of one year, and examining the abundance of each cohort relative to the total sample. The percentage number of fish in each age class for each period of capture (i.e. each year) is calculated and the mean percentage value each age class is then obtained for use as a standard. Relative year class strength is found by summing the percentage contribution of each year class through all years of capture and comparing this value with the sum of the standards for the same period. Table 2.2 shows the original data from Mann (1973) using River Stour roach as an example. The value for the 1967 year class was calculated as: 100 ((57.1 + 21.2)/(41.7 +16.8)) = 133.8.

Table 2.2. **Derivation of Relative Year Class Strength Following Mann (1973). Example based on numbers of roach in age classes 3-13 caught from the River Stour in successive years between 1969 and 1972**

Year of capture		**Age class**											
		3	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**Total**
1969-1970	**No**	21	21	27	11	8	3	4	6	2	3	0	106
	%	19.8	19.8	25.5	10.4	7.5	2.8	3.8	5.7	1.9	2.8	0	
1970-1971	**No**	12	2	3	2	0	1	0	0	0	0	1	21
	%	57.1	9.5	14.3	9.5	0	4.8	0	0	0	0	4.8	
1971-1972	**No**	25	11	4	3	5	2	0	1	0	0	1	52
	%	48.1	21.2	7.7	5.8	9.6	3.8	0	1.9	0	0	1.9	
Mean %		41.7	16.8	15.8	8.6	5.7	3.8	1.3	2.5	0.6	0.9	2.2	

Calculated values >100 are considered stronger year classes than values <100. This restricts the method to data sets containing two or more surveys in consecutive years. To reduce bias from sampling size selectivity the method omits fish <3+ years old. An assumption is made that all other age classes are sampled with the same probability of capture and the method is vulnerable to changes in capture efficiency between surveys.

Year class strength (YCS) analysis (Linfield 1981)

This method is based upon "standardised" mortality (or survival) rates, derived from existing data (Anglian Water survey reports and published data). The YCS is calculated by examining the difference between the observed percentage abundance of a particular age class and the expected abundance derived from a standard annual survival rate (*S*). The expected value is derived by plotting a line of ln % numbers against age with the gradient of the line equivalent to the standard mortality. The deviation of the actual % number from the line is the measure of year class strength. The analysis is restricted to cohorts >2+ years old, the limit of the sampling used, and the year class where the observed population has fallen to 1% of the total sample (thus removing the influence of a few older individuals). YCS values of twice the expected number are considered a strong year class, whilst a result of –100 indicates an absence of fish in a particular cohort. The standard survival rates calculated by Linfield (1981) were: 0.40 and 0.70 for roach (the two rates reflect differences found in the Anglian Region), 0.50 for dace, 0.70 for chub and 0.65 for common bream. A worked example of the method is given below based on roach caught in the June 1987 survey in Oulton Broad.

Age	1	2	3	4	5	6	7
Number of fish caught	14	1044	488	31	32	8	7
Year class	1986	1985	1984	1983	1982	1981	1980

The annual survival rate of the population based on regression analysis of the number of fish against age was S = 0.34, therefore the standard survival rate of 0.40 was adopted. The data indicate fish survive to age to Age 7 and sampling did not adequately catch age 1 fish.

Year class	1985	1984	1983	1982	1981
Expected %	60.6	24.3	9.7	3.9	1.5
Observed %	65.2	30.4	1.9	2.0	0.5
Difference	+4.6	+6.1	-7.8	-1.9	-1.0
% Difference	+7.6	+25.1	-80.4	-48.7	-6.2

As with the RYCS method of Mann (1973), the analysis is conducted on fish >2+ years old to reduce any size selective sampling bias from "under-sampled" younger cohorts. The analysis shows advantages over the RYCS method since it can be conducted on data from a single survey, removing any inter-year sampling variation that may occur through spatio-temporal variations within the population.

Year class strength (YCS) analysis (Cowx & Frear submitted)

The proposed method is based on a single survey of the target fish population(s) using any of the traditional active capture methods such as electric fishing or seine netting (Cowx 1995, 1996). It is important that the sampling method is not selective against specific age or length groups, although some account can be made for this problem.

During the fish survey a representative catch of all the size/age classes in the population is made, and scales or other hard structures are removed from a proportion of fish in each size group for ageing (Bagenal & Tesch 1978). The fish are aged from the scales in the normal manner to develop an age-length key in which the proportion of each size group is designated to an age class. The number of fish in each age class in the whole sample is then determined either directly from the fish aged or from the proportional representation of each age class in each length class, i.e. a static life table is produced.

From the ageing analysis, the number of fish in each cohort is used to determine the instantaneous mortality rate (Z) of the target population using the linear relationship between the natural logarithm of the number of fish in each age class (lnN_t) and age (t) (Fig. 1), according to $\ln N_t = \ln N_0 - Z_t$. Graphical presentation of these data should show if certain age classes, in particular the younger fish, are under-represented in the catches, although care should be taken to discriminate whether the poor catches are due to sampling efficiency or reflect weak year classes. If the younger age classes are considered to be under-represented then these data can be excluded from the determination of Z and the subsequent determination of YCS. It is also possible that longer-lived fish increase their mortality rate as they get older, often associated with the age at which they attain sexual maturity (Cowx 1990), and this should be taken into account when determining YCS.

The number of fish at time zero (N_0) is then calculated independently for each age class using rearrangement of the instantaneous mortality equation $N_0 = N_t \exp Zt$, where N_t is the number of fish at age t. If the mortality exhibits a marked inflexion at a specific age the number of fish at the age of inflexion (N_{inflex}) is first calculated using $N_{inflex} = N_t \exp\text{-}Zt$ where t is the number of age classes between N_t and N_{inflex}, and then the number of fish at N_0 is calculated from $N_0 = N_{inflex} \exp Zt_{inflex}$ where t_{inflex} is the age of the fish at the inflexion point.

The final step in the estimation of YCS is determining the mean number of fish in each age class at N_0 ($\overline{N}_0$) as $\Sigma^{tmax} N_0 / t_{max}$, where t_{max} is the total number of age classes represented. The strength of each age class, which can then be related to the spawning year (YCS), is determined by expressing the number of fish determined at time t_0 for each age class (or year),as an index standardised against a value of 100:

$$\text{YCS at age } t = (N_0 / \overline{N}) \times 100$$

A value greater than 100 represents a strong YCS and a lower value a weak YCS. Where data from a number of consecutive surveys are available, the analysis is carried out on each sample independently. The YCSs for each cohort from the separate analyses are then averaged to give relative (‘mean’ might be a better term) YCS values for the cohorts.

A worked example of the method is given below based on roach caught in the 1990 survey on the Yorkshire River Ouse.

Age	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Number of fish caught	59	51	20	36	9	16	9	4	5	1
Year class	1989	1988	1987	1986	1985	1984	1983	1982	1981	1980

The instantaneous mortality rate (Z) derived from the relationship between ln number of fish and age is 0.39. Back-calculation of the number of fish at time 0 (N_0), with a mean of 112. and the year class strengths derived by the Cowx and Frear method are shown below.

Year class	**1989**	**1988**	**1987**	**1986**	**1985**	**1984**	**1983**	**1982**	**1981**	**1980**
Back-calculated number at age 0 (N_0)	87	112	65	172	64	168	139	92	169	50
Year class strength – Cowx & Frear method	78	100	58	154	57	150	125	82	152	45

The analysis has the advantage over the Linfield method because allows incorporation of the younger and older age groups where adequate data are available.

2.2.4 Relationship between year class strength, fry growth and environmental variables

A series of linear regressions were calculated to investigate the relationships between water temperature, river discharge, latitudinal position of the North Wall of the Gulf Stream position (source for these data needs to be identified), and mean length and YCS of roach, chub and dace, and to identify the key correlates between the variables. The latitudinal position of the North Wall of the Gulf Stream was tested because it has been proven to be influential in affecting recruitment of shad (Aprahamian & Aprahamian 2001) and perch (Paxton & Winfield 2000). Data relating to the latitudinal position of the North Wall of the Gulf Stream for 1966-99 were obtained from the web site of the Plymouth Marine Laboratory (www.pml.ac.ac.uk/pml/srp1/gulfstream/gulfstr.htm).

3 RESULTS

3.1 Comparison of Methods for Deriving Year Class Strength

Fisheries survey data from the Yorkshire River Ouse, UK (Table 3.1) were used to evaluate and compare the outputs of the various methods. Triennial survey data were available from 1987, 1990 1993 and 1996, and annually from 1996 to 1998. Sample sizes were relatively consistent for both periods reflecting some changes in abundance from changes in year class strength. Data from the three consecutive years 1996 - 1998 were used for comparison with the method used by Mann (1973). For the Linfield method, which is based upon standardised survival rates derived from previous surveys, the average survival rate determined from all River Ouse surveys (S = 0.56) was adopted. The Linfield analysis was restricted to cohorts >2+ years old and the oldest year class where the observed population had fallen to >1% of the total sample (thus removing the influence of a few older individuals).

Table 3.1. Number of Fish and Percentage (in brackets) Caught in Each Age During Fisheries Surveys in the Yorkshire River Ouse

Survey year	Age class											
	1	2	3	4	5	6	7	8	9	10	11	12
1987	121 (62.7)	6 (3.1)	14 (7.3)	23 (11.9)	10 (5.2)	10 (5.2)	3 (1.6)	1 (0.5)	0 (0.0)	0 (0.0)	2 (1.0)	3 (1.6)
1990	59 (28.1)	51 (24.3)	20 (9.5)	36 (17.1)	9 (4.3)	16 (7.6)	9 (4.3)	4 (1.9)	5 (2.4)	1 (0.5)		
1993	52 (26.7)	21 (10.8)	33 (16.9)	65 (33.3)	12 (6.2)	4 (2.1)	2 (1.0)	1 (0.5)	4 (2.1)	1 (0.5)		
1996	298 (48.4)	119 (19.3)	35 (5.7)	63 (10.2)	53 (8.6)	28 (4.5)	18 (2.9)	2 (0.3)				
1997	455 (45.3)	312 (31.1)	134 (13.3)	41 (4.1)	29 (2.9)	18 (1.8)	13 (1.3)	0 (0.0)	2 (0.2)			
1998	455 (41.4)	324 (29.5)	217 (19.7)	41 (3.7)	16 (1.5)	32 (2.9)	8 (0.7)	4 (0.4)	2 (0.2)	1 (0.1)		

The mortality rates of roach derived from each of the fisheries surveys on the River Ouse were relatively consistent (Fig. 3.1), with variation mainly the result of the longevity of dominant year classes, which tended to be exhibited by an increase in survival. The highest survival rate was observed in 1990 (S = 0.67), when the population had not shown any strong recent recruitment of fish >2+. The lowest rate was noted in 1993 (S = 0.43), concomitant with a high representation of younger fish in the population.

Both the Cowx and Frear method, and that developed by Linfield, more or less described the same strong and weak year classes within each survey (Table 3.2), and overall (Fig. 3.2), but the Linfield method returned negative values for the weaker year classes, whilst the Cowx method returned positive values only. The Cowx and Frear method was also able to define a wider range of year classes from each survey because the younger classes (< 2+) were included when the data were considered adequate. Both analyses highlighted the strong 1981 year classes, but the Linfield method failed to discriminate very strong 1983 and 1984 year classes identified by the Cowx and Frear method. The remainder of the year classes in the 1980s were relatively weak, most notable in 1985 and 1987, and were discriminated by both methods. However, the Cowx method highlighted an increase in YCS from a low in 1987 to a series of relatively strong year class strengths between 1990 and 1992, followed by a notable poor year class represented by the 1993 cohort and a very strong 1995 year class. These are known trends in the fish populations exhibited by angler catches but the Linfield method was less able to discriminate these later strong and weak year classes.

Table 3.2. Comparison of Year Class Strength Data for Roach from the River Ouse Derived by the Cowx (Cowx & Frear, Submitted) and Linfield (1981) for Individual Surveys

Survey year	Method	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
1987	**Cowx**	61	103	193	109	141	48	12	133											
	Linfield	-39	2	90	6	37	-53													
1990	**Cowx**		55	184	100	152	182	69	188	70	121	95								
	Linfield		30	265	63	106	105	-35	45	-55										
1993	**Cowx**					251	438	48	42	36	48	113	25	7	7					
	Linfield							7	139	-67	-62	-58	-29	114	-39					
1996	**Cowx**										37	207	178	197	136	44	88	128		
	Linfield												-60	113	76	86	24	-61		
1997	**Cowx**										130	0	223	159	132	96	161	192	144	
	Linfield													20	-7	-16	-34	21		
1998	**Cowx**										99	114	114	113	226	56	72	190	141	99
	Linfield											-56	-50	-44	25	-65	-50	49		

The Mann YCS method indicated a strong 1988 year class, with a slightly weaker 1989 YC (Fig. 3.3), the converse of the Cowx method. Trends in the other year classes (1990-1995) showed good agreement between these two methods.

For reasons discussed in Section 4.2, the Cowx method was adopted as the mechanism for deriving YCS for this report.

3.2 Year Class Strength and Mortality

Data from 11 English rivers within four EA regions were found to be suitable, at least in part, to support the analysis. There were 32 samples representing the four target species roach, bream, chub and dace. The rivers and species for which data were utilised in the initial stages of the project are described in Table 2.1. A full record of the data and their limitations are available from the Coarse Fisheries Science Group at Kidderminster. Evaluation of the variation in YCS is presented in the following sub-sections for the four species. The data presented are the mean YCS for the individual rivers. Full details of the results based on individual surveys are held by the Coarse Fisheries Science Group at Kidderminster. In this report, only the most notable variations are highlighted. Where possible differences in YCS resulting from temporal variation in sampling time, variation between different reaches of the same river and sampling intensity are described.

The mean instantaneous mortality rates for the four species under study varied between rivers and between sampling occasions (Table 3.3). Reasons for the variable mortality rates are unknown but may be due, in part, to sampling biases and discrepancies in the data. The longer lived species, chub and bream had the lower instantaneous mortality rates. This would be expected given the propensity for large individuals to survive and often dominate the population structure. This is an aspect that needs further study.

Table 3.3. Variation in Mortality (*Z*) in Different Rivers. Mean and Range from Surveys on the Various Rivers are Given

	Roach	Bream	Chub	Dace
Ancholme	1.06 (0.94-1.23)	1.19 (0.76-1.55)		
Witham	1.20 (0.74-1.34)	0.61 (0.40-1.00)		1.02 (0.86-1.12)
Thames	0.77 (0.48-1.10)			
Ouse(Yorkshire)	0.64 (0.39-0.83)			
Wharfe	0.82 (0.65-0.97)		0.36 (0.20-0.57)	0.58 (0.38-0.89)
Stour(Dorset)	0.76 (0.56-0.96)		0.27 (0.21-0.32)	1.11 (1.05-1.17)
Suffolk Stour(lower)	1.00 (0.69-1.30)			0.92 (0.63-1.51)
Suffolk Stour(middle)	0.77 (0.62-0.81)		0.37 (0.13-0.84)	0.98 (0.69-1.16)
Suffolk Stour(upper)	0.65 (0.46-0.70)		0.50	0.98 (0.62-1.27))
Suffolk Stour(All sites)	0.71 (0.65-0.81)		0.49 (0.23-0.64)	1.07 (0.69-1.44)
Colne		0.57 (0.36-0.52)	0.32	0.55 (0.31-0.82)
Blackwater			0.52 (0.35-0.50)	0.58 (0.15-0.99)
Chelmer & Blackwater	0.76 (0.40-1.04)	0.49		1.13 (0.90-1.39)
Avon (Hampshire)	0.95 (0.40-1.44)		0.22 (0.17-0.27)	0.73 (0.69-0.93)
Nidd			0.31	

3.2.1 Roach

Roach were ubiquitous within the sample data, providing the largest sample sizes in all but the Hampshire R. Avon and R. Wharfe. The results of the year class strength analyses are presented in Figure 3.4 where the outputs for individual rivers are compared with the average for all rivers studied.

Roach data from the main **R. Witham**, referred to in survey reports as section 4 (Bardney to Boston), had the most extensive data set represented by up to 11 year classes in a single sample (1988), and up to 20 269 fish in the 1988 survey. These samples were obtained by similar methods and effort (N. Bromidge, pers. comm.) indicating notable intra-population fluctuations (in age composition and therefore recruitment). The 1975 year class was by far the strongest in the R. Witham, with 1976-1979 year classes becoming progressively weaker. The 1981 and 1982 year classes were notably stronger than an apparent phase of poor “production” between 1983 and 1987. The 1988-1990 and 1992 were also relatively strong. The differences between strong and weak year classes suggests that there is a 5-6 year “cycle” between periods of good recruitment.

Sample sizes from the **R. Ancholme** ranged from 3835 (1979) to 11 233 (1993). The 1975 year class was particularly strong, as were the 1982-1984 cohorts. In later years the 1989 and 1990 year classes were the strongest.

Sample sizes from the **Chelmer & Blackwater Canal** taken in spring were relatively consistent between 1104 (1998 survey) and 1808 individuals (1989 survey), with the exception of a notably large sample of 3234 in 1992, reflecting a large number of individuals from the 1989 year class. The strongest of the older cohorts was from 1976, a characteristic generally atypical of that found in the other rivers, and may be the result of error arising from ageing old fish where the annuli on scales of older fish are hard to discriminate and are frequently overlooked. The 1983, 1989 and 1990 year classes were also strong, similar to the R. Ancholme.

Sample sizes from the autumn surveys were similar to spring, with the exception of 1992, when the autumn sample size was notably lower (n = 217 fish). Good agreement was generally found between the strengths of the year classes derived from the spring and autumn surveys in 1986 and 1989, but the complementarity was less in later surveys (Fig. 3.5). The trends observed in the spring surveys were generally consistent with those of the autumn in describing the strong 1976, 1983, 1989 and 1990 year classes (Fig. 3.5) but not in all surveys. These data suggest that differences in population structure exist between spring and autumn, possibly brought about by aggregations of larger fish in the spring prior to spawning.

There was relatively large variation in sample sizes from surveys on the **R. Colne**, with 525 fish in 1990 and 2426 in. The strongest year classes were similar to those observed in the spring Chelmer and Blackwater surveys, except the strong mid-1970s year class in this case was 1975 and not 1976, In addition 1983, 1989 and 1990 were good recruitment years.

Wide variation in sample size was prevalent in surveys from the **R. Blackwater**, with a relatively low sample size in 1984 (n = 376) but a notably larger sample (n = 1109) in 1989. The largest sample attained in 1993 (n =1341) reflected the strength of the 1989 and 1990 year classes. The structure of the samples again reflects a strong 1976 year class, although 1975 was also strongly represented. The 1982 year class was the strongest of the early 1980s, whilst the 1990 cohort was the strongest in the period of apparent good recruitment between 1988 and 1991.

The **R. Stour** was surveyed in three reaches (upper, middle and lower) giving three discrete samples enabling examination of spatial variability in year class structure (Fig. 3.6). The upper R. Stour survey sample sizes varied from n = 233 in 1980 to 2471 fish sampled in 1985. The 1980 survey was the earliest available for analysis for this project and as such gave a brief insight into cohorts prior to the "dominant" 1975-1976 year classes found in other rivers, with the 1972 year class particularly prominent. The mid-1970s year classes in the upper River Stour were relatively weak and unlike other sections of the river did not dominate the population. As in other rivers, good recruitment in 1981 generated the strongest cohort within a decade. Relatively strong year classes were also observed from recruitment during 1984 and 1985. Improved recruitment was observed in 1988, but by far the strongest cohort to appear in this period was 1991.

Sample sizes from the middle reaches of the R. Stour ranged from relatively small in 1981 (n=182) to 1824 fish in the 1988 sample. This variability in catch appears to reflect the absence of strong older cohorts in the middle section samples compared with the upper section samples. The strong 1972 year class was absent in the 1981 survey and therefore the 1970s year classes were dominated by the 1975 cohort. The notable strong 1982 year class was absent in the upper reaches suggesting a possible ageing error or that the population recruited well in two consecutive years, with each cohort expressing some degree of spatial separation. The 1983 and 1985 cohorts are relatively weaker than the 1984 cohort compared with respective YCS in the upper reaches. Similarly the 1989 cohort in the middle reaches was the strongest of the late 1980s and early 1990s year classes.

Sample size variability was greatest amongst the lower R. Stour surveys, with the smallest sample in 1994 (n = 39) based on only two cohorts and the largest sample size was in 1985 (n = 1032) as a result of good recruitment in 1981 and 1984. The YCSs detected in the lower river showed similarities to those of the other reaches with strong 1972, 1983-85 and 1991 year classes similar to one or both the other reaches. The 1977 and 1986 year classes were particularly strong in the lower river. Although this may be highlighting spatial variability, it may also be highlighting potential ageing errors.

The combined R. Stour site data show the least inter-survey sample size variability, with the largest sample recorded in the 1985 survey (n=4109) as a result of the 1981 and 1982 cohorts, whilst the smallest sample was recorded in 1997 (n=1246). The combined YCS data indicate that the 1975 year class was relatively strong in the R. Stour, but it was replaced by the 1981 cohort. The "anomalies" in YCS observed between the middle and upper sections of river, with respect to the 1981 and 1982 year classes indicate that these were both relatively strong cohorts, as was 1984. 1989 was the strongest of the late 1980's cohorts in the combined sample, whilst 1991 was particularly noticeable in all samples and was the strongest of this period.

Potential ageing errors were highlighted as a result of the 1975 and 1976 year classes interchanging in the outputs. This raises the need to examine all adjacent cohorts. In the R. Stour examples this would require scrutiny of scale samples from 1981 and 1982 cohorts and 1984-85 samples to ensure the validity of the above observations.

As indicated in Table 3.1, data from the **R. Thames** were taken from small, non-stratified scale samples and occasionally fish were not aged or assigned ages for the older (>9+) cohorts, which may have affected the interpretation of the YCS of some of the older cohorts. Despite fluctuations in the number of fish caught in each survey, the 1989 year class was very strong. The 1994 year class was also strong, which is contrary to other rivers examined. The 1986 and 1993 year classes were the poorest, whilst little differentiation was evident in year class strength during the period 1987-1991.

Two surveys (1987 and 1991) from the **Hampshire R. Avon** were examined for trends in YCS in southern chalk streams. The output indicated the presence of a relatively strong 1976 year class, with 1975 and 1977 also prominent, again possibly suggesting that scale samples require some further evaluation. The 1982 year class appears to be the strongest of the early 1980s, although the 1983 and 1984 year classes were also prevalent, but it should be noted that these values are constructed from relatively small sample sizes. A relatively large sample of 3+ fish (1988 year class) in the 1991 survey generated a very strong year class, whilst effectively suppressing the representation of other cohorts. More recent survey data will be required to determine how successful the 1988 year class has been.

Two surveys (1992 and 1998) were available for examination from the **Dorset R. Stour**, each having relatively large sample sizes (n = 2903 and n = 1411 respectively). Too few older fish were caught to elucidate the presence of the mid-1970s cohorts, but the early 1980s year classes were similar to those observed on the R. Avon, with the 1982 year class appearing as the strongest, whilst 1983 and 1984 were also evident. The late 1980s were represented by a very strong 1989 year class, whilst the 1994 year class, similar to the R. Thames, appears the strongest in the 1990s.

Triennial survey data were available from 1984 to 1993 and annually from 1996-98 for the **Yorkshire R. Ouse**. Sample sizes were relatively consistent throughout, reflecting some changes in abundance from changes in year class strength. There was evidence from the 1984 and the 1997 samples that some minor variability in sampling occurs, which could be associated with a spatial component of the programme. The analysis again highlighted the strong mid-1970s year classes, but the 1975 year class was the stronger of the 1975 and 1976 cohorts. 1981 was a relatively strong year class, similar to observations from the R. Witham and the Suffolk R. Stour. The 1983 and 1984 year classes were the strongest in the R. Ouse in the 1980s, whilst the mid-1980s year classes were relatively weak, most notably in 1985 and 1987. An increase in YCS was observed in 1989, with the strongest in this period being 1990, a trend similar to that in the R. Colne and R. Blackwater. Year class strengths were similar in 1990-1992, with a notable poor year class represented by the 1993 cohort. 1995 was the strongest of the later 1990s cohorts.

Sample sizes from the **R. Wharfe** were relatively small for all but the 1998 survey in which fish from the 1995 year class were numerous. The two main objectives for retaining this sample for analysis were: 1) the river supported good dace and chub populations and therefore it would be useful to make comparisons between species; 2) to evaluate the use of small samples. YCS values reflected trends similar to those observed in other rivers. The 1975 year class was by far the strongest. The 1982 year class was the strongest in the period 1981-1983, but the very strong 1985 year class was biased by a single fish in the 1990 survey. The 1989 and 1990 year classes were relatively strong, along with 1995.

Due to the lack of data across all rivers, the mean YCS values constructed from data prior to 1975 and after 1995 are not included in the profile. **In summary**, a consistent and very strong 1975 year class was prevalent in all rivers followed by poorer recruitment in the period 1977-1979. A period of good recruitment was observed during 1981-1985, with 1983 being consistently the strongest year class, but again followed by a period of poorer recruitment during 1986-87. There was again a production of stronger year classes during 1988-1991, with the 1989 year class appearing the most consistent. The 1993 year class was consistently poor across all rivers. The 1995 year class was strong across several rivers, whilst the R. Thames and Dorset Stour exhibited a stronger 1994 year class.

3.2.2 Bream

Bream data were suitable for analysis from only four watercourses (Witham, Ancholme, Chelmer & Blackwater canal and Colne), plus possibly the R. Thames (Fig. 3.7). In each sample the mortality rates were difficult to determine due to notable inflexions (see section 2.3).

The sample sizes from the **R. Witham** were the largest of the four available, but showed notable variation, n = 247 (1981 survey) to n = 2757 (1985 survey). It is suggested that these differences may be associated with the spatial distribution of the fish during the survey and not sampling effort (N. Bromidge, pers. comm.) A small sample of bream caught in the 1991 survey again indicates either a marked spatial shift in the population or inconsistent post-catch scale sampling and fish measuring, but there is no mention of either of these possibilities in the report from which these data were extracted. A very strong 1973 year class was evident, but this was superseded by the ubiquitous 1975-76 fish, of which the latter appears stronger. This contrasts with the picture in the roach population where the 1975 year class was by far the stronger. The early 1980s produced a relatively good 1982 year class, the same as the roach, whilst 1987 was the strongest in the late 1980s. This again contrasts with the roach YCS data in which 1988 appears the stronger. The 1994 year class was the strongest in the 1990s, analogous to a strong cohort in the R. Thames roach population, whilst the R. Witham roach population exhibits a stronger 1992 year class.

Three surveys (1989, 1993 and 1996) were available for analysis from the **R. Ancholme**, and again catches suggest that shoaling behaviour and spatial variability may have affected sample, with a notable increase in 1996 (n = 594), particularly of older (>10+) fish. The 1972 year class was, similar to the R. Witham, very strong and also superseded by the 1975 and 1976 year classes. The apparent longevity of the bream has given rise to these cohorts being "dominant" in the population for at least 10 years. In general, recruitment was weak until the 1982 and 1994 year classes contributed strongly to the population.

Very strong year classes were indicated for the years 1977-79 in the **Chelmer & Blackwater Canal.** However, these may have arisen from a few old individuals (>10+) surviving through to the time of the surveys. Also, the low likelihood of three consecutive strong year classes suggests that the ageing may be problematic and these fish may have originated from the very strong 1975-76 period. The 1981-83 period also produced three relatively strong year classes, in which 1981 and 1982 were particularly strong, the latter concomitant with the roach population.

The sample sizes from the **R. Colne** were relatively consistent, reflecting changes in recruitment success (n = 108, 1984 survey to n = 316, 1990 survey). The 1975 year class was the stronger of the 1975-1976 classes, whilst 1979 appeared to be the start of a series of years in which recruitment was good. This may be an artefact of sampling selectivity in surveys in the late 1980s missing younger age classes or highlight the lack of any strong year classes coming through from the mid-1980s. Coincidentally, roach populations in the R. Colne were also supported by a strong 1979 year class.

Data for the **R. Thames** are somewhat dubious with a series of strong year classes from 1978-1982 followed by an almost complete disappearance of bream from the catches. Whether this is the actual situation needs clarification.

In summary, only four watercourses were available to examine trends in bream YCS, the rivers Ancholme and Witham in Lincolnshire and the R. Colne and Chelmer and Blackwater canal in Essex, all of which were in the Anglian Region. The rivers Witham and Colne were the only rivers in which pre-1977 cohorts could be studied. Both rivers demonstrated strong 1975-1976 year classes, with possibly ageing drift a likely source of error. All the bream populations exhibited strong year class production in the 1980-1983 period. The 1981 year class was the strongest in the R. Colne but 1982 was stronger in the R. Witham; a single strong year class is less evident in the R. Ancholme and the Chelmer and Blackwater canal. The R. Witham data indicate a period of increased recruitment during 1987-89 and a similar situation in the Chelmer and Blackwater canal, but this was not detected in other rivers, suggesting spatial variation may be affecting the interpretation of these year classes or bream had disappeared from the community.

3.2.3 Chub

Data were available for analysis from nine rivers (Thames, Colne, Blackwater, Suffolk & Dorset Stour, Warwickshire and Hampshire Avon, the Nidd and Wharfe) (Fig. 3.8). The longevity of the species along with accuracy of age determination in older cohorts creates problems with interpretation of year class structure and relies on the ability to follow cohorts through a series of samples. The calculation of mortality rates was even more problematic than for the bream samples, primarily due to the "dominance" of older cohorts.

Five triennial surveys (1984-1996) on the **R. Colne** were available for analysis, with relatively large sample sizes, making it one of the best groups of data for examination. Sampling effort was consistent (R. Burrough, pers. comm.), which is reflected in the sample sizes, although some spatial variation in fish distribution may have been present. The 1975 year class was extremely strong in comparison to all others suggesting that the relatively strong 1976 and 1977 cohorts may result from "ageing drift" as a result of problems associated with accurately ageing older chub (>14+). Poorer recruitment/survival was evident during 1985-1988, followed by improved success with the 1989-90 year classes.

The **R. Blackwater** chub data were the most comprehensive set available for analysis, with large samples from a series of five triennial surveys (1984-1997). The 1976 year class was exceptionally strong and was not replaced until a series of good year classes between 1983 and 1985. Again it is suggested that "ageing drift" may be responsible for this phenomenon of several strong year classes.

Only two of the three discrete sampling areas in the **R. Stour** (upper and middle) contained sufficient fish to examine any spatial variability in year class structure (Fig. 3.9). A series of strong year classes was found between 1975 and 1981, 1979 being the notable exception.

Thereafter recruitment was very poor, although this could be a reflection of the strong 1970s year classes surviving in the population and influencing the analysis, or spatial segregation, as these cohorts were prevalent in the middle R. Stour. A similar, but less pronounced, pattern of spatial separation was observed in the roach population. As described above the year class strengths of chub in the middle reaches of the R. Stour were consistently around average except for strong year classes in 1973, 1976 and 1991. The period between 1984 and 1987 was associated with a series of weak year classes. The combined R. Stour data resulted in two periods of strong year classes between 1974 and 1979 and again between 1991 and 1993. These strong year class clusters dominated the population of chub in this river.

Two surveys were available for analysis from the **Hampshire R. Avon** (1987 and 1991), the latter of which was split into two spatial components of 11 and 22 sites to assess whether the output of the analysis changes as a result of sampling intensity. The instantaneous mortality rates based on the 11 and 22 sites were 0.27 and 0.17 respectively. A comparison of YCS data from the 1991 survey (Figure 3.10) indicated no significant difference in describing the trends in YCS structure of the population between the 11 and 22 sites, although the data from the 11 site were slightly biased towards an increased YCS of the 13-15+ age classes. These data suggest no significant spatial age differences amongst the sites. The 1975-1977 year classes were strong and dominated the populations. It is unclear if the 1977 year class strength is an artefact of "ageing drift" or a genuine strong year class. The year class strengths of other cohorts were comparatively low due to the very strong mid-1970s year classes, although 1986 was notably poor.

Data for the **Dorset R. Stour** were available from surveys in 1992 and 1998, when sample sizes were 207 and 110, respectively. The YCS analysis indicated only four age classes >3+ in both surveys, which was based on a very strong 1981 year class and a relatively strong 1982 year class. 1983 to 1985 were notable for poor year classes, with 1987, 1990 and 1992 being slightly stronger.

Data from the **R. Wharfe** were available from a series of five triennial surveys (1984-1996) and a further two annual surveys (1997-1998). Increased sampling effort during 1996-1998 was undertaken to improve spatial coverage, hence the increase in sample sizes. Again the 1975 and 1976 year classes were very strong. There was a series of relatively strong year classes between1982 and 1985. The 1989 1990 and 1995 cohorts were also relatively strong.

Data from a single survey on the **River Nidd** (1996) were included for analysis due to the large sample sizes attained from an intensive survey designed primarily to remove as much spatial sampling variability as possible. A total of 625 fish, representing 16 age classes were included in the analysis. High recruitment and mortality variability in cohorts <10+ made calculation of mortality and survival rates problematic. The best-fit regression was attained from 10+-18+ fish, with a mortality rate = 0.31. The YCS structure was dominated by 1981-1983 cohorts, with 1980 to 1985 also well represented. These data may reflect a component of ageing error about a single strong year class, since the construction of the year class analysis relied upon the accurate ageing of many fish >10+, including fish up to 18 years of age. Where they were represented, the younger cohorts (for which ageing errors are far less likely) indicated that the 1994 year class was relatively strong.

The combined chub data highlighted similar problems to those found for bream, with ageing drift sometimes masking what initially appeared as a single strong cohort across several rivers. **In summary**, all rivers again demonstrated a strong period of recruitment for chub in

1975 and 1976, with the peak of recruitment for the rivers Wharfe and Colne in 1975, whilst 1976 was the strong year class in the rivers Stour, Blackwater and Hampshire Avon. 1977 to 1980 was a period of low recruitment success for most rivers, after which stronger year classes were recorded in several rivers between 1981 and 1985, although ageing drift may account for this broad window of strong recruitment. Weaker year classes were noted during 1986 and 1988, whilst improved recruitment was again seen during 1989-91 and in 1995.

3.2.4 Dace

Data were suitable from all watercourses apart from the rivers Ancholme, Thames and Yorkshire Ouse (Fig. 3.11). Sample sizes were highly variable across rivers, with good samples for analysis from the Suffolk R. Stour and Hampshire R. Avon.

Data related to the **River Witham** were from a restricted number of surveys as ageing data were incomplete for earlier surveys. The YCS analysis indicated three strong cohorts between 1978 and 1993, i.e. the 1979, 1984 and 1990 year classes. The 1982 and 1983 year classes were also relatively strong, but the lack of age data from the 1997 survey prevented any further interpretation with regard to the future strength of these later year classes. The 1986 year class was absent and the 1993 year class was very weak.

Five triennial surveys (1986-1998) were available for analysis of YCS of dace in the **Chelmer & Blackwater Canal**. In all but the 1989 survey, fish over 5+ (4+ in the 1986 sample) were absent. Due to the short life span of dace in this system or the effect of spatial distribution of older fish, very few year classes were evident from one triennial survey to the next, which affected the analysis. The 1980 year class was particularly strong in the 1989 survey, despite its absence in 1986, whilst the 1984 year class was overall stronger in this two triennial survey period. The 1987 year class was by far the most dominant in the 1992 survey, when survival rates were estimated to be low at 0.27 yr^{-1} and despite the 1989 year class being represented in both the 1992 and 1995 surveys it was relatively weak. The 1993 year class was the stronger of those represented in the relatively poor sample size of the 1998 survey.

The samples attained from the five triennial surveys (1984-1996) on the **R. Colne** indicated that the number of cohorts represented by each survey got progressively less over the 12 year period and provided a similar result to other rivers in that the sample sizes also fell. The YCS analysis highlighted the presence of strong 1975 and 1976 year classes, which is consistent with the other species. Despite this similarity with other species the 1979 year class was the strongest during the 1970s and not the 1975/1976 year classes. Strong year classes then appeared every 3-4 years through the 1980s, with the 1982, 1986 and 1989 and 1990 relatively strong.

Apart from the R. Witham, the **R. Blackwater** had the largest sample sizes of dace available for analysis in the 1987 and 1990 surveys. The 1982 year class was by far the strongest of the year classes described, which is analogous to the R. Colne. However, unlike the R. Colne, the overall strength of most of the other year classes relative to 1982 was similar, reflecting much less variability in the overall final contribution of each cohort.

The **R. Stour** was surveyed in three reaches (upper, middle and lower) enabling examination of spatial variability in year class structure (Fig. 3.12).

Sample sizes from the upper reaches of the R. Stour were relatively consistent except where a prolific year class was detected, e.g. 3+ year old fish in the 1985 and 1991 surveys. The 1976 year class was the strongest of the mid-1970s, but ageing drift may account for the almost equally strong 1977 year class. A series of relatively strong year classes (1982, 1988, 1989 and 1992) were found through the 1980s and early 1990s. The years 1979-81, 1987 and 1991 were notable for poor recruitment.

The middle section of the R. Stour has a much reduced age distribution compared with the upper section, with an apparent decline in age range post 1988, which is a trend not too dissimilar to that observed in the R. Colne. A series of strong year classes every 3-4 years (1975, 1979, 1982, 1985, 1989, 1993) was apparent. The strong 1982 year class evident in the upper section was also the strongest in this section, but no other cohort was particularly strong in the remaining surveys.

The lower section of the R. Stour also exhibited a reduced number of age classes compared with the upper section. Due to the relatively low number of older age classes in this section, the mid-1970s cohorts were not described and only the 1983 and 1986 year classes were particularly strong, despite initial indications that the 1981 and 1982 year classes had recruited well. This strongly suggests that spatial separation of age classes was evident across the sections.

The combined R. Stour data, eliminating as far as practically possible spatial variation, indicated a shift in longevity of the species with time. The population post-1988 comprised fish <7+ years old, whilst prior to this, in the 1985 and 1988 surveys, 7-12+ fish were evident. The combined YCS data indicated a strong 1977 year class, which may indicate some ageing drift (i.e. mis-ageing older fish from the 1975/76 cohorts) and bias from single fish within the samples of more recent surveys. The 1982 year class was the strongest in comparison to all other age classes, whilst the 1985 and 1988 year classes were relatively strong. The 1992 year class was the strongest in the 1990s. These data reflect similar trends to those observed in the rivers Colne and Wharfe whereby good recruitment is punctuated by one or two poorer years.

The two surveys available for analysis from the **Hampshire R. Avon** showed a greater range of age classes present in the 1987 (11 sites) survey than the 1991 survey, primarily as a result of a prolific 1976 year class. As with other species, the 1976 year class was prevalent, but was less evident in dace in other rivers. The 1982 year class was particularly strong, whilst neither the 1983 and 1984 year classes developed into strong year classes. The strong 1982 year class is analogous to those seen in the rivers Blackwater, Colne and Suffolk Stour.

Two surveys were available from the **Dorset R. Stour** in 1992 and 1998, with sample sizes n = 440 and n = 200 respectively, both of which had younger cohorts (3-4+) numerically dominant. The 1987 and 1990 year classes were notably the strongest, with a relatively strong 1995 year class more recently.

Although the sample sizes from the **R. Wharfe** were low (n = 33-102) in comparison with other rivers, the relatively consistent sampling approach over the 14-year period of five triennial surveys plus two additional annual surveys provides one of the largest temporal data sets on which to examine year class trends. A similar pattern of year class strength, and ultimately recruitment, to that seen in the R. Colne data was found. There are periods of either one or two years of poor recruitment in between stronger year classes, with the most notable poor periods being 1979-80, 1986-87 and 1993. The strong 1970s year classes were 1977 and 1978, generally atypical of most other rivers, whilst the 1981, 1982 and 1984 year classes were relatively strong, with a strong 1982 year class being analogous with the rivers Colne and Suffolk Stour, whilst a stronger 1984 year class was similar to the R. Witham. The 1989 year class was by far the strongest recorded, whilst the 1992 and 1994 year classes were relatively strong in the 1990s.

In summary, all rivers except the Witham showed an increase in YCS during the 1975-77 period, but with little consistency (Fig. 3.10). The R. Colne exhibited a strong 1975 year class, whilst the strong year class in the Hampshire Avon was 1976 and the Suffolk R. Stour, R. Blackwater and the R. Wharfe had strong 1977 year classes. The R. Wharfe also had a strong 1978 year class, and the strongest year class observed in the R. Witham was 1979. The consistently strongest year class across seven of the eight watercourses was from the 1982 cohort. Only the Chelmer and Blackwater canal failed to respond in a similar manner. Post 1982 there was very little consistency across all rivers, although often pairs of rivers are noted to respond in producing strong year classes in the same year. For example, the R. Wharfe and R. Colne year classes reflect similar trends apart from 1986 when the R. Colne exhibited an "improvement" in YCS, whilst a very weak year class was observed on the R. Wharfe. Similarly the Dorset R. Stour and the Chelmer and Blackwater canal share some common trends in several post 1982 year classes.

3.2.5 Comparison of year class strength between species

All species indicated a period of good recruitment and stronger year classes during 1975-76, with roach and chub supporting the strongest YCS (Fig. 3.13). A period of weaker year classes was observed during 1977-80 for all species except bream, the latter possibly because of ageing drift. The strength of the 1980-83 bream year classes is reflected in the relatively low YCS of many cohorts since this period, with 1987 and 1994 being the only two year classes that were prominent.

Year class strengths of both roach and dace increased in 1982, with an even stronger roach year class present in 1983. Their YCSs remained relatively weak during 1984-87 and then increased again in 1988-90. Roach YCS was again relatively poor until 1995. Dace YCS increased in 1992, but responded less well than roach in the mid-1990s. A strong 1981 year class was observed in chub, a year before roach and dace, but it was followed by a series of weak year classes until 1995.

The analysis indicated that the strong roach and chub, and to a lesser extent bream and dace, year classes of 1975-76 have not been repeated in recent years and only roach appeared to be recruiting in a "consistently" cyclical pattern since this period. Dace have not expressed a very strong year class since 1982 and may reflect considerable variation in YCS between rivers after this period. Chub also appear to exhibit a similar degree of variability in YCS between rivers in recent years, although ageing drift may account for some of this lack of complementarity.

3.3 Coarse Fish Fry Growth and Year Class Strength

Fry were collected annually from a number of sites on the Yorkshire Ouse. However, the number of fish varied between years and between species. Fry growth for the combined site data were examined for nine species (Fig. 3.14) and also relative to their long term mean (Fig. 3.15). The growth for all species exhibited a “cyclical” pattern of poor and good growth, with notable similarities in the occurrence of these phases across species, i.e. dace:chub r = 0.89, df =16, $P < 0.001$. Phases of good and poor growth for all species normally fell between a factor of 0.8 and 1.2 of their mean length; exceptionally, some species, e.g. bleak, attained maximum growth of 1.4 times their mean value in 1990. In the North East Region fry exhibited periods of good growth during 1983-84, 1989-91 and 1995. Poor growth phases were prevalent in 1985-88 (poorest 1986-7) and exceptionally poor in 1993, whilst, more recently, fry growth was poor in 1998. Roach, chub and gudgeon all expressed their maximum recorded fry lengths in 1995, bleak and dace in 1990. The lowest recorded fry lengths were in either 1987 (dace and chub) or 1993 (gudgeon, bleak and roach).

The mean fry lengths of roach for eight rivers in the North East Region (Figure 3.16) reflect the above observations, although some inter-river differences in growth were evident. For example, fry growth was consistently lower in the R. Aire at Keighley compared with most other rivers, whilst the R. Hull at Hempholme exhibited the greatest variability in mean fry length. Fry data for the R. Ouse at Beningbrough are the most consistent in terms of catches, with samples of n>20 obtained for every survey 1981-1999 and are the most suitable for comparison with other variables.

Year class strengths of roach from the **River Ouse at Beningbrough** exhibited a weak, although significant relationship with the mean length attained by roach fry during the 1981-1998 period (Figure 3.17; $r^2 = 0.44$, df = 14, $P < 0.005$). All strong year classes identified in the adult population, particularly the 1984 and 1995 year classes, were characterised by relatively large fry in the September of their first year of life. Conversely the weaker year classes, notably 1985-87 and 1993 had low mean fry lengths. However, not all years in which fry attained large mean length in September were transposed into a strong year class. This was most evident in the 1989-91 period. From the period 1985-87, the 1986 year class was dominant in the adult population yet the mean fry lengths for all three years were very similar.

No relationships were found between mean fry lengths of roach, dace and chub from the **River Wharfe at Boston Spa** in September and their respective YCSs (Fig. 3.18). Despite the poor correlation in roach fry data, the strong 1989 and 1995 year classes were associated with large mean fry sizes in September and conversely the weaker 1986-87 and 1993 year classes correspond to low fry lengths. Dace show far fewer associations between fry length and YCS, with the weaker year classes of 1986-87 and 1993 the only notable associations with lower fry growth. The very strong 1989 year class corresponded to a mean fry length (45.1 mm) similar to the long term mean value for this site (44.8mm).

The growth of fry and 1+ fish in the **River Thames** is well documented in the TWARP study and is only briefly described here for chub, dace, roach and bream to draw comparisons with YCS data. The mean lengths attained by 0+ and 1+ fish are compared with their long-term mean (5 years; Figure 3.19). The poorest growth year for 0+ chub, dace, bream and 1+ chub was 1993, although 1995 was notably poor for all species and age classes. Although 1998 was a relatively poor growth year for 0+ fish, all 1+ fish attained lengths above their mean values. 1994 saw the highest lengths attained by 0+ chub, roach and bream, whilst dace were larger in 1996 and 1997. The differences in mean length attained between “good and bad years” about the long-term mean show less variation than in the North East Region, although at this stage it may reflect the relatively short run of R. Thames data for comparison.

A relatively strong correlation was found between year class strength of the adult roach and mean length of 0+ fish ($r^2 = 0.63$, df = 4, $P > 0.05$) and 1+ fish ($r^2 = 0.79$, df = 4, $P < 0.02$) (Fig. 3.20), however, the former was insignificant as both are based on small samples. Notwithstanding this, the strong 1994 year class corresponded with the largest mean lengths attained by 0+ and 1+ fish, indicating that conditions that helped determine the strong 1994 cohort were also beneficial to increasing the growth rate of the weaker 1993 year class. Similarly the weak 1995 year class was associated with both low 0+ and 1+ growth, with the most notable effect observed in the 1+ fish, i.e. the strong 1994 year class grew poorly in 1995. This suggests that growth in either the first or second years of life, or both, determines YCS.

The length frequency data from both the R. Thames and several of the North East rivers exhibited pronounced bimodality (e.g. Figure 3.21). This has been recorded since the early fry surveys in 1981 in the North East region (D. Hopkins, pers. comm.) and subsequently in other fry distributions from the R. Tees (S. Welton, pers. comm.) and the R. Trent (Nunn *et al*. 2001). The causes for this are unknown but may have serious implications on analyses of mean fish length against other parameters.

3.4 Fry Growth, Temperature and Flow

3.4.1 Inter-river temperature comparisons

Daily mean temperature data for the rivers Thames, Warwickshire Avon, Severn and Yorkshire Ouse for the period 1993 to 1998 were compared. These data demonstrated that the water temperature profiles in each river were similar, although there were slight differences in the temperature ranges. For example, the Warwickshire R. Avon was marginally warmer than the R. Severn by up to 2°C during the summer, but these differences become smaller (<1°C) during the winter. A similar relationship was found between the R. Avon and the R. Thames, with the Avon being warmer than the Thames. The temperature profiles for the River Thames and Yorkshire Ouse were similar.

3.4.2 Temperature and fry growth

Fry growth and temperature relationships were examined in the TWARP study for R. Thames populations. The conclusions drawn indicated that only weak and insignificant correlations existed, and that temperature was a poorer descriptor of fry growth than, for example, fry density. This result contradicts the published literature, where significant relationships between fry growth and temperature (usually measured in degree days above 12°C) are indicated (e.g. Mann & Mills 1985; Mann 1995). These weak relationships for the Thames were probably the result of fry samples being taken in July, before 0+ group fish had achieved maximum growth for the first year of their life.

By contrast, growth of chub fry sampled from the Yorkshire R. Ouse and the R. Wharfe in September exhibited significant correlations with R. Thames water temperature data at >9°C, (*Fry length* = 29.5 *DD^9°C* – 404.1; $r^2 = 0.48$; $P < 0.05$) 12 (*Fry length* = 24.0 *DD^12°C* – 3.7; $r^2 = 0.55$; $P < 0.05$) and 14°C degree days (*Fry length* = 19.7 *DD^14°C* – 158.1; $r^2 = 0.57$; $P < 0.02$). Positive, but insignificant, correlations were observed for the R. Wharfe, but again indicate the similarities in river temperature regimes across Regions.

Roach fry data (1984-98) for the Yorkshire R. Ouse were used to evaluate temperature and flow interactions in more detail. A significant correlation ($P < 0.05$) was found between the mean length attained by 0+ group fish in September and the number of degree days >12°C (Fig. 3.22). However, the very strong 1995 year class, which was associated with good fry growth (the largest recorded fry ever at this site) had only the third highest number of degree days above 12°C in the period 1992-1998, with higher values recorded in 1997 and 1996 (Fig. 3.23). The temperature regimes experienced during the 1990s varied markedly, with 1995 experiencing temperatures below 12°C as late as mid June, after which they rose rapidly. Temperatures in 1996 and 1997 rose much quicker in the early part of the year. In 1993, the year with the poorest fry growth on record, there was a much warmer spring than 1995, but the summer temperatures were much lower, with temperatures below 12°C recorded in August.

3.4.3 Fry growth, flow and year class strength

The contrasting mean lengths of 0+ roach in September in the R. Ouse for 1993 and 1995 were associated with the contrasting flow regimes experienced in these years (Fig. 3.24). 1995 was a dry year with low river flows recorded from April and continuing through the following winter, whilst flows in 1993 were characterised by high flows, particularly during spring and summer and in some cases floods (May and September).

Flow regimes experienced by roach fry in the Yorkshire R. Ouse, for the 1984-98 period, were examined using the degree days concept, by calculating the number of days with mean daily flow above the basal flow rate in each month. The basal flow was determined as the mean daily flow over the 15-year period. The mean length attained by roach fry in September was related to five different flow conditions: number of days above the basal rate and the number of days flow was 1.5, 2, 2.5 and 3 times above the basal rate (Table 3.4). Lengths of 0+ fish in September were negatively correlated with all these monthly basal flow characteristics but the strongest relationships were with flows in April, May and September, especially under basal, x 1.5 and x 2 conditions.

Year class strength of roach in the Yorkshire R. Ouse was examined in a similar way to evaluate the effect of flow (Table 3.4). Low YCS values were correlated with elevated flow characteristics experienced in the July-September period, with no particular flow regime contributing any major significant affect.

In order to examine the likely effects of a single high flow event affecting fry growth and YCS the maximum mean daily flows for each month in the 1984-98 period were also examined for roach in the Yorkshire R. Ouse (Fig. 3.25). Maximum 0+ fry length was negatively related to maximum mean daily flow, especially in May, June and September. Similarly, YCS was negatively correlated with maximum mean daily flow, especially in May and September.

A summary of the influence of environmental parameters shows low flows, and high temperature conditions are associated with increased fry growth and subsequent strong YCS of that cohort (Fig. 3.26), although further multiple regressions are needed to confirm this observation. From 1984-1995 these associations were prevalent, but they diverged in 1996 and 1997, when high cumulative degree days >12°C were not associated with strong year classes, but days above basal flow rates were higher than those observed in years of very

Table 3.4. Relationships Between Number of Days Above Basal Flow Rate (basal rate, basal rate x 1.5, basal rate x 2, basal rate x 2.5, basal rate x 3) in Different Months and Length of 0+ Roach in September and Year Class Strength

		Length	Year class strength
April	Basal rate	$y = -0.38x + 35.2$ ($r^2 = 0.384$)	$y = -1.38x + 108.0$ ($r^2 = 0.08$)
	Basal x 1.5	$y = -0.62x + 35.1$ ($r^2 = 0.37$)	$y = -2.57x + 109.5$ ($r^2 = 0.09$)
	Basal x 2.0	$y = -0.84x + 34.8$ ($r^2 = 0.41$)	$y = -3.81x + 108.2$ ($r^2 = 0.11$)
	Basal x 2.5	$y = -1.14x + 34.7$ ($r^2 = 0.39$)	$y = -4.92x + 107.2$ ($r^2 = 0.09$)
	Basal x 3.0	$y = -1.01x + 33.56$ ($r^2 = 0.23$)	$y = -1.76x + 98.4$ ($r^2 = 0.01$)
May	Basal rate	$y = -0.44x + 35.1$ ($r^2 = 0.56$)	$y = -2.27x + 112.3$ ($r^2 = 0.28$)
	Basal x 1.5	$y = -0.46x + 33.8$ ($r^2 = 0.37$)	$y = -2.10x + 105.7$ ($r^2 = 0.14$)
	Basal x 2.0	$y = -0.75x + 33.7$ ($r^2 = 0.38$)	$y = -3.60x + 106.1$ ($r^2 = 0.16$)
	Basal x 2.5	$y = -1.04x + 33.7$ ($r^2 = 0.40$)	$y = -4.93x + 105.3$ ($r^2 = 0.16$)
	Basal x 3.0	$y = -1.21x + 33.6$ ($r^2 = 0.40$)	$y = -5.97x + 105.5$ ($r^2 = 0.17$)
June	Basal rate	$y = -0.41x + 35.0$ ($r^2 = 0.47$)	$y = -2.58x + 111.7$ ($r^2 = 0.19$)
	Basal x 1.5	$y = -0.39x + 33.5$ ($r^2 = 0.25$)	$y = -4.29x + 106.4$ ($r^2 = 0.14$)
	Basal x 2.0	$y = -0.50x + 33.2$ ($r^2 = 0.25$)	$y = -10.89x + 108.4$ ($r^2 = 0.30$)
	Basal x 2.5	$y = -0.57x + 33.0$ ($r^2 = 0.23$)	$y = -15.92x + 109.3$ ($r^2 = 0.33$)
	Basal x 3.0	$y = -0.66x + 32.8$ ($r^2 = 0.19$)	$y = -21.02x + 105.6$ ($r^2 = 0.23$)
July	Basal rate	$y = -0.27x + 34.1$ ($r^2 = 0.23$)	$y = -2.85x + 117.2$ ($r^2 = 0.42$)
	Basal x 1.5	$y = -0.24x + 32.9$ ($r^2 = 0.08$)	$y = -3.44x + 110.7$ ($r^2 = 0.29$)
	Basal x 2.0	$y = -0.38x + 33.0$ ($r^2 = 0.10$)	$y = -5.02x + 110.6$ ($r^2 = 0.33$)
	Basal x 2.5	$y = -0.52x + 32.9$ ($r^2 = 0.10$)	$y = -6.50x + 107.4$ ($r^2 = 0.26$)
	Basal x 3.0	$y = -0.39x + 32.3$ ($r^2 = 0.04$)	$y = -6.71x + 103.6$ ($r^2 = 0.18$)
August	Basal rate	$y = -0.36x + 34.5$ ($r^2 = 0.40$)	$y = -3.06x + 119.6$ ($r^2 = 0.50$)
	Basal x 1.5	$y = -0.36x + 33.8$ ($r^2 = 0.31$)	$y = -3.21x + 115.9$ ($r^2 = 0.45$)
	Basal x 2.0	$y = -0.37x + 33.3$ ($r^2 = 0.24$)	$y = -3.42x + 111.4$ ($r^2 = 0.37$)
	Basal x 2.5	$y = -0.48x + 33.1$ ($r^2 = 0.22$)	$y = -4.41x + 109.4$ ($r^2 = 0.33$)
	Basal x 3.0	$y = -0.65x + 33.0$ ($r^2 = 0.21$)	$y = -5.64x + 107.6$ ($r^2 = 0.28$)
September	Basal rate	$y = -0.40x + 35.2$ ($r^2 = 0.33$)	$y = -3.37x + 125.4$ ($r^2 = 0.43$)
	Basal x 1.5	$y = -0.56x + 34.8$ ($r^2 = 0.31$)	$y = -5.16x + 125.2$ ($r^2 = 0.46$)
	Basal x 2.0	$y = -0.76x + 34.6$ ($r^2 = 0.28$)	$y = -7.21x + 123.6$ ($r^2 = 0.46$)
	Basal x 2.5	$y = -1.03x + 34.2$ ($r^2 = 0.26$)	$y = -10.83x + 123.4$ ($r^2 = 0.51$)
	Basal x 3.0	$y = -1.47x + 33.9$ ($r^2 = 0.28$)	$y = -12.83x + 116.6$ ($r^2 = 0.38$)

strong year classes, suggesting the flow component in "warm, wet years" remains a controlling influence in growth and subsequent YCS.

3.5 Climatic Factors Influencing Recruitment

Data relating to the latitudinal position of the North Wall of the Gulf Stream (Paxton & Winfield 2000) for 1966-99 were obtained from the web site of the Plymouth Marine Laboratory (www.pml.ac.ac.uk/pml/srp1/gulfstream/gulfstr.htm). Simplified observations of the mean annual latitudinal position indicate periods of south shifts during 1969-1982, with the exception of positive (north shift) phases in 1975 and 1977 (Fig. 3.27). North shifts were predominant during 1983-1995, with two negative phases in 1986-87.

Roach mean fry lengths from the R. Ouse at Beningbrough were examined in relation to temporal variation in latitudinal position of the North Wall of the Gulf Stream. Mean 0+ fish length in September was best correlated, although not significantly, with the mean annual latitudinal position of the North Wall (Figure 3.27). Year class strength data for roach from the R. Ouse also showed a very strong positive correlation, with the August and mean annual North Wall latitudinal position ($P < 0.001$ and $P < 0.005$ respectively), for 1975-1995 (Figures 3.28).

The same relationships were found for other river systems and species (data available from the Coarse Fisheries Science Group at Kidderminster). Most of the river systems expressing a strong 1975 year class of roach fit well with the August latitude, but inverse relationships were seen with August latitude for several other strong year classes, particularly in the Dorset, R. Stour. Rivers such as the Colne and Blackwater suggest a lag phase between strong YCS and North Wall latitude, although how much of this observation and that found with several other rivers is an artefact of ageing drift is unclear.

3.6 Diseases of Coarse Fish Fry

3.6.1 *Myxobolus* sp. infections in muscle

Data on the prevalence of *Myxobolus* sp. in chub, roach and dace between 1993 and 1996 across 22 sites, primarily in the North East Region were provided by CEFAS (M. Longshaw pers. comm.) (Table 3.5). The highest incidence of infection was in 1993 for all species. The percentage of chub infected in 1994 was lower than the previous year and no infected roach or dace were found. Infection levels generally increased in 1995 and 1996, although inter-site variability was high.

3.6.2 CEFAS 1996 fry parasites investigation

Histological material from roach, chub, dace and minnow from 14 sites in the North East Region were screened for parasites (Table 3.5). Protistan parasites were observed in the greatest number of locations within the host, including: muscle, kidney, gills, fins, spine, urinary bladder, stomach wall and mouth (Table 3.5). Parasites belonging to the Monogenea, Digenea, Nematoda, Acanthocephala and Cestoda were all recorded in a range of host tissues. The prevalence of the various parasites and their location and level of infestation vary between species (Table 3.5).

<u>Roach</u> (10 sites, nine rivers examined): The highest level of incidence of all parasites detected in roach was *Myxobolus* sp. and *Posthodiplostomum* sp. in muscle tissue; 58% (n = 31) and 94% (n = 17) respectively. *Myxobolus* sp. occurred in 50% of the 10 rivers examined, whilst *Posthodiplostomum* sp. was recorded in 70%.

<u>Chub</u> (11 sites, nine rivers examined): *Myxobolus* sp. was found in chub muscle tissue at all 11 sites surveyed. This parasite had the highest mean incidence of infection of all the other species of fish and parasites recorded (72.3%; n = 11 sites). The highest incidence (91.3%; n = 23 fish) occurred in fish from the River Tees at Low Moor. Similar to roach, *Posthodiplostomum* sp. was also found at a relatively high incidence across rivers (8 out of 11), with 100% of fish (n = 27) infected in the River Ouse at Beningbrough. The overall mean level of infection for this parasite in chub was 32.2%. *Myxobolus* sp. cysts were also

found in gill tissue at seven sites, although the mean incidence of infection was relatively low (6%; n = 29).

Table 3.5. **Parasites Recorded in 0+ Fish - Description and Pathology**

Parasite	**Tissue location**	**Fish species infected**	**Pathology comments**
***Myxobolus* sp.**	muscle, gills, spine	Roach, dace, chub	Significant in high numbers particularly muscle and spine infections and after cysts rupture.
Myxozoan	Fins and urinary bladder	Roach, dace	No significant tissue damage observed
***Myxidium* sp.**	Kidney	Roach, minnow	Significant in large numbers
***Hoferellus* sp.**	Kidney	Roach, dace, chub	No significant tissue damage observed
***Trichodina* sp.**	Gills, urinary bladder	Roach, dace, chub, minnow	Significant in heavy infections
Peritrichous ciliates	Gills, mouth	Chub, minnow	Significant in heavy infections
***Coccidia* sp.**	Stomach wall	Roach	Significant. Most of stomach wall appears non-functional due to parasites.
***Gyrodactylus* / *Dactylogyrus* sp.**	Gills	Roach, minnow	Significant in heavy infections
***Posthodiplostomum* sp.**	Muscle	Roach, dace, chub, minnow	Significant in heavy infections
***Phyllodistomum* sp.**	Urinary bladder	Roach, dace, chub, minnow	Not known.
***Diplostomum* sp.**	Eye, brain	Roach, dace, chub, minnow	Significant in heavy infections. Cranial cavity overtaken by parasite in certain rivers.
Digenea	Gut, viscera, liver	Chub, minnow	Minor significance at levels observed
***Sanguinicola* sp.**	heart, gills, kidney	Chub	All levels of infection may be significant.
Nematodes	Gut, viscera	Roach, chub, minnow	Minor significance at levels observed
Acanthacephala	Gut	Roach, dace, minnow	Minor significance at levels observed
Cestodes	Gut	Roach, minnow	Significant. Occlusion of the gut observed.

Dace (5 sites, 3 rivers examined) *Myxobolus* sp. in muscle tissue and *Phyllodistomum* sp. were recorded in the urinary bladder of dace from four of the five sites surveyed. The prevalence of *Myxobolus* sp. in dace was much lower than other fish species (13.6%), whilst the opposite was found for *Phyllodistomum* sp. (3 out of 5 sites), with all fish sampled from the River Swale at Thornton Bridge (n = 9) and the River Derwent at Bubwith (n = 10) infected. The Bubwith sample showed the highest number of individual parasites found per fish (n = 90), with a notable 586 parasites recorded from the ten fish.

Minnow (14 sites, 7 rivers examined) Minnow data are included to highlight comparisons with the major species studied and to emphasise the broad parasite groups detected. The parasite fauna were notably different to the other fish species, with *Diplostomum* sp., the most widespread detected parasite (at 12 of the 14 sites), found in brain tissue. The level of incidence (x = 34.5%) was highly variable, from 1-50 parasites per fish. *Trichodina* sp. was found on the gills of minnows at 10 sites, with up to two-thirds of the fish infected. *Posthodiplostomum* sp. was noted at 8 sites, with the River Derwent at Bubwith again showing the highest level of infection.

4 DISCUSSION

4.1 Data Quality and Availability

4.1.1 Fish population data

Much of the project time was used to collate and format the adult fish population survey data from 59 individual surveys, up to four species in each survey producing 223 data sets in all. Of these 42 were considered unsuitable due to small sample sizes or notable ageing anomalies. Juvenile coarse fish data representing a large temporal span were collated from the NE Region, and together with the six-year TWARP study, provided the only link in Agency data between adult and juvenile fishes.

As highlighted in the data review, the key component of this study relied fundamentally on data sets from surveys covering long temporal spans, which described the age structure of populations. Of the 12 key river data sets identified in the review as being suitable for inclusion in Phase II, eight were used for analysis, primarily due to the time constraints associated with compiling the data into suitable format. The main problems associated with the data not considered suitable were:

- the requirement to convert length frequency data into age distribution data using length for age keys;
- obtaining the age data;
- short temporal data sets;
- accessibility.

However, six data sets, originally not regarded as meeting the selection criteria were analysed in Phase II (Yorkshire R. Ouse, R. Colne, Suffolk R. Stour, R. Blackwater Hampshire R. Avon and Dorset R. Stour). The last two rivers were included due to the general paucity of Agency data, particularly on the southern chalk streams.

Good quality data within the Agency domain and fulfilling the criteria required for Phase II analysis were dominated by surveys in the Anglian Region, most of which were based upon triennial surveys dating back to the early 1980s. Supportive data were readily available from the North East Region, although one of the key data sets (R. Wharfe) identified in the data review was limited by small sample sizes of roach. The Yorkshire R. Ouse roach data were later included into Phase II primarily to examine associations with the good fry data set available for this river.

The annual survey data available for the R. Thames, R. Wharfe and Yorkshire R. Ouse were more useful than the triennial based data for quickly identifying anomalies in ageing results between surveys and examining trends in YCS. Cohorts for species such as dace, which at best will be present in only two consecutive triennial surveys, give just two observations of the year class under study, whilst annual data are key to describing trends in shorter-lived species. This project would have been greatly enhanced by more annual data to support observations made from the triennial ones, but more importantly to give greater accuracy to age determination. All the age data retrieved for analysis from the individual survey reports or Brampton Archive had undergone analytical quality control (AQC) procedures during age determination and had been considered correct in survey reports. However, in the course of the project it became apparent that notable year classes would apparently oscillate between years. This phenomenon referred to as "ageing drift" (i.e. incorrectly determining the age of older fish from scales because of difficulties in discriminating annuli on the scale margin) was assumed to be due to the inherent difficulty of correctly ageing fish as they become older, because of such difficulties as false checks and scale erosion This source of error when describing YCS can also be generated by the inappropriate use of age:length keys when non-stratified scale sampling (i.e. the length categories from which the scale samples were taken were not representative of the population of the whole) has been undertaken. This type of error was most obvious in the R. Thames data and as a result the chub and bream were unsuitable for cohort analysis.

The inherent problems associated with the accurate ageing of old fish can be significantly reduced by increasing sampling frequency, thus detecting strong cohorts at an earlier age and following their life history through subsequent surveys. The element of risk for the scale reader associated with this approach is to always "fit the age to the scale" to ensure that a strong cohort previously observed is maintained. The very nature of this and future projects reliant on accurate age data will need to increase accuracy from age determination processes.

It was difficult to obtain some data held by contractors who had undertaken the work for the Agency and its predecessors. The TWARPS data were readily available and supplied to the project in full, whenever requested. Difficulties in retrieving the data held by CEH, relating to the R. Tees study precluded their use in this project. Data held by CEH relating to the long-term study of fish recruitment in the Great Ouse, which were identified in the data review as a key data set for Phase II, were initially considered, but cost associated with their retrieval again precluded their use in this phase of the study.

Survey data relating to the five key species identified in Phase I (roach, bream dace, chub and barbel) were of restricted occurrence, with only roach present in all data sets. No suitable data sets containing temporal trends for barbel were found. Bream data were the most limited of the data sourced, relying exclusively on survey information from four rivers in the Anglian Region.

4.1.2 Temperature and flow data

One aspect of this project was to examine the value of Agency data for understanding the relationships between growth, temperature, flow and YCS (e.g. Mann 1973; Mills & Mann 1985; Ladle 1991; Cowx *et al*. 1995; Paxton & Winfield 2000).

Since temperature is a key energetic component of biological systems it was surprising to find so few records, particularly in the possession of or available to biologists within the Agency. Temperature records were exclusively in the domain of the Water Resources & Flood Defence and Environmental Protection Departments, often related to specific projects and of short temporal duration. Also archive material were often difficult to obtain. In the few instances where Fisheries staff had collected temperature data, it was often in more recent years and by battery operated temperature loggers, which seem prone to down time leaving unsuitable gaps in data.

The continuous temperature recorders linked to other telemetry systems, such as flow, run by the Water Resources departments provided the most robust temperature data sets available in the Agency and seemed exclusive to the Midlands and Thames Regions. These data were utilised in the project and some comparisons made, such as the similarity between summer temperature regimes across regions and specifically the correlation between fry growth in the NE Region and the temperature regime of the River Thames. Although not ideal, it does indicate that these temperature records can be used as surrogates for study of other biological systems across the country as an initial investigation using a relatively coarse scale such as degree days.

Observations relating to temperature similarities in large UK rivers are well documented (Smith 1979) and have been shown to be relatively stable about their diurnal fluctuations. However, fluctuations in winter temperatures can be more marked since the greatest source of variation is caused primarily by localised weather conditions and therefore any specific studies relating to winter periods will need to rely upon local temperature records.

Flow records were more readily available, since data for Water Resources and Flood Defence purposes have been collected for many years. For example, daily mean flow data were available as far back as the early 1970s for the Suffolk R. Stour, enabling comparisons of flow during the exceptional year class production of the 1975-76 period and flow regimes in more recent years of both good and poor recruitment.

4.2 Year Class Strength Methods

The methods adopted by Mann (1973), Linfield (1981) and Cowx & Frear (submitted) all appear capable of measuring year class strength, although differences were found between the outputs of the different methods. The disparity in descriptions of the 1988-1989 year classes between the methods adopted by Mann and Cowx and Frear can, in part, be explained from the derivation of mean YCS values by the method proposed, whereby the Cowx and Frear method only relies on one sample and so was able to use data from years prior to those of the Mann YCS calculation, which requires sampling in consecutive years. The YCS values from the Cowx and Frear method included analysis from the 1993 survey, in which relatively young cohorts did not appear, particularly strong and as such lowered the mean YCS. The absence of the 1989 cohort of roach in the 1997 survey on the Yorkshire River Ouse also lowered the value in the Cowx and Frear method, but affected the Mann YCS less since the absence of the cohort is included in the mean percentage age class prior to calculating the relative values. These disparities highlight inadequacies of the relative year class strength method used by Mann. It is basically less flexible because good runs of annual data are required (at least two and preferably three consecutive years), and these are rarely available within the Agency. Also examining the relative strength of cohorts across triennial samples is not always easy, primarily because spatio-temporal changes in fish distribution probably occur between sampling periods.

Some marked differences were found between the outputs from the Cowx and Frear method and that of Linfield. This was largely because a mean survival rate for the river ($S = 0.56$), as proposed by Linfield, was applied to the latter analysis. This is a potential bias because the use of mean survival rates does not necessarily account for changes in mortality over time brought about by shifting biotic (e.g. competition and predation) and abiotic (e.g. temperature and discharge) conditions. If the survival rate derived directly from the survey data was used instead of the mean applied, the same trends in year class strength found using the Cowx and Frear method were elucidated. Indeed, if the survival rates for the specific surveys are applied to the Linfield method, the results are virtually the same as the Cowx and Frear method, except that the YCS values are not weighted to become positive.

The method developed by Linfield is also a more cautious approach since it defines an upper cut off point when the number of fish in the oldest cohort falls below 1% of the total sample. This potentially has the disadvantage of missing the end of a strong cohort, which may be important although it falls below the 1% threshold. Also, if a cohort is absent at any point in the age structure it prevents the description of any cohorts beyond the cut-off point. The Linfield method also returns both positive and negative values whilst the Cowx and Frear method only returns positive values, which has considerable advantage for future analysis of the factors influencing year strength (see Cowx 2001, and Nunn *et al.* 2003). The other advantage of the Cowx method is that there is no upper age cut off criteria, and as such has the ability to assign a YCS value to the entire sample. This can cause problems if a single or few fish from a very old age class are present because it can lead to a very large back-calculated value of the N_0 that it represents. In this respect, it is important that the samples used to derive YCS represent the population structure as whole. Consequently, the sampling procedure should not be selective against a particular size/age class, particularly younger size groups, or these size groups are omitted from further analysis, as suggested. The sample size should also be sufficiently large to accurately determine the instantaneous mortality rate (Z).

One of the potential problems linked to any approach to calculate YCS is accurate ageing of the individuals or provision of a mean length for age key. Ageing older fish is notoriously difficult (Mann & Steinmetz 1985) and errors introduced from this source are manifested in the YCS value. This is particularly true for long-lived species such as chub and bream where identification of annuli on scales in the older age classes can become subjective. Care must therefore be taken to ensure accurate ageing of the populations under assessment.

In addition, one of the main assumptions of the Linfield method is that the instantaneous mortality throughout life is constant for all age classes. This may not be strictly valid because of density dependent interactions increasing or decreasing mortality at different life stages or in different cohorts (Wootton 1990), or abiotic factors, such as adverse climatic conditions, increasing mortality. Where data allow, this is partially overcome by the Cowx and Frear model because the increased mortality in the older age classes, at the point of inflexion is used to adjust the model. Furthermore, the procedure is designed to be a relative estimate of YCS and not an empirical measure, and it is the changes in YCS caused by the aforesaid factors that is being derived. However, the method has an advantage over the Linfield method because it does account for variation in mortality between surveys.

Perhaps the main advantage of the Cowx and Frear and Linfield procedures is that they are simple and based on one sample only, thus the need for intensive surveying on an annual of biennial basis is precluded, as required for the method adopted by Mann (1973). This is particularly relevant where intensive surveying over consecutive years is not possible and the procedure can easily be adopted by many of the agencies who manage fisheries and only sample on a 3-5 years rolling survey programme or on an *ad hoc* basis. Notwithstanding this argument, shorter-lived species should be sampled at sufficiently regular frequency to enable several observations of any individual year class during its life history.

If the Agency is to adopt the use of YCS analysis to underpin the examining the status of stocks for management purposes, the most suitable approach would be to centralise the analysis through the Fish Ageing Service at Brampton. In this way, the AQC could determine the most suitable cut-off criteria for each individual sample. However, irrespective of which approach is used to describe YCS, an issue that needs to be addressed is the field collection of scales to ensure an adequate sample is taken, particularly from older fish. Also, it is imperative that the sample is representative of the age composition within the population so that the correct mortality and interpretation of the YCS is derived. In addition, any changes in age-related sampling efficiency will markedly affect comparisons of YCS between surveys, so constant effort must be applied during each survey.

4.3 Factors Affecting Recruitment

Despite all the potential ageing errors, marked degrees of consistency and similarities in YCS across species and rivers were observed. Most notably, the 1975 year class was exceptionally strong and had not been equalled in strength or longevity in recent years in most rivers. Environmental conditions that prevailed in this period, often referred to as the 1975-1976 drought, must have been conducive to good fry growth and survival. However, it is a unique combination of conditions and factors that are thought to have driven the success of this exceptionally strong year class, primarily:

- roach populations across the UK had been greatly impacted by Roach Ulcer Disease during 1969-70 and population densities are likely to have been very low. The condition was originally attributed to *Flexibacter columnaris.* The causative agent is now widely regarded to be by the bacterium *Aeromonas salmonicida* subsp. *achromogenes.*
- in 1976 Perch Ulcer Disease (also caused by *A. salmonicida*) resulted in major mortalities across the UK reducing both competition and predation. (see Byström & Garcia-Berthou 1999);
- weather patterns across the UK in the 6 years proceeding 1975 had been dominated by characteristics associated with a negative shift of the latitudinal position of Gulf Stream North Wall;
- August 1975 saw weather associated with a large positive shift in the latitudinal position of the North Wall of the Gulf Stream, which was not repeated until 1983.

All the study rivers with long temporal data sets highlight the longevity of the 1975 year class and a shift, which occurred in the mid 1980s, in population age structure, focussed towards a shorter lifespan. This trend is particularly noticeable in dace and roach populations, but less clear amongst the chub and bream. It is unclear from these data alone what are the contributing factors to this response by the fish populations, and whether it is a true shift in life history strategy. The apparently widespread increase in instantaneous mortality rates of dace, and thus shorter lifespans, is particularly noticeable and needs further examination because of the implications for management of the dace populations.

In cyprinid populations, strong year-classes are often correlated with high water temperature during the first summer of life (Mills & Mann 1985; Cowx 2001; Grenouillet *et al*. 2001), and several studies have demonstrated that a major influence on summer water temperatures is the latitudinal position of the North Wall of the Gulf Stream (e.g. Taylor & Stephens 1980). Any change in the latitudinal position of the North Wall of the Gulf Stream should, therefore, manifest itself in terms of a change in recruitment, with higher recruitment associated with a more northerly position of the NWGS (Aprahamian & Aprahamian 2001). Arguments for a climate driven mechanism for coarse fish production in the UK are supported by the analyses carried out on the Agency data, although there is considerable noise in the output and further analysis is required to determine the role of temperature and the latitudinal position of the North Wall of the Gulf Stream on YCS, plus discharge (see Nunn *et al*. 2003) in individual reaches of rivers.

Temperature alone, in the form of degree days above a threshold, does not appear to be a good predictor of year class strength based on comparison of the Thames and Ouse fry data, although some good correlations supporting this were found with the North East region fry data. For example, despite a high number of degree days >12°C and low flows, 0+ roach in the Yorkshire R. Ouse in 1995 were large compared with the R. Thames, and 1995 did not produce a strong year class in the Thames. In the R Thames, the best association with 0+ roach growth was with July degree days >12°C, the highest being in 1994, when the strongest Absolute Year Class Index, AYCI, (i.e. the greatest density of 0+ fish in a standard netting sample) was observed (Ball *et al.* 1997). This high abundance index coincided with the largest 0+ roach observed during the TWARP study. This anomaly may have arisen because the TWARP data were collected during July whereas the North East region data were collected during September after growth of young of the year had presumably slowed down or ceased for the year. The importance of the later sampling was also evident from the studies of Paxton & Winfield (2000) and Hodgson (1993) who showed that perch in Windermere and roach and dace in the Welsh R. Dee, respectively, underwent rapid growth in August, primarily due to diet shift. This could affect the subsequent YCS. Welton *et al.* (1999) also showed abundance of fry in September was the best predictor of YCS for dace and chub in the R. Tees. However, the study also identified that the strongest YCSs of adult dace and chub (1995) coincided with their largest 0+ size, and these were in turn related to degree days >12°C in their first year, but linear relationships between 0+ size and YCS were generally poor. Roach in the same study gave poor associations with temperature, growth, abundance and YCS. In view of the above arguments, it is recommended that fry surveys are concentrated in September to ensure the 0+ fish have achieved their growth potential for the first year of life and before they disperse to overwinter refuge areas.

Similarly, the role of discharge in determining year class strength was alluded to in the present analysis. This parameter may be linked to the latitudinal position of the North Wall of the Gulf Stream so problems with autocorrelation may exist. Consequently, further work is needed to determine the role of temperature, flow regime and position of the North Wall of the Gulf Stream in setting YCS. Nunn *et al.* (2003) carried out multiple regression analysis on a limited data set and showed that flow is a key driver. Further work from a range of rivers is needed to confirm that this relationship is consistent across the UK.

These indicators of fry size and strong YCS may suggest that size thresholds for 0+ fish govern future YCS in many situations. This emphasises a key area of research, to confirm the nature of this apparent relationship. For example, major differences were found in the mean length of 0+ fish in September between 12 Yorkshire rivers and yet the fish responded in an almost identical manner in terms of good or poor growth in the same year, which suggests a factor such as climate is a driver. However, a link between their growth and future YCS in the respective rivers has not been made. It may be that a relative size threshold is a key factor in 0+ fish recruitment establishing strong year classes, and that the threshold size varies between rivers. The growth and abundance of 0+ fish is likely to be an initial key indicator to the fishery manager in determining the likelihood of the future success of adult stock. This needs to be examined in a number of UK rivers to recognise those rivers and populations that have greater influence from other factors, particularly negative ones. This use of 0+ fish growth and abundance to quantify future adult stock has been demonstrated as a valuable tool in North America, to the point where sampling larval forms early in spring is used as an efficient predictor of year class strength (Sammons & Bettoli 1998).

Although discharge and water temperature account for a great deal of the variance in YCS, there are likely to be other complicating factors of varying importance. Large cohorts of 0-group fish may be inconsequential to eventual YCS if overwinter survival is poor. For example, lack of overwintering habitat may severely restrict YCS of many fish species in some rivers, particularly during severe winters that have prolonged periods of elevated flow.

Inter- and intra-cohort and inter-specific competition may also influence YCS. Grenouillet *et al*. (2001) found that survival of roach in the first year was density-dependent, and stated that intraspecific competition within the 0-group cohort could influence recruitment to older age-classes. This may be of particular importance in years of good recruitment. Cryer, Peirson & Townsend (1986) and Perrow & Irvine (1992), studying lacustrine populations of roach, demonstrated that abundant 0-group roach can sometimes show poor growth as a result of depression of their prey populations. Variations in prey (zooplankton) abundance may therefore influence the initial growth rates of fish larvae, and a switch in the diet of 0-group roach in late June from small invertebrates (Cladocera, Chironomidae) to one dominated by detritus may explain discrepancies between the observed growth rate and that predicted from temperature growth models (Mann 1997). Moreover, competition for food resources may influence 0-group overwinter mortality. Overwinter survival is positively related to fish length, although it is the condition (lipid content) of the fish (which is a function of length), rather than length itself, that is the key factor (Griffiths & Kirkwood 1995; Kirjasniemi & Valtonen 1997). It is also important, therefore, to consider the impacts of increased river flows on the food supply of juvenile fish, since discharge can influence fish populations indirectly larger rivers through its key role in controlling phytoplankton and, hence, zooplankton populations (Bass, Pinder & Leach 1997; Marker & Collett 1997; Reckendorfer *et al*. 1999).

The effects of river discharge (including increases caused by anthropogenic activities) on YCS of particular fish species may, therefore, be either direct or indirect. For example, a poor year class may be the result of high river flows causing high mortality during a critical period in the life history of a particular fish species, such as the larval period, or it may equally be the result of poor growth caused by a reduction in water temperature or a lack of suitable food. It was not possible in the present study, however, to separate the roles of either. Whilst it is likely that water temperature is the limiting factor with respect to fish growth, river discharge may be the factor that ultimately controls YCS, either directly or indirectly. It could be that, in effect, water temperature determines potential YCS while discharge determines realised YCS.

Evidence of bimodality and possibly trimodality, in fry sample length frequencies was found in this study, and has been identified and discussed elsewhere (Ladle 1991; Nunn *et al*. 2001), yet the importance of this phenomenon remains unclear. Baras and Philippart (1999) identified a mechanism in barbel recruitment that focussed on two distinct life histories. An early spawning, that benefited from a long growing season, but risked wash-out, or a converse mechanism. This type of life history strategy may begin to explain some of the bimodal length frequency observations, but a great deal of work would be required to determine which component or life strategy is important. Agency data suggest that large fry are more likely to contribute to a strong year class and yet little description has been made of the importance of “average year classes” that are present and may support fisheries.

Evidence for protracted or multiple/batch spawning events is largely circumstantial and should be supplemented by further, more detailed studies. Species which adopt protracted or multiple/batch spawning strategies are likely to have a greater size range of young at the end of the growing season than those that do not, and the importance of progeny from later spawnings on the eventual year class strength may largely be determined by conditions during the first winter. If the smallest fish survive the winter they will have a selective advantage over young of the year because they will be larger and able exploit a wider range of food sizes and thus may contribute to the YCS of that cohort. Fry samples taken from the rivers Trent, Warwickshire Avon and Yorkshire Ouse in early spring have huge numbers of very small fry that have clearly survived over the winter suggesting they may also be important (A. Nunn, pers. comm.). It may be that fisheries management could potentially be tailored to enhance the survival of such fish, and hence augment recruitment to older age classes.

In addition, a greater understanding of the mechanisms behind increased growth rates of fry from the lower sections of river as seen in the Hampshire R. Avon (Gribble 1988; Ladle 1991) and whether it is the faster growing fishes from the lower reaches that make the greatest contribution to the YCS in the river as a whole. These observations focus a need to understand more about fry movements, their recruitment to the stock and likely pressures, particularly anthropogenic, that may affect recruitment.

Aspects of fish diseases affecting wild adult stocks are well documented and yet little work has focussed on the role of parasites and diseases at the critical fry stage. The CEFAS work described here indicates that coarse fish fry are infected at a very early stage in their development, with a range of potentially pathogenic parasites. One of the most significant of all these is *Myxobolus cyprini,* which is relatively widespread and abundant across species and rivers in Yorkshire. The incidence of infection has been 100% in some populations, with chub appearing the most susceptible. The intensity of infection by several parasite groups is likely to lead to increased mortality (Feist *et al*. 1997) suggesting this is another avenue of research to determine the significance of fish diseases in population dynamics. It should be noted that some of the highest infection rates of *M. cyprini* were observed in 1993, a cool, wet year which produced one of the weakest of all year classes, whilst infections were low or absent in 1995 in several rivers, when strong year classes were produced.

4.4 Future Studies

This study would greatly benefit from a cross checking of scale age data to verify some of the YCS analysis and try to eliminate the shifting year class strengths assumed to be derived from ageing drift. This would allow attention to focus on the true strength and persistence of year classes initially noted as strong and to examine in more detail some of the related environmental variables.

A simple approach is needed for examining coarse fish 0+ data from a large number of sites across the UK with particularly reference to 0+ growth and abundance, and linking this to comprehensive adult population data. It is equally important to link 0+ growth to temperature and there is a need to establish a more robust way of collecting good quality temperature data. Temperature data gathered at flow telemetry stations have proved the most useful for this study. Since surrogate data sets showed good correlations, few additional data sets may be needed to confirm initial findings. Temperature recording stations in distinct geographical regions of the UK would be desirable, although these data may already exist, but were not uncovered during the early course of Phase II.

A further distillation of these data, linked to more robust statistical analysis would be a suitable approach for Phase III. Relating the findings of such a synthesis to other key research in the UK, such as the Great Ouse and Frome for example, would be essential if predictive models for coarse fish recruitment were to be attempted.

This study has highlighted that the overall concept of recruitment in fisheries is a complex problem involving many independent and interacting factors. However, it has also identified key areas where research must be targeted. The problems can be broken down into three key areas, which are probably inter-linked and cannot be treated as separate issues. These are:

- role of reproductive strategies in regulating larval recruitment;
- abiotic and biotic factors affecting the survival (mortality) of fish and the subsequent year class strength;
- role of habitat in regulating the carrying capacity of the fish stock.

It is considered that the overall problem is too complex to be treated as a whole and that future research should be broken down in a suite of manageable components with the following specific objectives.

- To determine the basic habitat requirements of all life stages of coarse fish in rivers, and the seasonal habitat changes required for successful recruitment.
- To understand the impact of reproductive strategies, especially multiple spawning events, on the recruitment dynamics of fish populations.
- To determine the factors needed for the successful spawning and juvenile recruitment of the dominant coarse fish species in rivers.
- To understand further the critical factors affecting the early life stages of various coarse fish species in rivers, and identify the causes and rates of mortality under various ecological and environmental scenarios.
- To establish the causes and rate of mortality in post-one year coarse fish.
- To determine how fish populations and individuals respond to environmental change and the implications this has on stock dynamics.
- To determine the impact of river management activities on the recruitment dynamics of the dominant coarse fish populations and assess the underlying causes for any changes observed.

To achieve these specific objectives **a number of projects should be formulated, but they must be inter-linked to contribute towards elucidating the factors controlling coarse fish recruitment**. In view of the importance of understanding the processes of coarse fish recruitment in rivers, **it is recommended that, in the first instance, the Agency adjusts its field sampling programme to improve the quality and quantity of 0 group fish data.** This should involve sampling by micromesh seine netting at strategic sites on a number of index rivers throughout England and Wales in September of each year. It is also **recommended that the Agency establishes collaborative projects with external institutions working in this field to gain value added from existing and ongoing research.**

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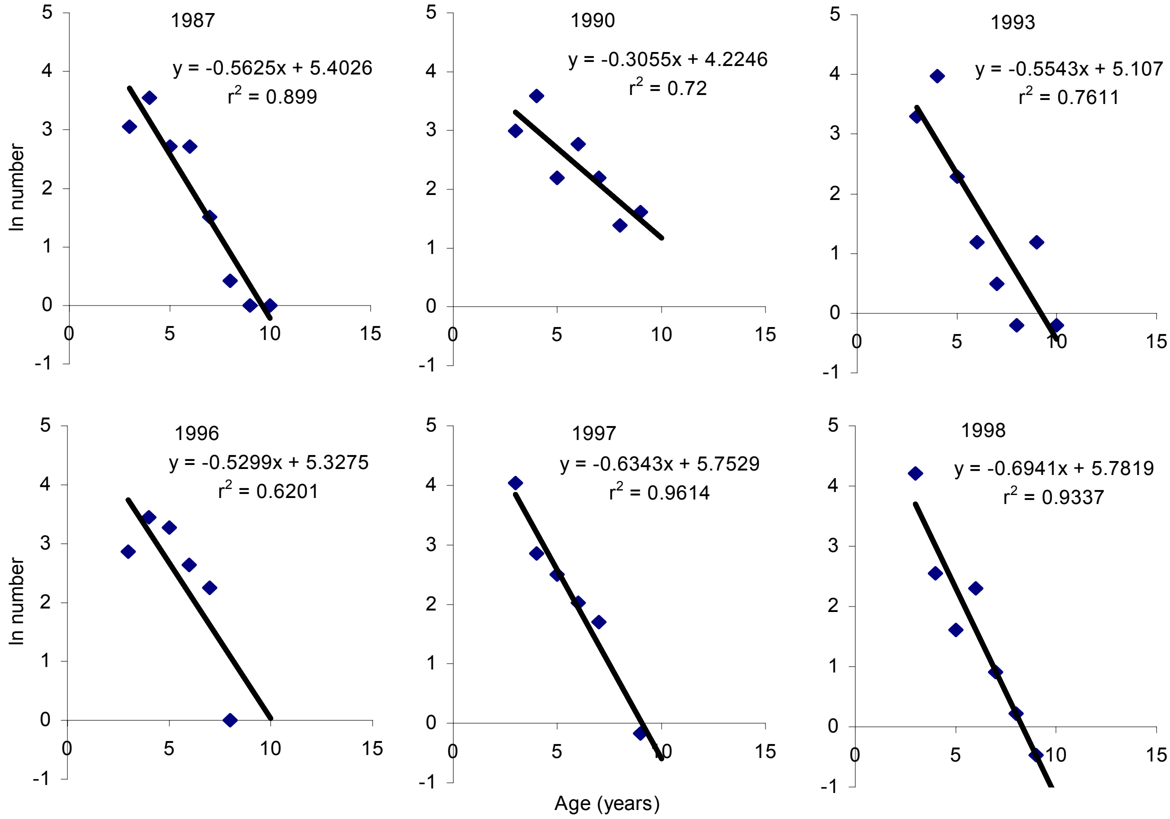

Figure 3.1. Derivation of total mortality of roach from survey catch data based on the relationship between natural logarithm of the number of fish in each age class and age.

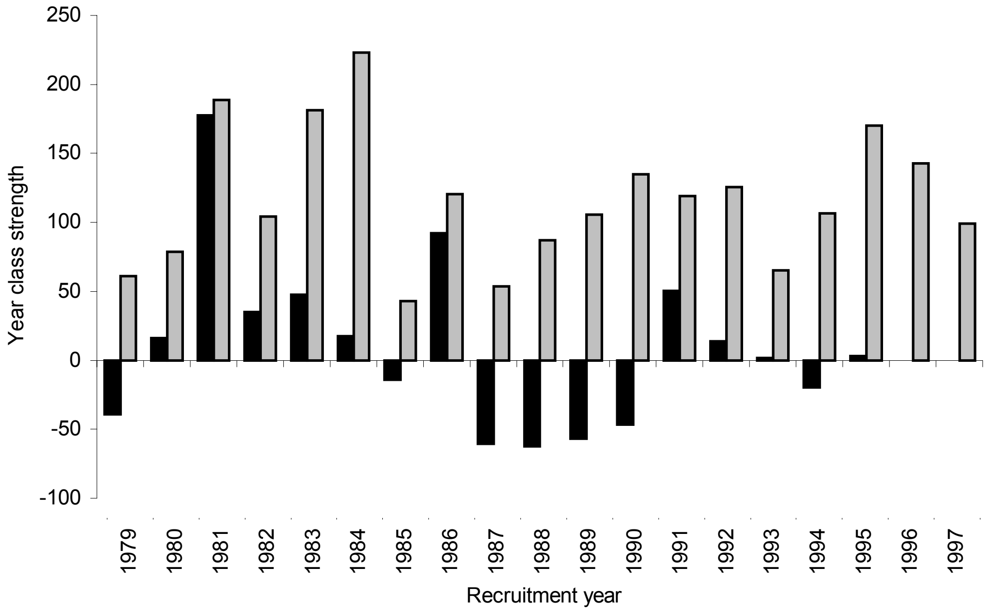

Figure 3.2. Comparison of relative year class strengths derived by the methods of Linfield (1981) (solid bars) and of Cowx & Frear (shaded bars)

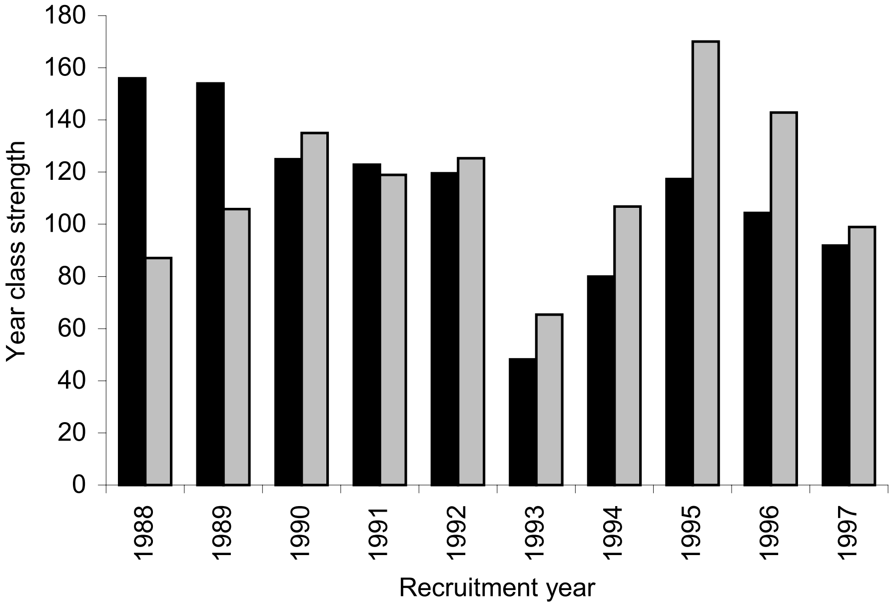

Figure 3.3. Comparison of the relative year class strengths derived by the methods used by Mann (1973) (solid bars) and by Cowx and Frear (shaded bars).

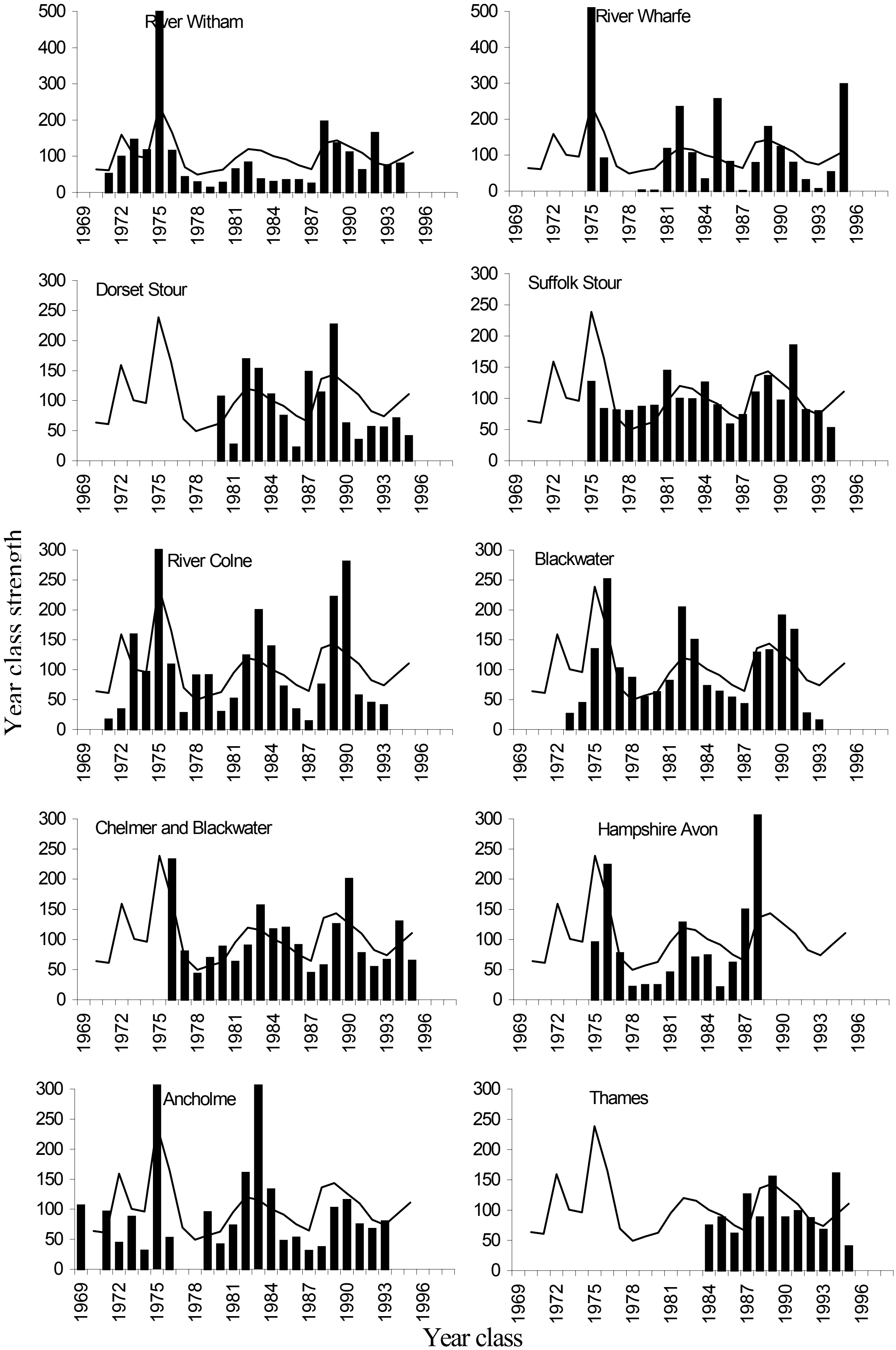

Figure 3.4. Variation in year class strength of roach in English rivers (bar) compared with mean YCS of roach for all rivers (line).

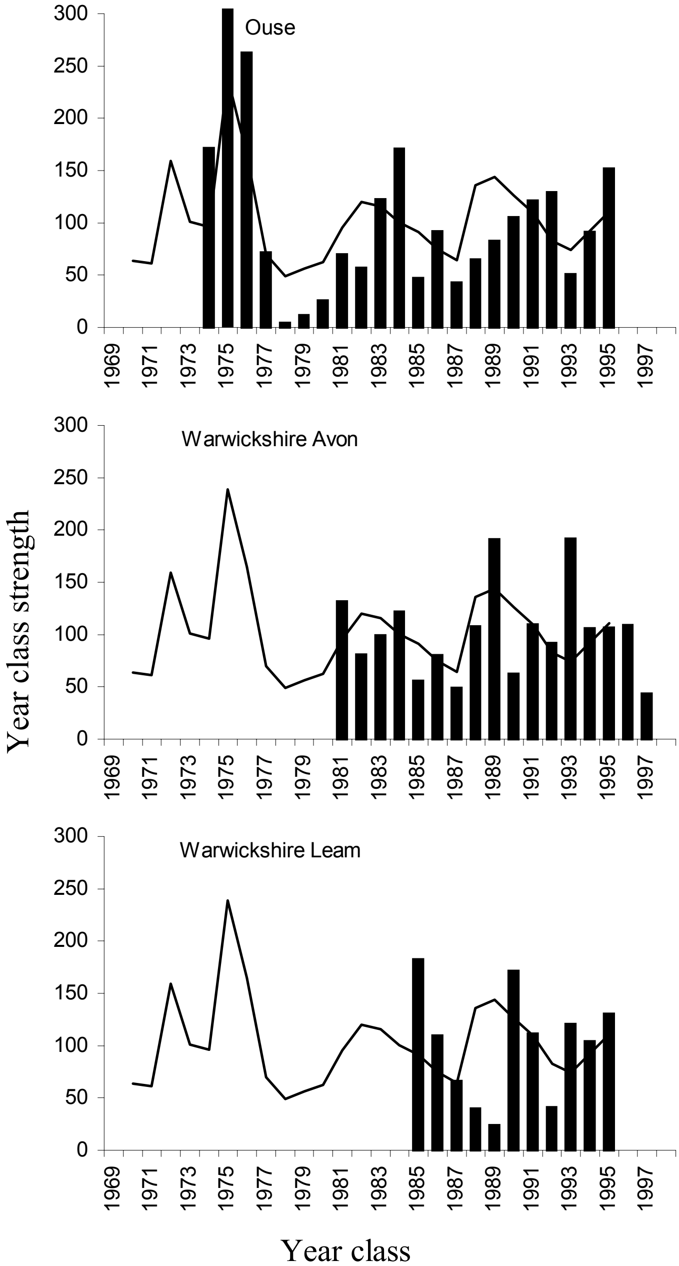

Figure 3.4 continued. Variation in year class strength of roach in English rivers (bar) compared with mean YCS of roach for all rivers (line).

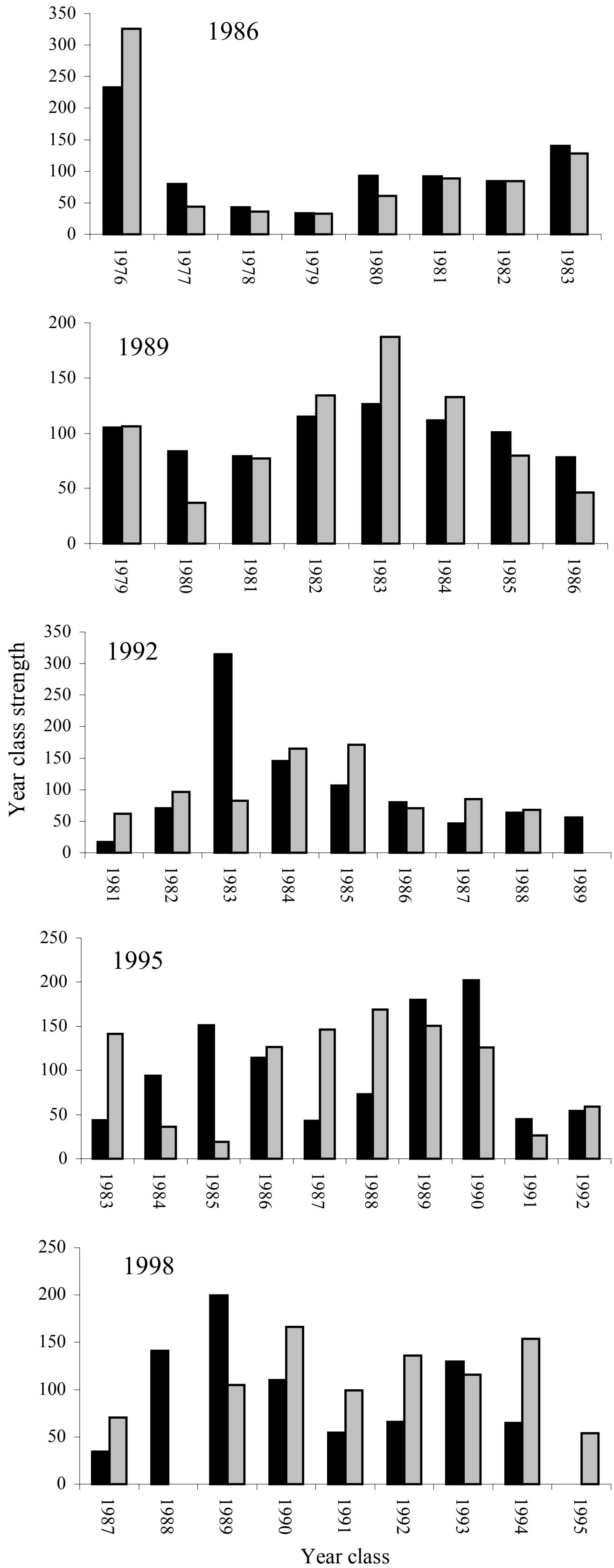

Figure 3.5. Variation in year class strength of roach in the Chelmer Blackwater Canal between spring (solid bar) and autumn in the same year (shaded bar).

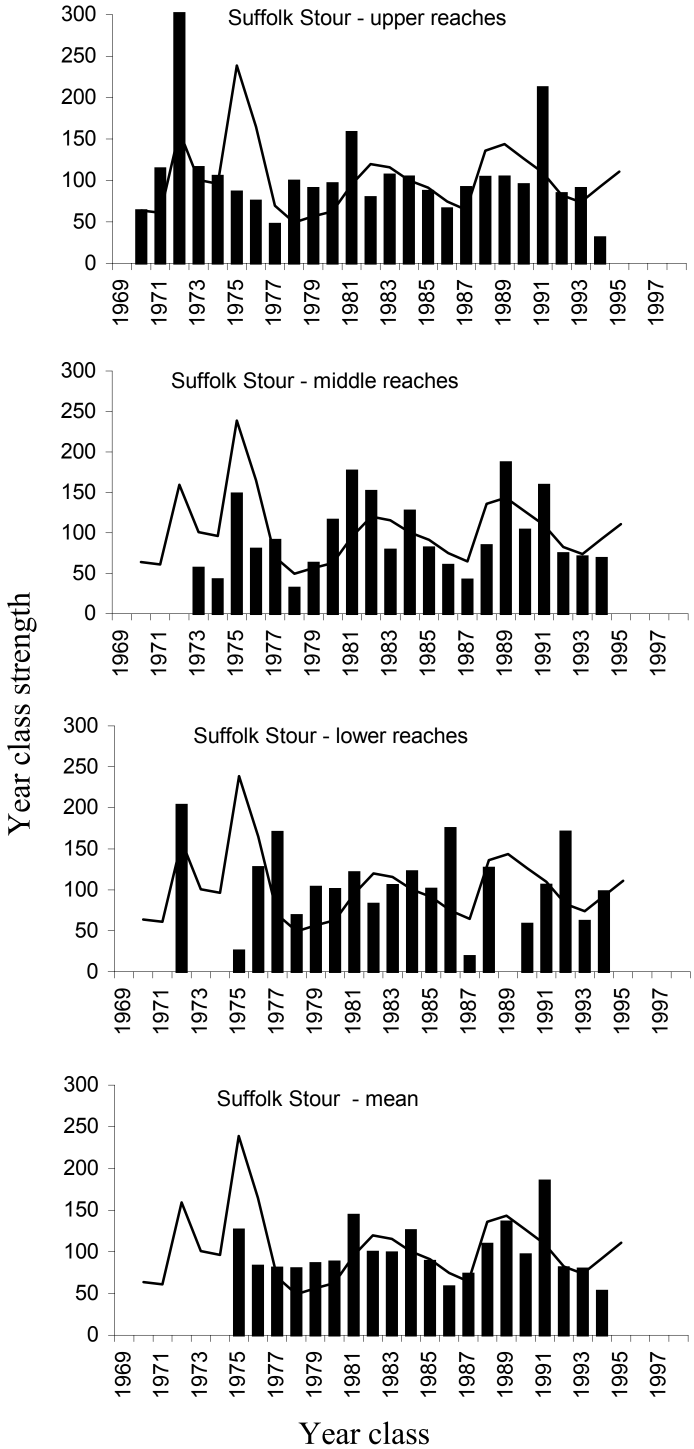

Figure 3.6. Variation in year class strength of roach in different reaches of the Suffolk R Stour (bar) compared with mean YCS of roach for all rivers (line)

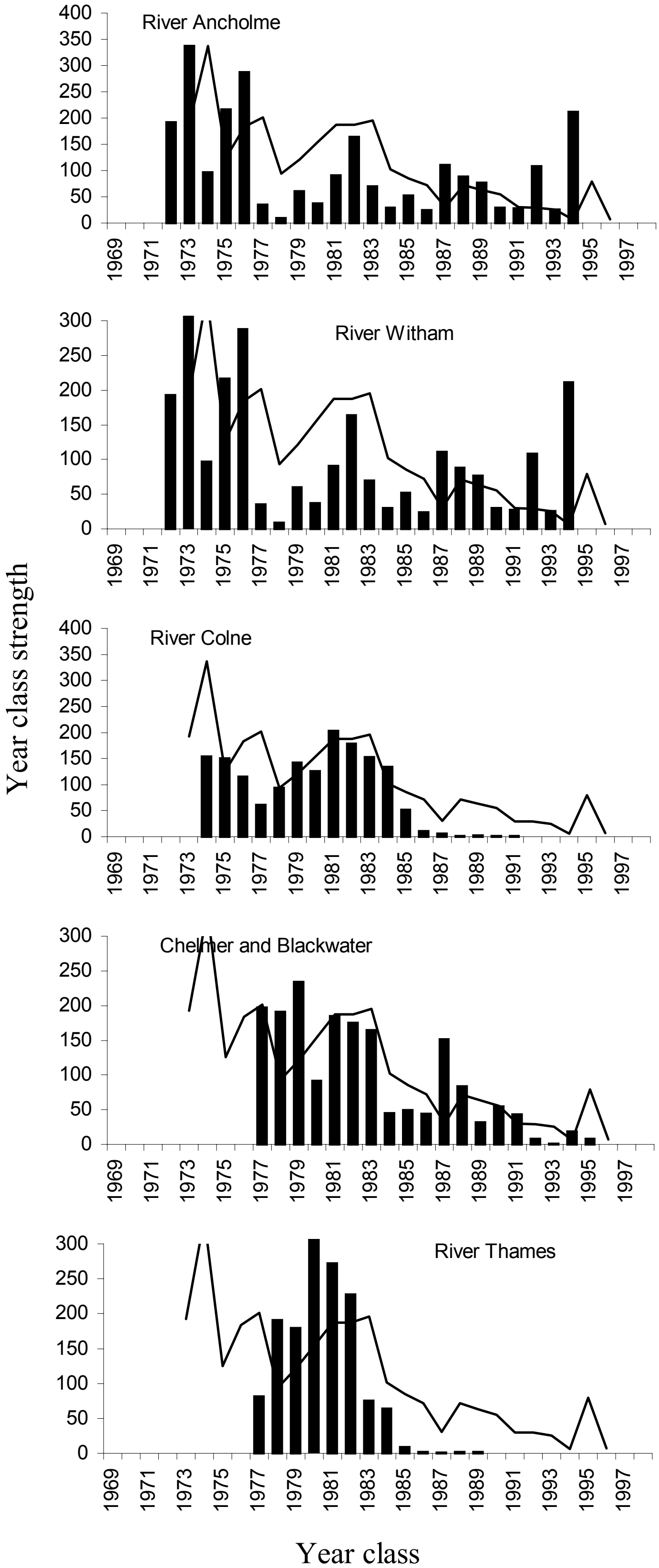

Figure 3.7. Variation in year class strength of bream in English rivers (bar) compared with mean YCS of bream for all rivers (line).

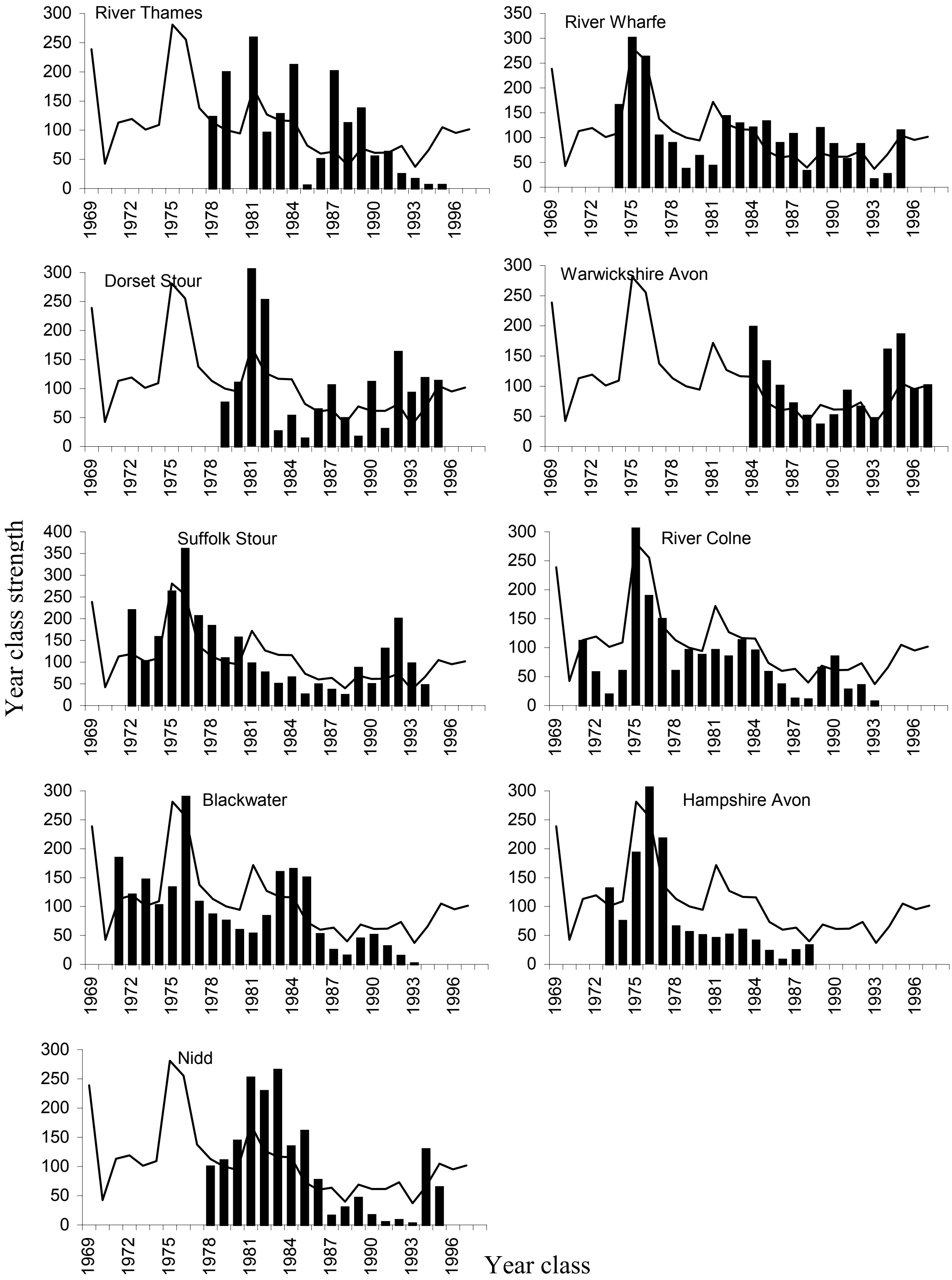

Figure 3.8. Variation in year class strength of chub in English rivers (bar) compared with mean YCS of chub for all rivers (line).

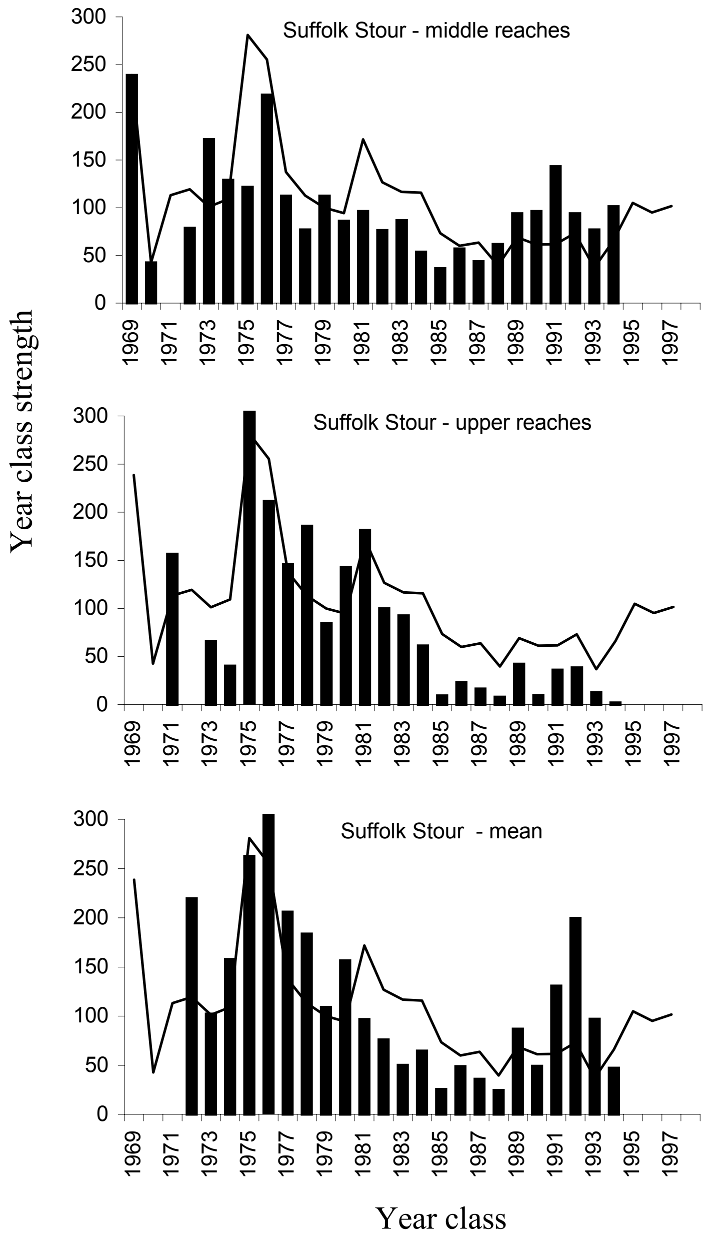

Figure 3.9. Variation in year class strength of chub in different reaches of the Suffolk River Stour (bar) compared with mean YCS of chub for all rivers (line).

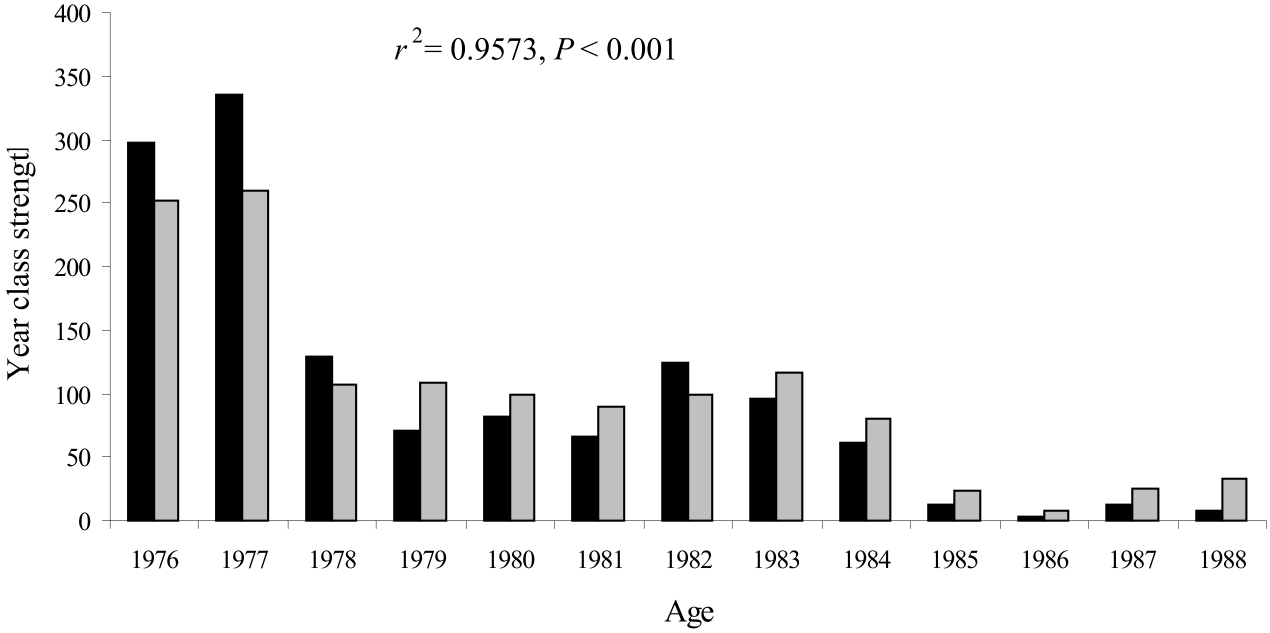

Figure 3.10. Comparison of the year class strength of chub in the Hampshire River Avon based on 11 sites (black bar) and 22 sites (shaded bar).

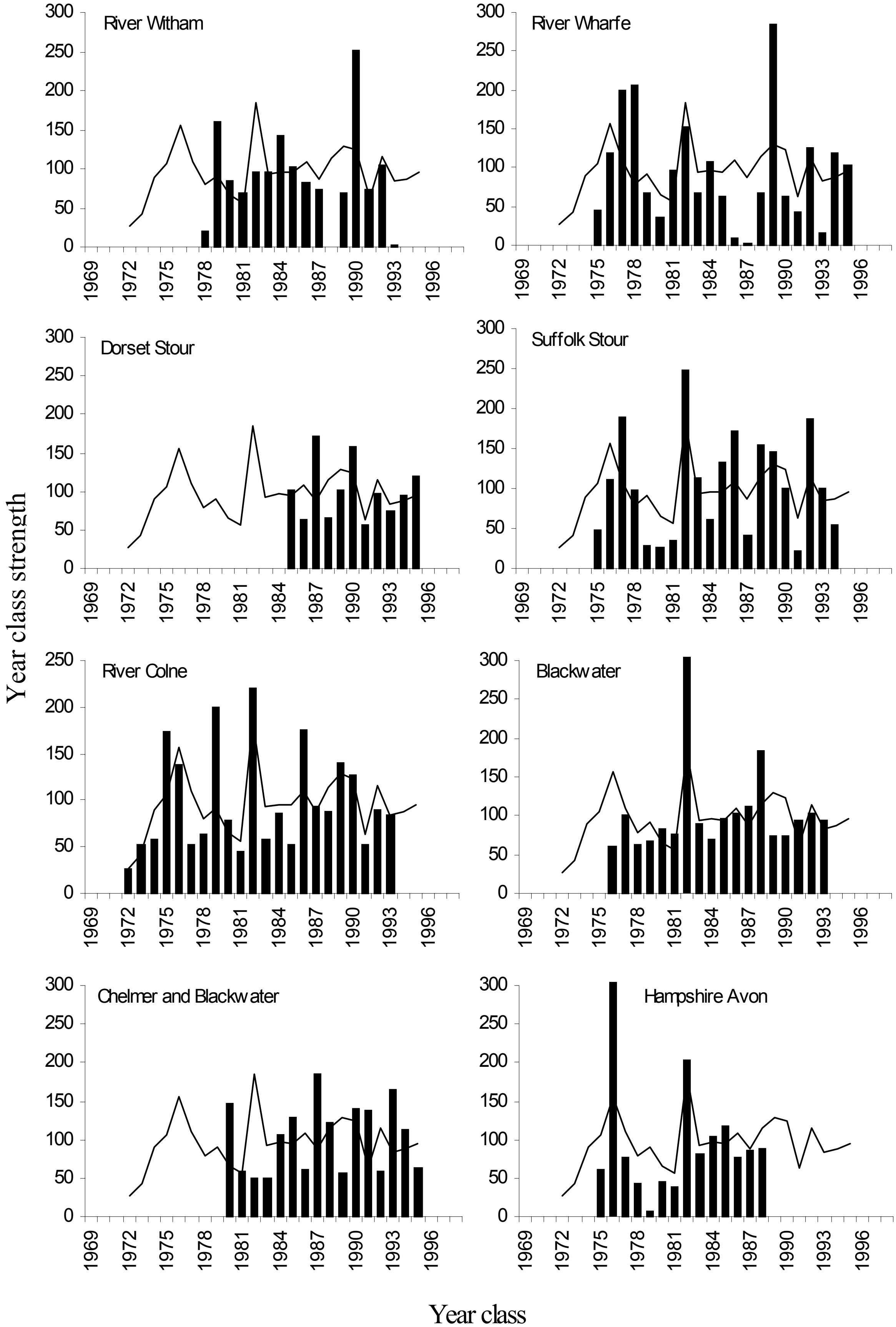

Figure 3.11. Variation in year class strength of dace in English rivers (bar) compared with mean YCS of dace for all rivers (line).

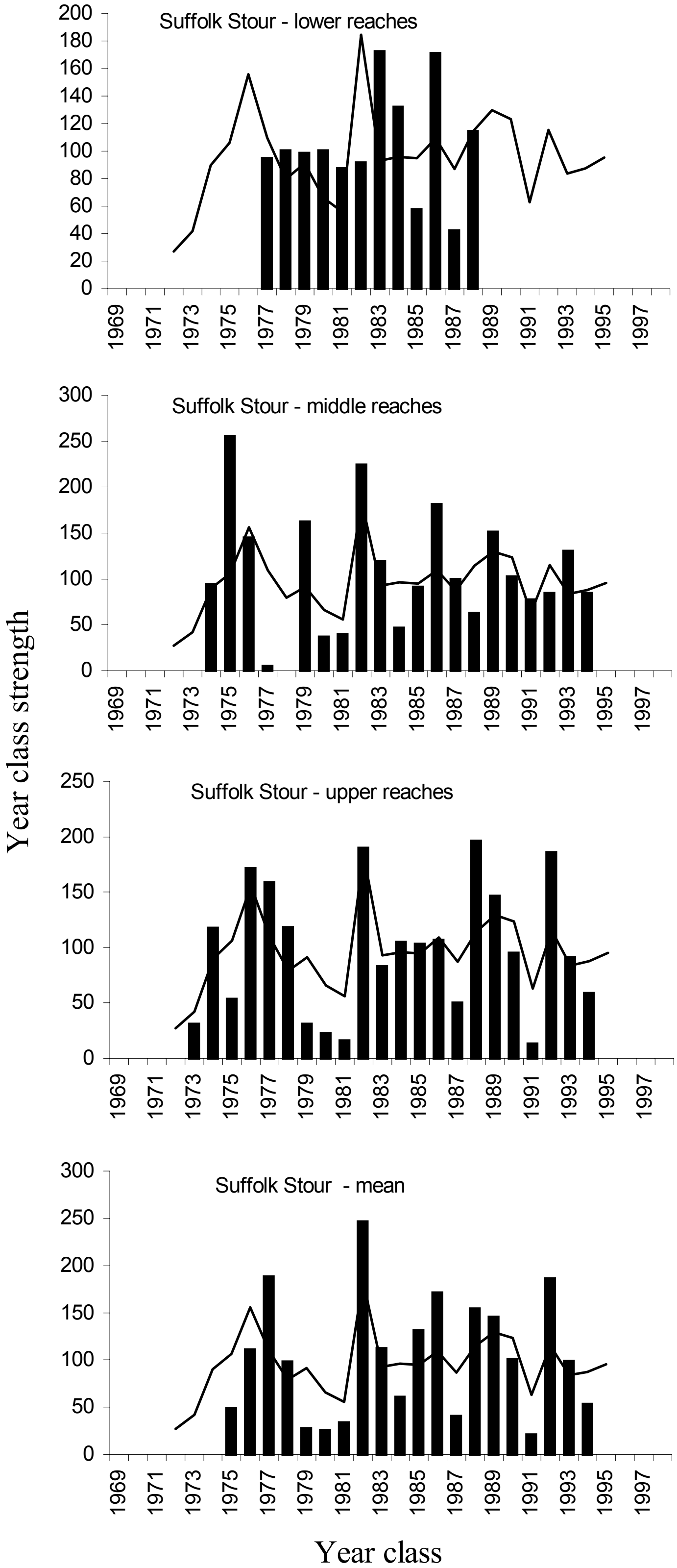

Figure 3.12. Variation in year class strength of dace in different reaches of the Suffolk River Stour (bar) compared with mean YCS of dace for all rivers (line).

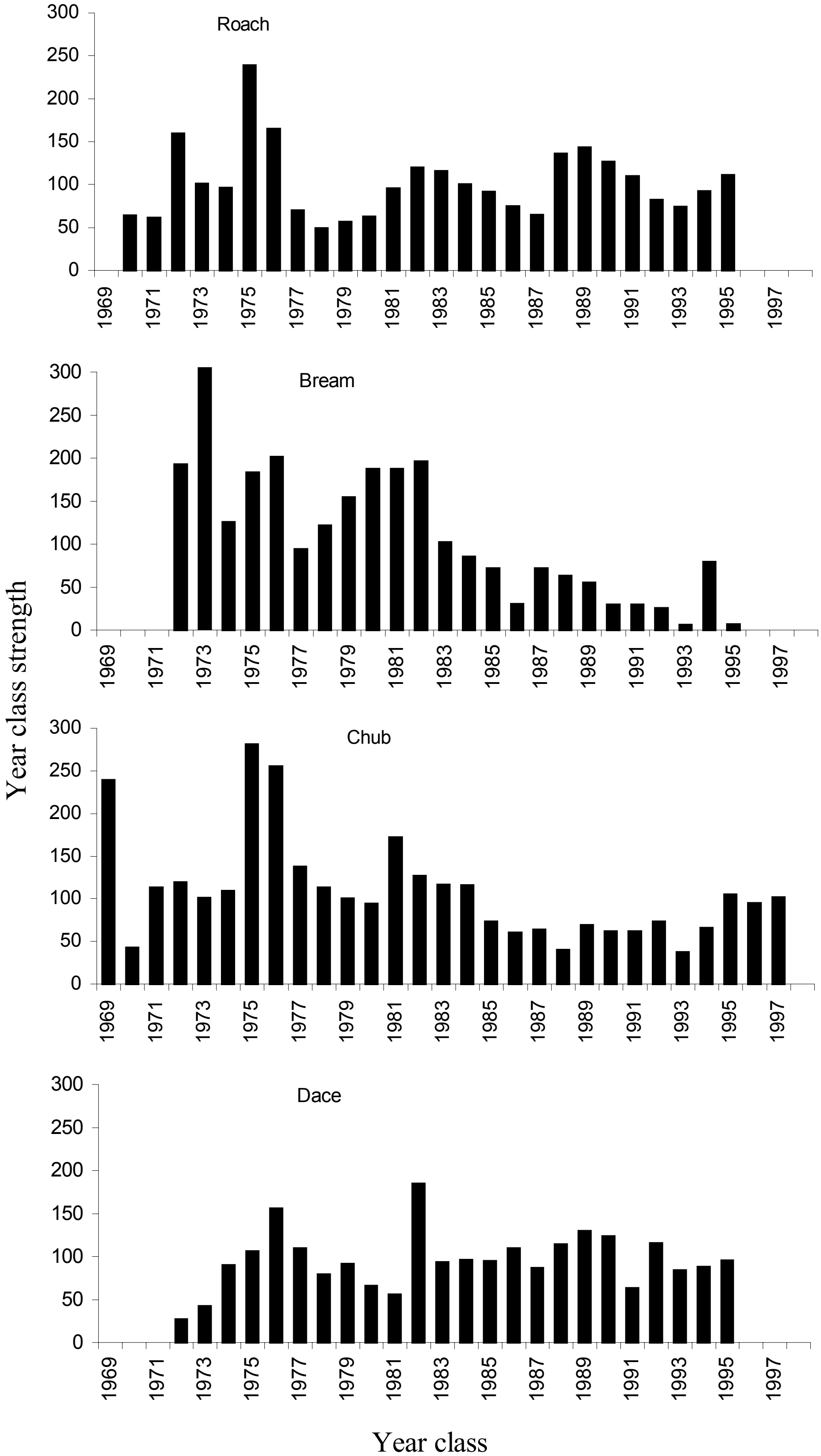

Figure 3.13. Comparison of the year class strengths of roach, bream, chub and dace based on the mean from all rivers analysed.

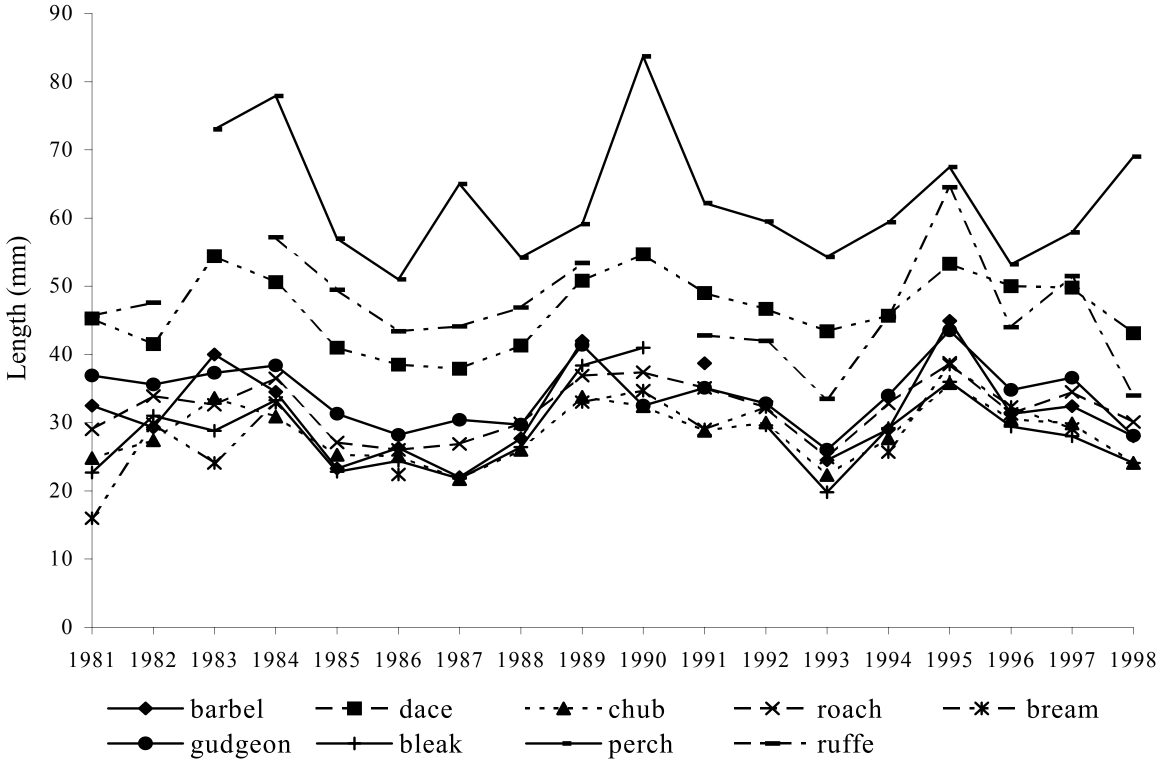

Figure 3.14. Variation in mean annual length (mm) of 0+ fish of different species in the Yorkshire River Ouse (all sites combined). (95% confidence limits omitted for clarity).

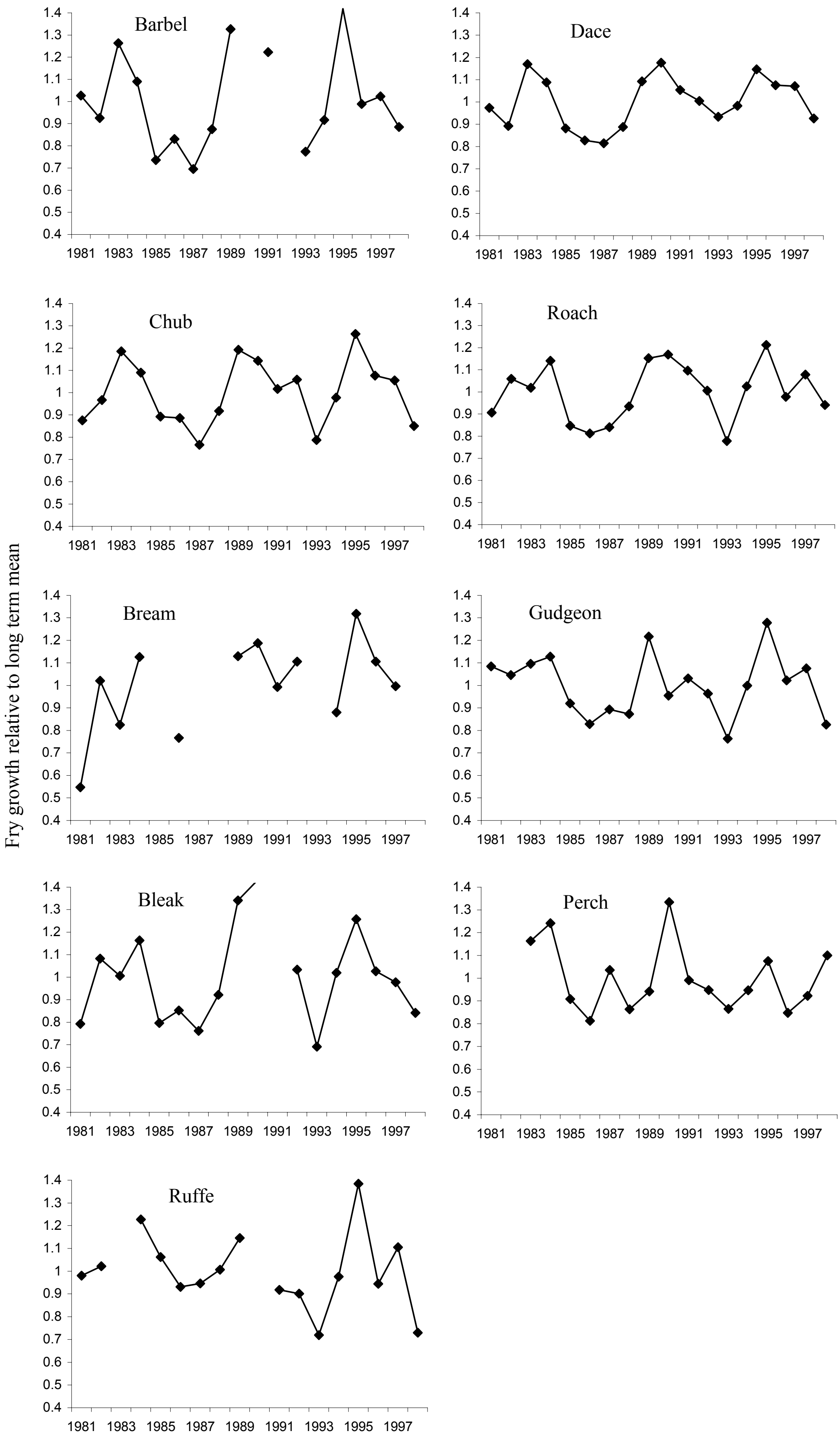

Figure 3.15. Variation in mean length of 0+ fish of different species in the River Ouse in September relative to long-term mean length.

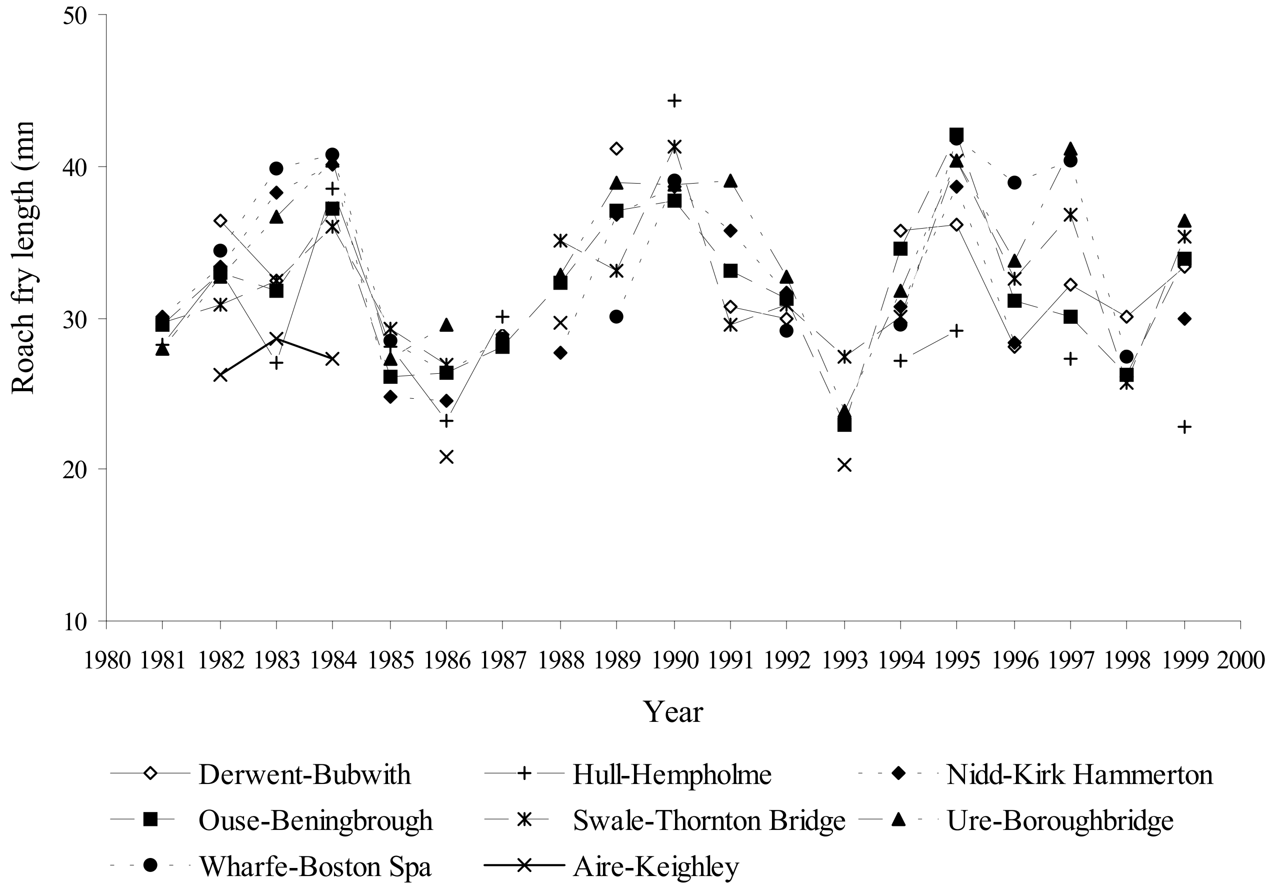

Figure 3.16. Variation in mean annual 0+ length (mm) of roach in Yorkshire rivers in September.

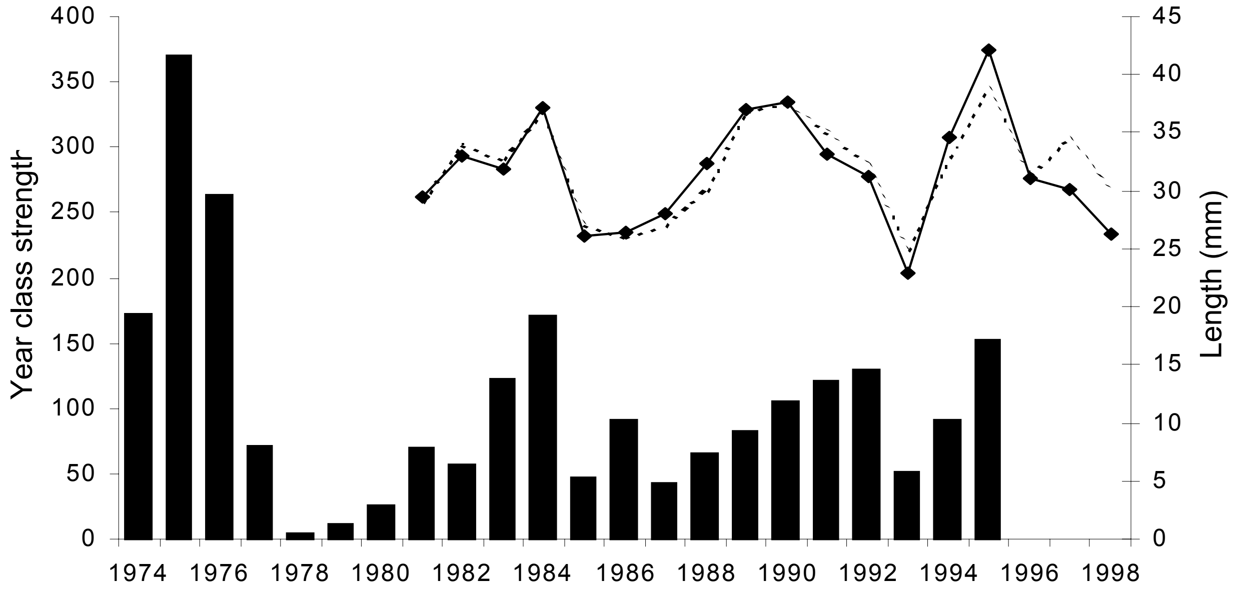

Figure 3.17. Comparison of year class strength (bars) and mean length of 0+ roach in the R Ouse at Beningbrough (solid line) and all sites combined (dashed line)

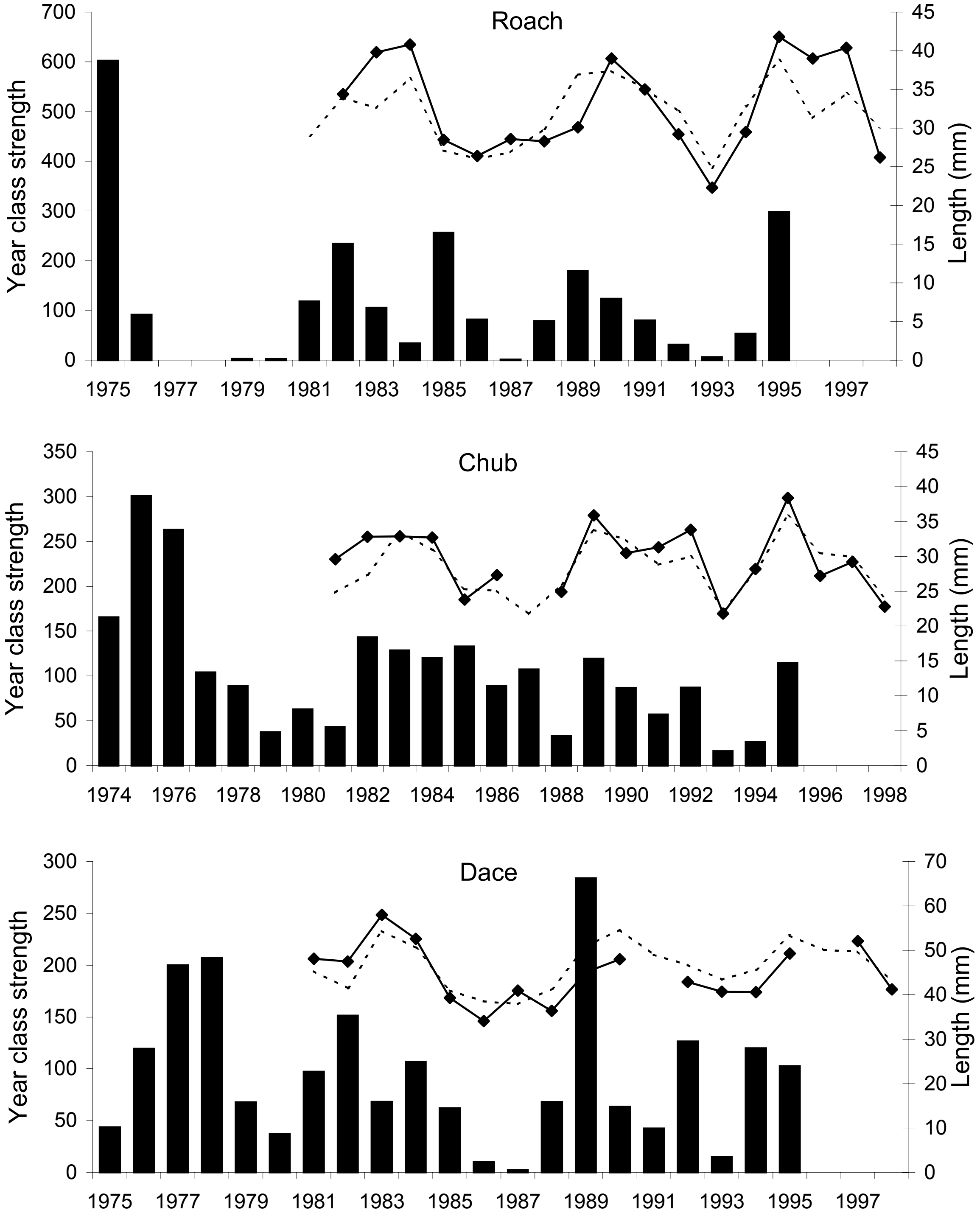

Figure 3.18. Comparison of year class strength (bars) and mean length of 0+ roach, chub and dace in the River Wharfe at Boston Spa (solid line) and all Yorkshire sites combined (dashed line).

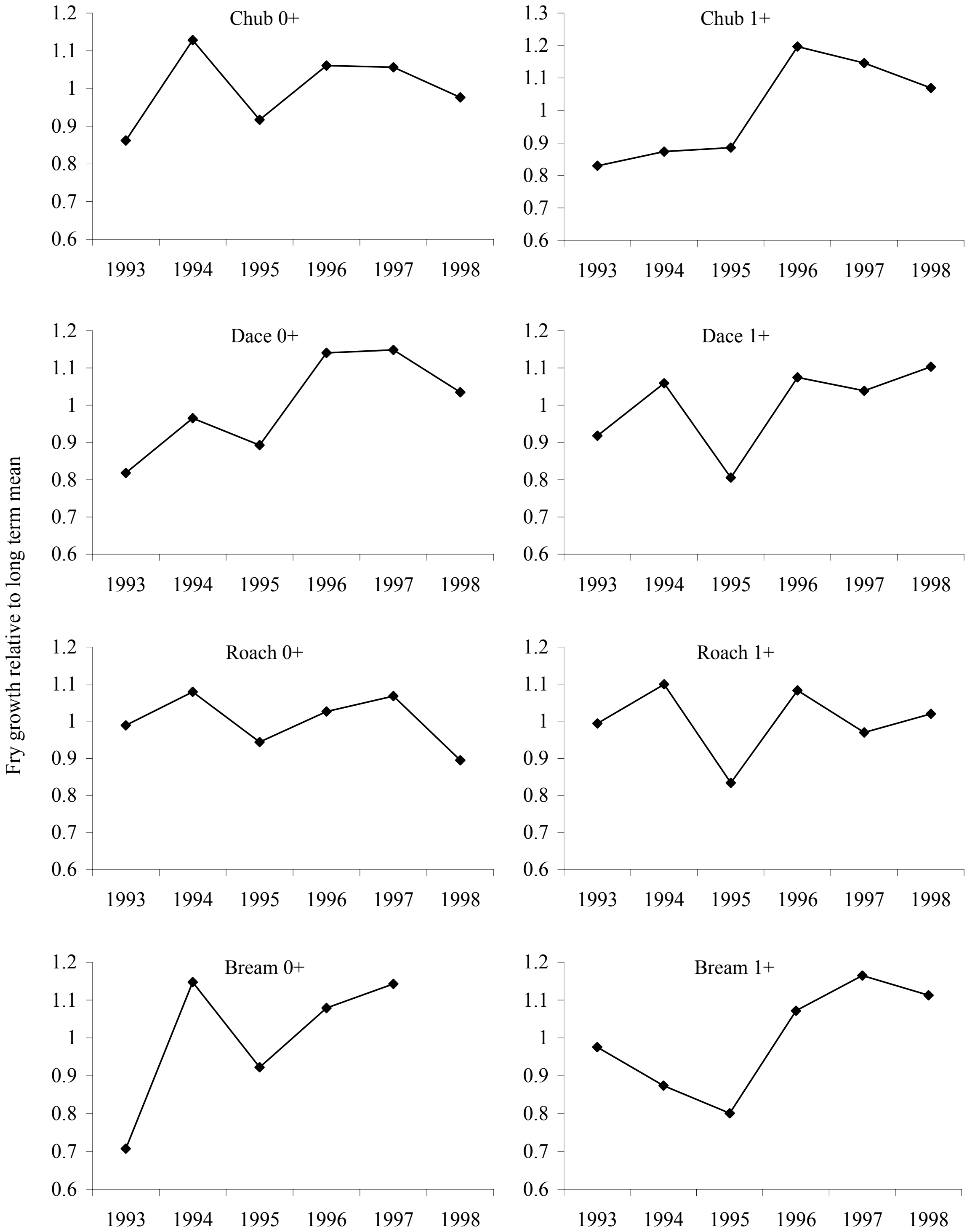

Figure 3.19. Variation in mean length of 0+ and 1+ fish of different species in the River Thames relative to long-term mean length.

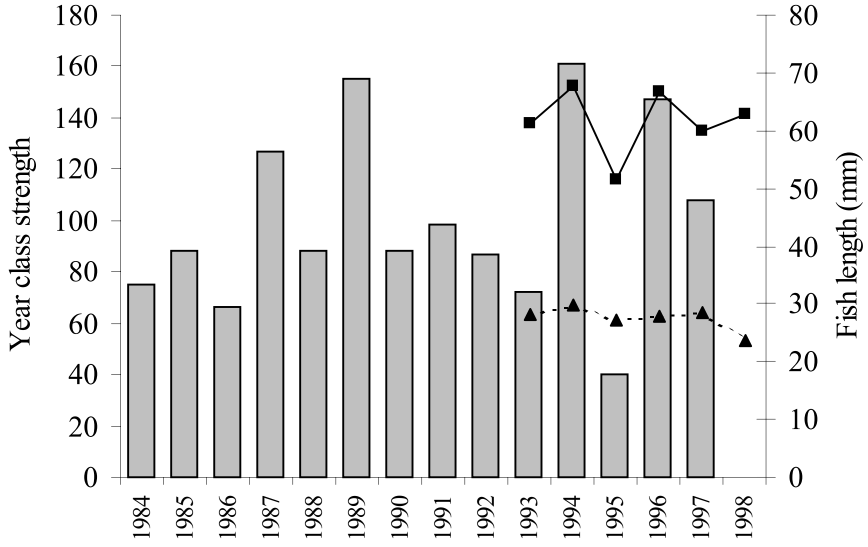

Figure 3.20. Comparison of size of 0-group (▲) and 1-group (■) roach in July from the River Thames with subsequent year class strength (shaded bar).

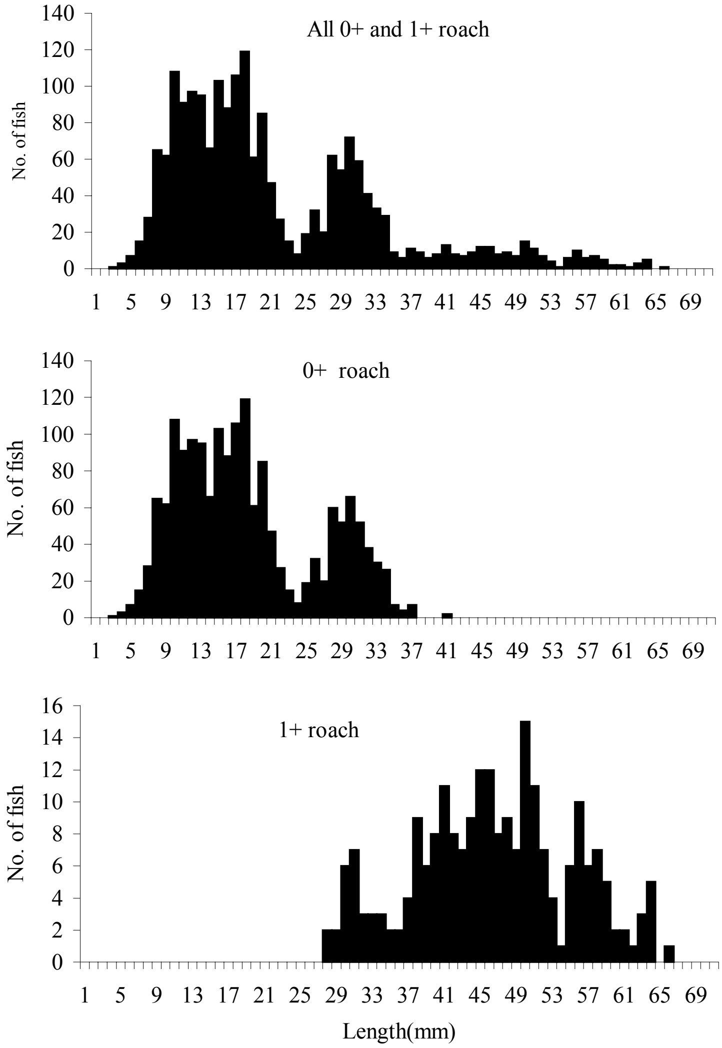

Figure 3.21. Length frequency histograms of 0+ and 1 + roach from the River Thames in 1995 to show biomodality in the cohort.

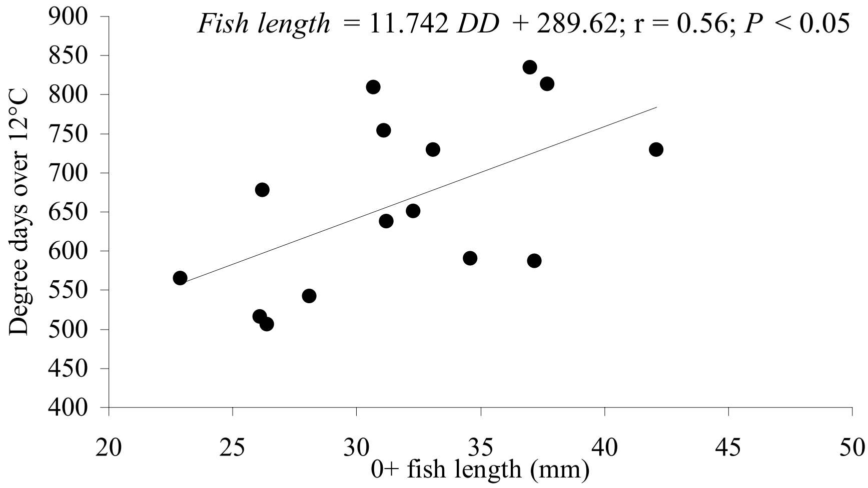

Figure 3.22. Relationship between length of 0+ roach from the River Ouse in September and temperature.

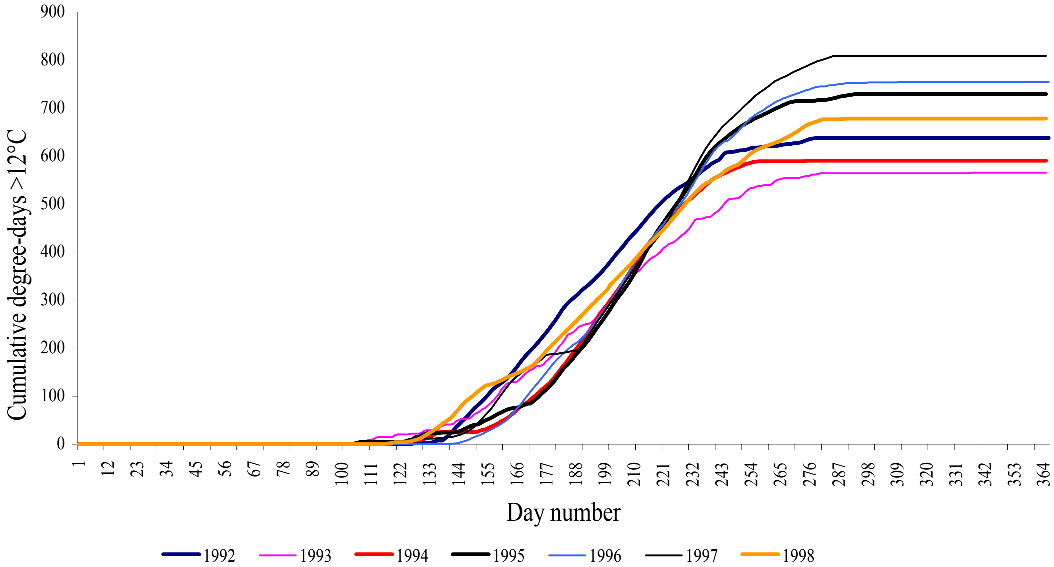

Figure 3.23. Patterns of cumulative degree days > 12°C in successive years in the Yorkshire River Ouse.

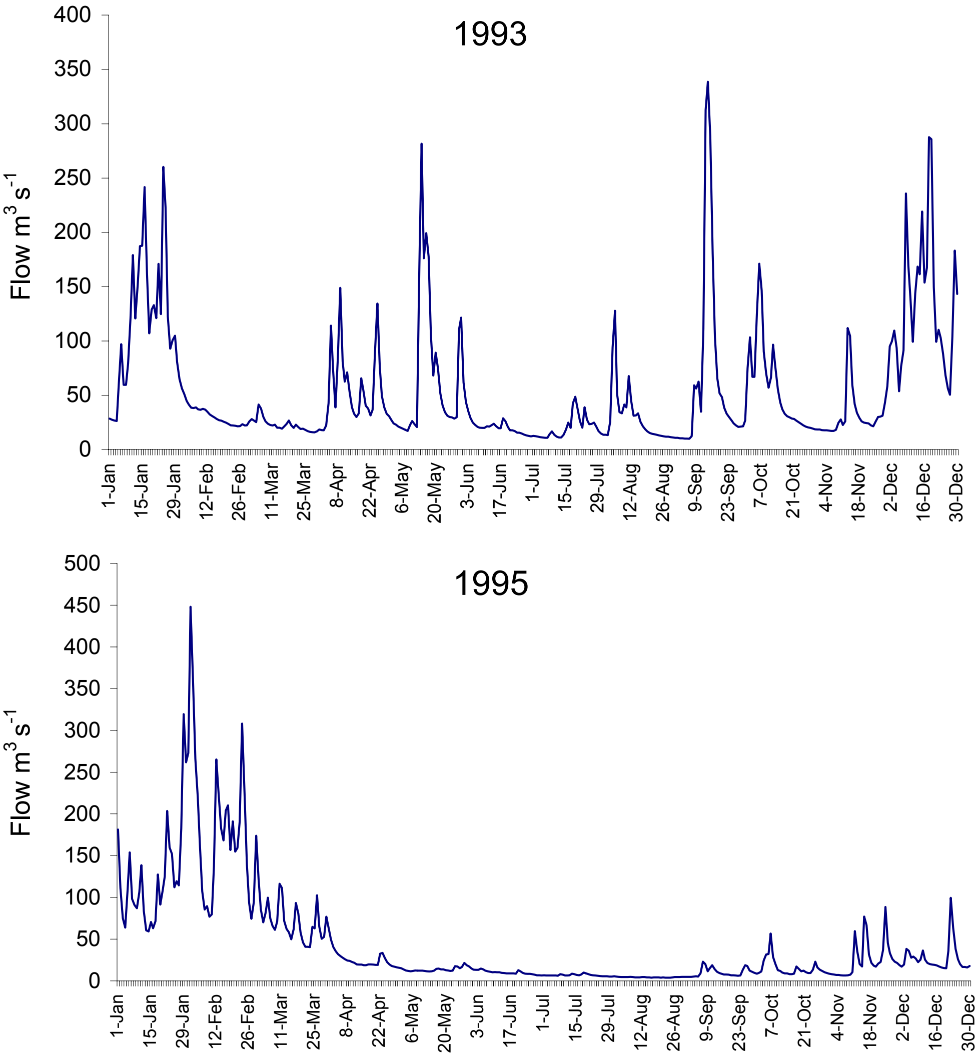

Figure 3.24. Comparison of mean daily flow regime in the River Ouse, recorded at Skelton, in 1993 and 1995.

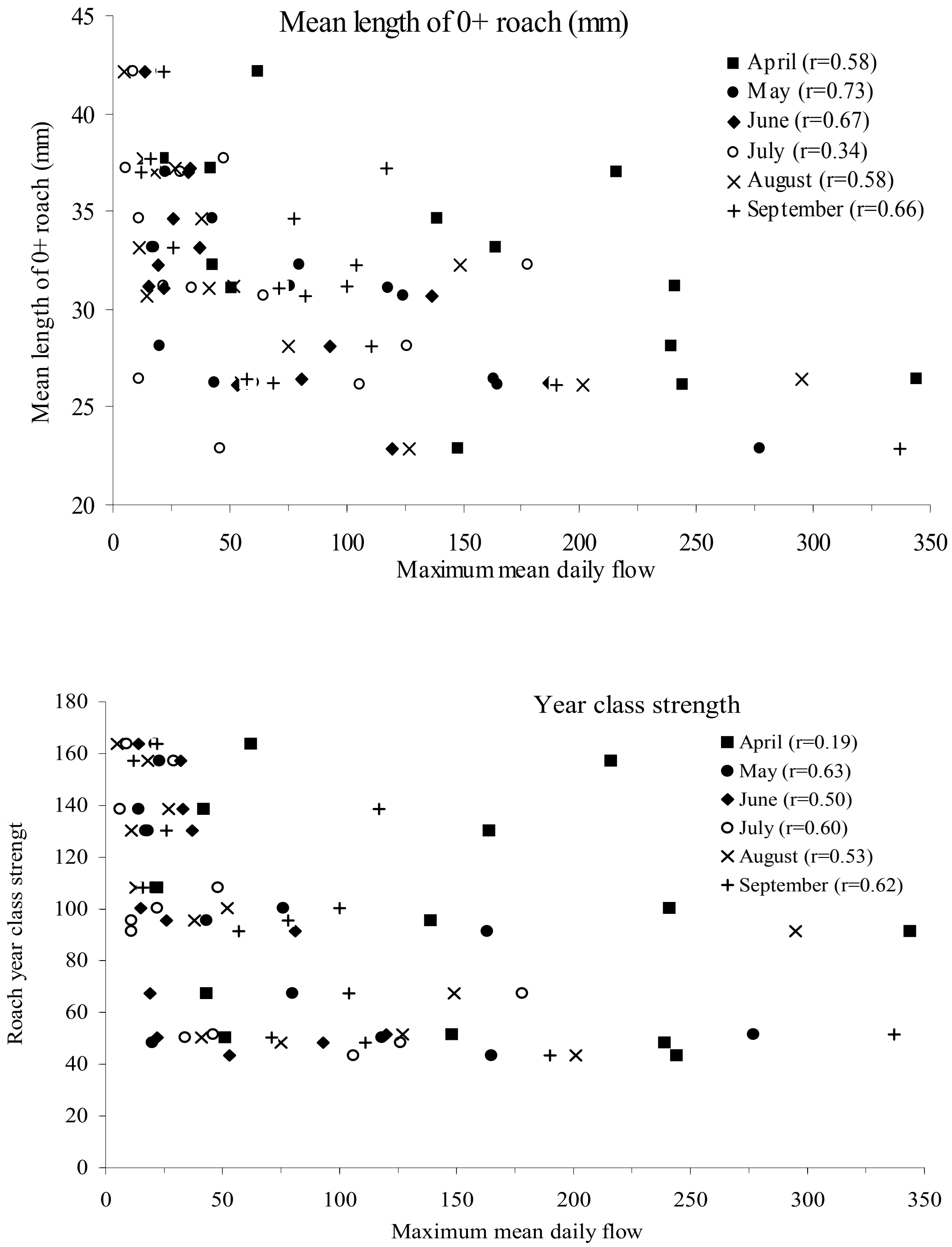

Figure 3.25. Relationship between maximum mean daily flow in different months and a) mean length of 0+ roach (mm) and b) year class strength of roach from the Yorkshire River Ouse.

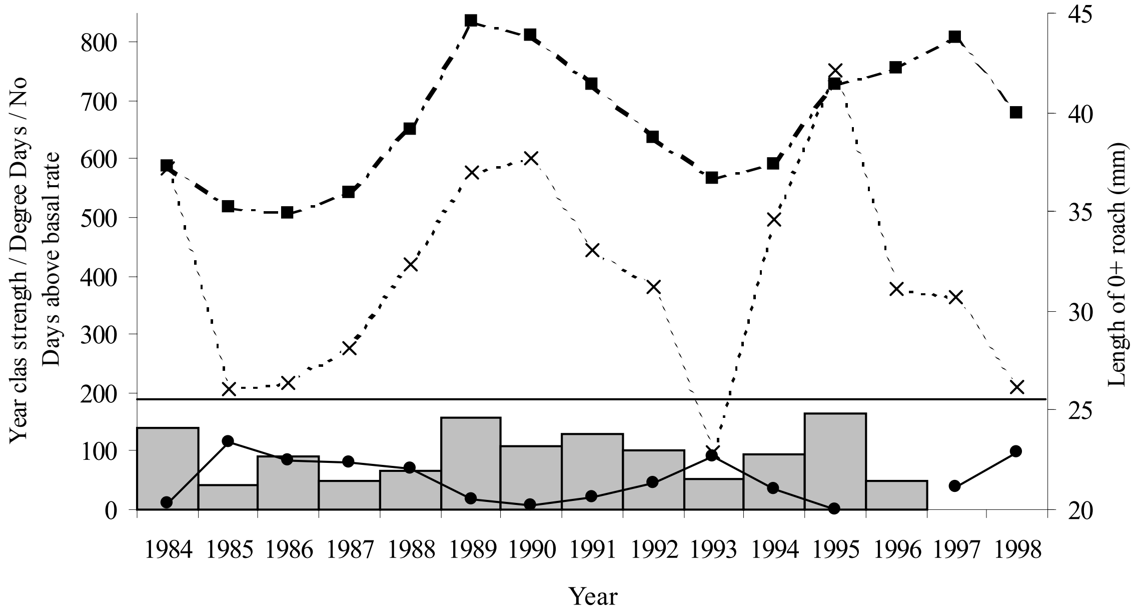

Figure 3.26. **Comparison of length of 0+ roach in September (x), roach year class strength (shaded bar), flow (number of days above basal rate, •) and temperature (degree days<12°C, ■) in the Yorkshire River Ouse.**

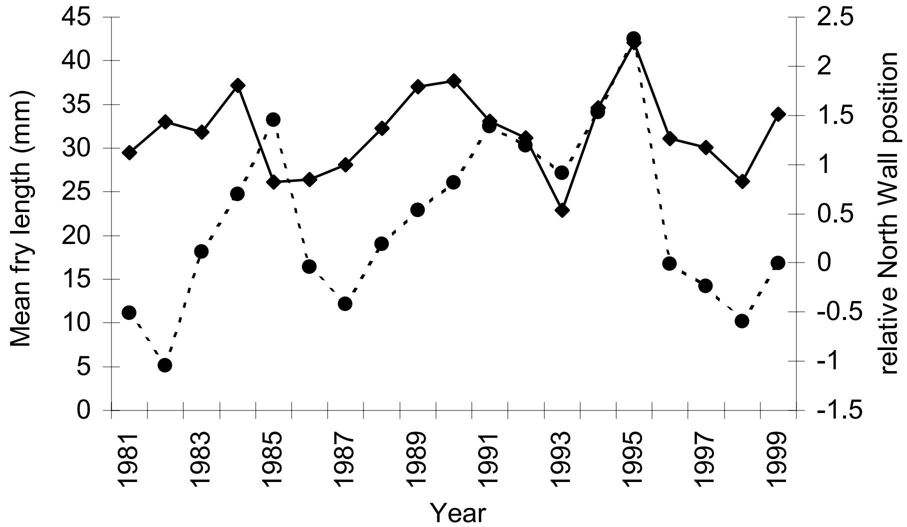

Figure 3.27. Relationship between mean length of 0+ roach in the Yorkshire R Ouse at Beningbrough and relative position of the Gulf Stream North Wall in August. ♦Roach year class strength, • relative position of Gulf Stream North Wall.

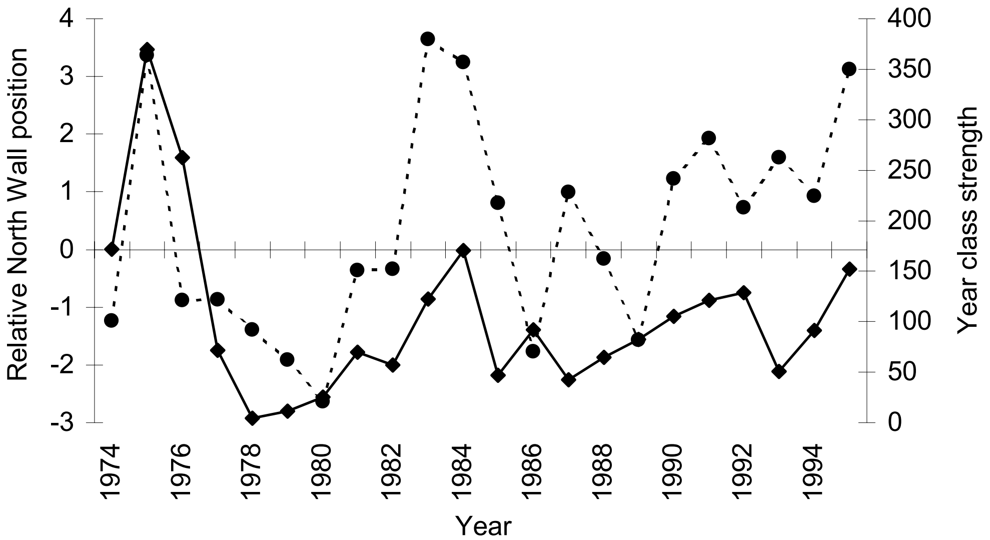

Figure 3.28. Relationship between year class strength of roach in the Yorkshire River Ouse and relative position of the Gulf Stream North Wall in August.