Optimum Stocking Strategies for Hatchery-Reared Riverine Coarse Fish

R&D Technical Report W2-i651/TR

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Statement of Use
The findings of project W2-i651 indicate that the optimum combination of age and season of introduction for hatchery-reared roach, chub and dace to small rivers was to stock 1+ (F2) fish in autumn. Therefore rearing of coarse fish on Agency fish farms for the purpose of fishery rehabilitation should continue to focus on production of 1+ fish for autumn release. Persistence rates of stocked fish in the target reaches were in any case very low and it is recommended that where the length of river in which a fishery is to be restored is 5km or less, methods other than restocking are employed. These recommendations will be implemented in the management plans for Agency coarse fish farms and by Agency fishery managers responsible for developing and restoring river fisheries, and will be incorporated into the forthcoming Fish Stocking Technical Manual.

Key Words
Stocking, Survival, Dispersal, Management, Monitoring

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EXECUTIVE SUMMARY

Stocking exercises represent a major element of current fishery management practice, whether carried out by the Environment Agency (the Agency), or by third parties under the Agency's guidance. As a Non-Departmental Government Body it is essential that the Agency has a formalised policy that:

- places stocking within the broad framework of integrated stock management; and
- enables its stocking objectives to be met, whilst taking due consideration of the different strategies for, and attendant risks of, the stocking process itself.

Although there is only a limited amount of information available on the success or otherwise of stocking exercises, it appears that much of the stocking carried out into rivers is only of limited benefit. Several factors are known to influence the potential success of a stocking exercise, and a number of areas of research for facilitating a greater understanding of these factors have recently have been identified. The current study was initiated to facilitate the identification of the optimum age and season for stocking of hatchery reared roach (*Rutilus rutilus*), chub (*Leuciscus cephalus*) and dace (*Leuciscus leuciscus*), so as to ensure the maximum survival over a 12-month post-release period in river fisheries.

An experimental approach was developed that would allow the relative significance of the two factors under consideration (age of fish and season of stocking) to be assessed. Two reaches on each of four rivers (the River Alderbourne, River Cherwell and River Hogsmill in Thames Region and the River Lostock in North-West Region) were, through consultation with local Agency Fisheries staff, selected for the study. In total, 44 sites were surveyed at approximately six monthly intervals for 2½ years.

Survey data was analysed quantitatively to provide information on post-stocking persistence (i.e. survival within a stocked reach), and quantitatively to provide information on post-stocking dispersal. In addition, and in parallel to the practical study, an economic appraisal of fish production at the Agency's main fish production facility (at Calverton) was undertaken.

Following the analysis of the completed data set it only proved practicable to assess post-stocking persistence for each age:season combination over a six month post-release period. Formal analysis indicated:

- 'river' was a significant factor in all of the analyses suggesting that river-specific factors (not accounted for in the study) are important in controlling the success of stocking exercises;
- post stocking persistence within the stocked reaches was generally low - the highest level of persistence was estimated at only 33.8% (i.e. only 33.8% of the fish stocked into a reach were estimated to be still present within that reach after a period of six months) - however, most of the estimates of persistence were considerably lower and (in practical terms) approached zero in several instances;
- no clear optimum strategy emerged from the survival analyses, although the inclusion of economic considerations suggests that the most cost-effective option (in terms of cost per fish remaining within the stocked reach after a period of six months) for each species:river combination is to stock with 1+ fish in the autumn;

- casual observation of the data revealed no clear patterns of dispersal, although it was evident that the apparent low persistence rates may be explained in part by emigration out of the stocked reach.

The apparent low persistence rates estimated in this study lead to the recommendation that, where the objective of stocking is the recreation of a fishery within a relatively restricted reach of river (for example 5km or less) consideration should be given to management methods other than stocking. In such instances, the 'within-reach' benefits of stocking (in terms of the persistence of stocked fish) are likely to be very limited.

It is further recommended that, should the Agency wish to continue with operational stocking, fish culture should concentrate on 1+ (i.e. F2) production - with stocking-out of fish being undertaken in the autumn. At the same time it is important to recognise the continued importance of the market demand for the older, larger fish that are produced at the Agency's fish production facilities and it is therefore recommended that the current flexibility in production enjoyed by the Agency's fish production facilities be maintained.

Further recommendations are made for work (including R&D) to support the development of the Agency's stocking policies, covering work on:

- stocking densities;
- post-stocking dispersal;
- the potential for natural recovery; and
- the potential for habitat improvement works as an alternative, or supporting, management strategy

1. INTRODUCTION

1.1 Background to the Project

Stocking exercises represent a major element of current fishery management practice, whether carried out by the Environment Agency (the Agency), or by third parties under the Agency's guidance. As a Non-Departmental Government Body it is essential that the Agency has a formalised policy that:

- places stocking within the broad framework of integrated stock management; and
- that enables its stocking objectives to be met, whilst taking due consideration of the different strategies for, and attendant risks of, the stocking process itself.

Although there is only a limited amount of information available on the success or otherwise of stocking exercises, it appears that much of the stocking carried out into rivers is only of limited benefit. Several factors are known to influence the potential success of a stocking exercise, and a number of areas of research for facilitating a greater understanding of these factors have recently have been identified. The successful completion of these research topics would enable the Agency to carry out its stocking programmes more cost-effectively, as well as improving the quality and reliability of advice that the Agency provides to angling clubs and other organisations wishing to stock with coarse fish.

The current study was initiated to facilitate the identification of the optimum age and season for stocking of hatchery reared roach (*Rutilus rutilus* L.), chub (*Leuciscus cephalus*L.) and dace (*Leuciscus leuciscus* L), so as to ensure the maximum survival over a 12-month post-release period in river fisheries.

This information will be used in the subsequent development of an economic model relating the time of stocking of hatchery reared roach, chub and dace to the implicit financial costs and potential success of the stocking exercise. In addition, guidelines on the stocking of hatchery reared roach, chub and dace will be produced for Agency fishery managers.

It is recognised that there are many factors that, together, influence the overall success of an integrated stock management programme. Whilst only constituting part of the overall programme, stocking strategy is a key and inherently complex component which ultimately affects overall stocking success. Furthermore, the identification of optimum strategies facilitates the cost-effective use of available fish production facilities within the Agency. Therefore, the proposed project is not only of importance in terms of the Agency's ability to meet strategic objectives, but also in terms of the its effective use of available resources.

1.2 Stocking Activities as a Fisheries Management Tool

1.2.1 Stocking objectives

Reasons for stocking fall into three broad categories:

- **mitigation** (to alleviate lost production which occurs due to a process that cannot be removed);

- **enhancement** (to supplement existing stock where production is believed to be less than the water body could potentially sustain);
- and **restoration** (to increase stock where limiting factors to recovery or improvement have been removed).

In any given situation there are a number of identifiable stages which together constitute the stocking process. These can be regarded as relating to policy (e.g. consideration of whether to stock; identification of specific objectives) and strategy (i.e. the actual stocking exercise). In addition it is likely that consideration will be given to a third phase, relating to monitoring (i.e. the subsequent assessment of stocking success).

1.2.2 Stocking policies

Although the stocking of coarse fish is a widely adopted and important tool, the management rationale and implications of stocking activities have not received the attention that they would be expected to demand (Cowx, 1998). However, it is possible to take arguments similar to those used in the consideration of salmonid stocking exercises and to employ them in the management of coarse fisheries. This effectively places the role of stocking within the wider framework of alternative management options. It is likely that the Agency's Fisheries Function will shortly seek to produce guidance on stocking practice; a development that will doubtless embrace the findings of this current study.

The planning phase of coarse fish stocking programmes can be seen as encompassing four main areas:

- the *need* for stocking;
- *alternative* management *options*;
- the *potential impacts* on resident communities;
- the *identification of* stocking *objectives*.

Of these, the first three represent the full range of factors that need to be involved in the decision of whether or not to stock.

The need for stocking

Coarse fish anglers utilising fisheries in British lowland rivers frequently express dissatisfaction with their catches (Pearce, 1983). Stocking can often be driven by the demands of such anglers, either as a restorative measure following a pollution event or as enhancement stocking to raise stock levels (see, for example, Gulson, 1990). Perceived declines in angling quality that drive requests from anglers are often likely to be the result of population fluctuations brought on by natural, as well as anthropogenic, factors. Indeed, natural fluctuations (especially those of a climatic nature) can have a profound effect on some fish populations (e.g. Mann, 1979; Mills and Mann, 1985; Cowx *et al.*, 1986).

Alternative management options

Pearce (1983) outlines three strategies for British coarse fish management. These were broadly described as:

- the ‘do nothing’ or ‘let nature manage’ strategy;
- the ‘conventional techniques’ strategy; and
- the ‘research’ strategy.

Consideration of potential impacts

The act of stocking can potentially carry risks - all of which should be fully appreciated and assessed before the final decision to stock is taken. There are, for example, potential risks of:

- parasite and disease introduction;
- adverse ecological interaction (through increased predation or competition);
- adverse genetic impact.

However, other than discussions on the implications of the introduction of ‘exotic’ or non-native species, such as grass carp (*Ctenopharyngodon idella* Val.) or zander (*Stizostedion lucioperca* L.), into UK waters (e.g. Stott, 1977; Hickley, 1986) or rudd (*Scardinius erythrophthalmus* L.) into New Zealand (Cadwallader, 1977) there is little information in the scientific literature detailing the potential impact of fish introductions on resident con-specific populations. Similarly there is little information available on likely levels of predation or competition between stocked fish and resident communities in UK waters.

In some cases, the monitoring of fish stocks following stocking exercises has suggested that the stocking itself has had an adverse effect on the original native fish populations (e.g. Gillet *et al.*, 1984). The tendency for introduced fish to predominate in a population (as shown by Gillet *et al.*, 1984) may well have implications in terms of the diversity of the gene-pool, an area which - to date - has received little consideration in coarse fish management.

Identification of objectives

The objectives of a stocking exercise may take several forms. For example, in the case of fishery enhancement, objectives are likely to be in terms of a ‘target’ population density or biomass. The attainment of such a target may be estimated through subsequent fishery surveys or by monitoring levels of angling success. For fishery restoration (e.g. following a fish kill incident) the principal objective may be to establish a breeding population of fish rather than to attempt to re-establish a full population of fish with a complete representation of all age-classes. In such cases the age structure of the restored population, along with its potential for successful reproduction, may be amongst the criteria used in the definition of stocking objectives.

Fish stocking activities in the Netherlands, over the period 1950-1990, were considered by Raat (1990). He noted that, although stocking exercises should have clear objectives and follow sound strategies, actual programmes were often based on assumptions that had not been validated through experimentation and few studies were carried out to evaluate their effects. This deviation from the ideal is compounded through stocking being undertaken for non-technical considerations (e.g. the alleviation of small-scale problems) or the necessity to adhere to established, standardised local authority programmes (EIFAC, 1988, cited by Raat, 1990). It would seem that the lack of clear guidelines and the general lack of follow-up work evident in the UK are, to some extent, paralleled in the Netherlands.

Policy within the former National Rivers Authority

A review of National Rivers Authority (NRA) stocking policy (Barnard, 1995) found that few of the former NRA Regions (e.g. Anglian Region and North-West Region) had formal, documented coarse fish stocking policies. Some Regions relied on draft Policy Implementation Notes (PINs), relating to fish kills and fish introductions, for guidance, whilst (at the time of the original consultation) others had no formalised policy to follow.

1.2.3 Stocking strategies

General

The strategies for stocking fish may be optimised by manipulating a large number of factors, including:

- source of fish (hatchery-reared or transferred);
- state/nature of receiving water;
- type of fish (species, age, size, health, condition, etc.);
- degree of acclimatisation;
- transport conditions;
- time of release;
- frequency of release;
- method of release;
- stocking density.

Stocking strategies within the Agency

Fish stocked by the Agency are generally released over a wide range of sizes and ages, and are obtained from a variety of sources, including rearing facilities; rescue operations; and strategic transfers[1]. Often it is the availability of fish for stocking which is seen as being the main factor dictating the age and size at release within most of Agency's regions. Similarly, time of release is dictated by availability, and this in turn is affected by many factors.

Notwithstanding this operational staff within the Agency will usually take account of a range of factors when assessing when to stock, including:

- the temperature of the receiving water (the lower temperatures of autumn and winter sometimes being favoured);
- the natural productivity of the receiving water;
- seasonal changes in the natural prevalence of disease;
- the rearing cycle on the fish farm;
- temporal availability of stock from other sources.

[1] Note, however, that the policy of inter-catchment transfers is now discouraged.

In general, a favourable combination of water temperature, acceptable flow rates and stock availability meant that autumn was one of the more favoured times of year for stocking.

Barnard (1995) found that trickle planting (the introduction of stock into the same reach over a period of time) was used routinely by only a couple of regions of the NRA, whereas scatter planting (the introduction of stock into several different sites within the same reach) was used by the majority of regions. Where regions undertook scatter planting of stocked fish, the degree to which the technique was used varied widely, being affected by many factors including:

- the original reason for the stocking exercise;
- the species being stocked;
- the availability of stock fish; and
- the accessibility and local habitat features of the different potential sites within the reach.

In the same study, the biomass of fish introduced through stocking exercises was found to be based on a series of measures including: the pre-impact population biomass (if this is applicable or, indeed, known); the perceived carrying capacity of the system; and the estimated biomass in the receiving water at the time of stocking. Estimating the biomass of stock fish required to yield the desired final population biomass within the fishery was complicated by several other factors. Whilst it was acknowledged that allowance needs to be made for post-stocking dispersal and mortality only the latter factor tended to be considered.

Current knowledge regarding stocking strategies

Much of the research into stocking strategies has focused attention on salmonids (e.g. Cragg-Hine, 1975; Egglishaw and Shackley, 1980; Strange and Kennedy, 1979; Kennedy and Strange, 1986; Kelly-Quinn and Bracken, 1989; Cresswell, 1981; Hesthagen *et al*., 1989; Wyatt, 1989). Few studies have been carried out to assess the success of coarse fish stocking in great detail (Gulson, 1990), and those that have, have not provided consistent evidence for the value of coarse fish stocking, or indications of optimum stocking strategies. Few studies have found high short-term survival of stocked fish (see, for example, Broughton, 1981).

Pearce (1983) felt that there had been only limited short-term, and scarcely any long-term benefits of stocking coarse fish in the lower Welsh Dee and, similarly, Linfield (1985) found stocking of marked coarse fish in the NRA Anglian Region to be largely unsuccessful. Axford (1974) concluded that the introduction of roach to the Hammerton fishery did not lead to an improvement in angling catch rates, other than for a short initial period, and Timmermans' study on Belgian watercourses stocked with roach of a catchable size (Timmermans, 1967) indicated that, even in the most favourable conditions, the success of restocking public angling waters with catchable fish would not exceed 50% (i.e. a maximum of 50% of stocked fish persisting in the waterbody over 8-9 months).

It should be noted that the fate of stocked coarse fish is often unclear, as it can be difficult to distinguish between mortality and movement. If the fish move upstream or downstream, they may still contribute to the fishery, albeit not in the area intended. Several authors have studied the mobility of coarse fish - which may be active or passive (e.g. Stott, 1967; Bruylants *et al*., 1986; Jordan and Wortley; 1985). Linfield, for example, reported that stocked fish may be lost downstream to saline waters in straight drainage channels where there are no habitat features to provide shelter during high flows (Linfield, 1985).

As noted in Section 2.1.3, there are several factors that are known to affect the potential for coarse fish survival and so, in turn, are likely to determine the effectiveness of stocking. However, there is little information in the literature that can be used to help define a 'best practice' for stocking.

The report on 'The survival and dispersal of stocked coarse fish' (Barnard, 1995) highlighted several areas where strategic research could be initiated (see Figure 1.1).

The findings from such research programmes would be taken in conjunction with information from operational work to help provide effective technical support for the development of stocking practice guidelines, applicable throughout the Agency. In effect, it is the last of these recommended research areas (research relating to stocking strategies) which is being addressed by the current R&D project.

1.2.4 Monitoring

Monitoring stocking exercises can provide information additional to simply the 'persistence' of a stock at the point of introduction. In this context, it is important that the assessment of whether a stocking exercise has been successful or not is undertaken in relation to the specific objectives of the exercise. For example, when stocking a small tributary for restoration after a fish kill, it may be important to have minimum movement of fish out of the target area, whereas when attempting to enhance a fishery through the introduction of a new species, the subsequent movement and dispersal of fish may be desirable. Such assessments of stocking success facilitate the continued management of the fishery, and provide valuable information that will enable stocking strategies to be further refined. However, despite the popularity of stocking there has been little systematic examination of its ecological effectiveness. In many cases stocking appears to be used more as a political tool, whereby user groups are reassured that action is being taken on their behalf, rather than as a mechanism for rational action (Welcomme, 1998).

Barnard (1995) found that both the occurrence and methods of post-stocking monitoring were variable across the NRA. Routine monitoring programmes were used to assess stocking success in a number of regions (e.g. Anglian, Severn-Trent, Northumbria, Wessex and Yorkshire) whilst angling returns or informal 'feedback' from anglers was taken into account by others (e.g. Thames and Southern). When marked, most stocked fish were Panjet marked (Hart and Pitcher, 1969) with Alcian blue dye, although Wessex region had also made use of fin-clipping.

There was little or no opportunity to make use of operational or strategic post-stocking monitoring data from within the Agency within the context of the current study.

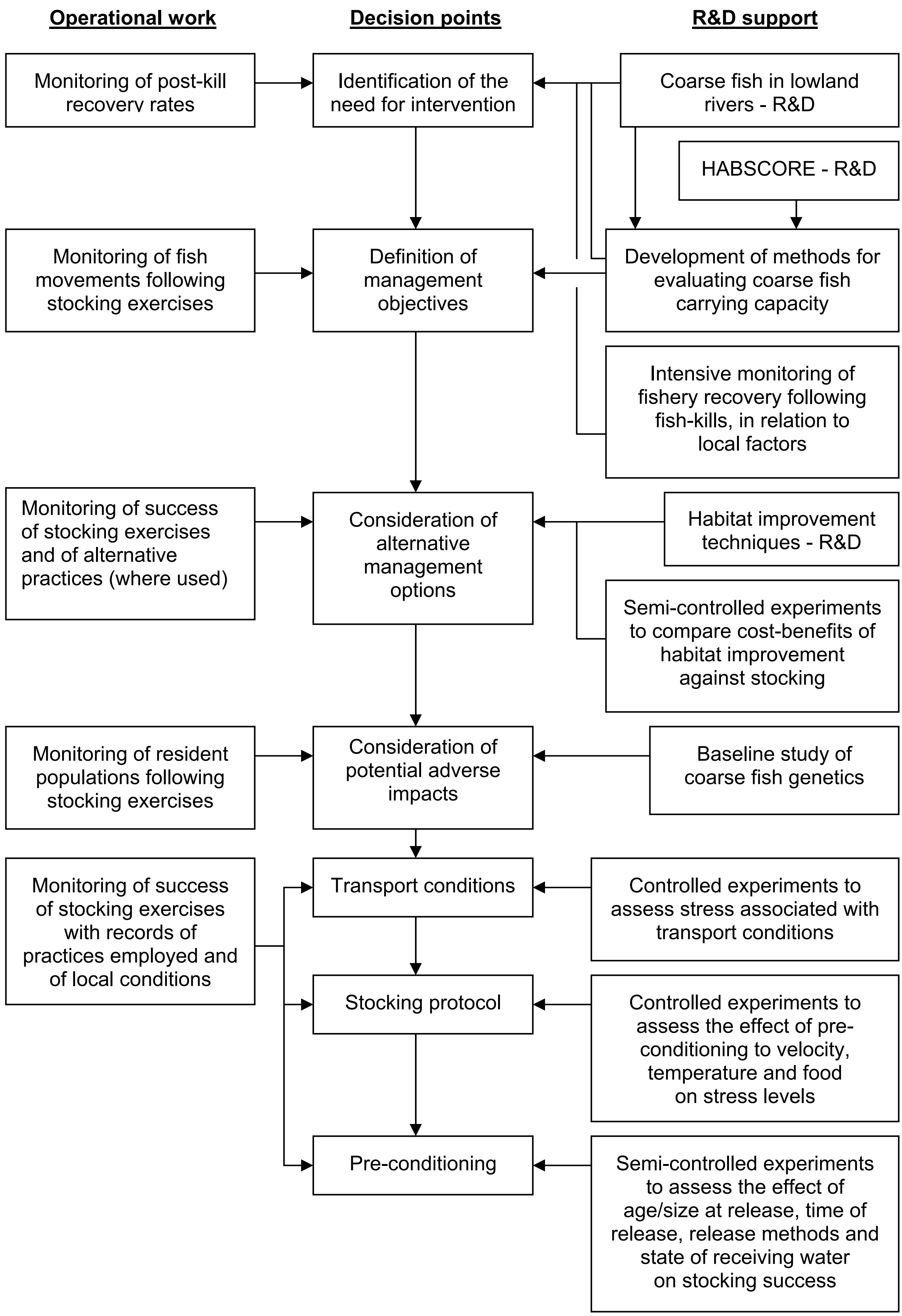


Figure 1.1: Recommended research within the framework of integrated stock management (after Barnard, 1995)

1.3 Project Objectives

1.3.1 Overall project objective

The overall objective of the proposed project was:

- to determine best practice for stocking hatchery-reared roach, chub and dace for restoration and rehabilitation of river fisheries, to enable the Agency to undertake coarse fish stocking programmes in a cost effective manner.

1.3.2 Specific objectives

The specific objectives of the project were as follows:

- to devise appropriate strategies and methods for monitoring the post stocking survival, dispersal and growth rates of hatchery-reared roach, chub and dace in rivers;
- to apply this methodology to identify optimum fish age and season for stocking of hatchery-reared roach, chub and dace to ensure maximum survival over a 12 month post-release period in river fisheries;
- to develop a simple cost-benefit model for hatchery-rearing and stocking of roach, chub and dace;
- to produce guidelines for Agency managers on the stocking of hatchery-reared roach, chub and dace.

2. METHODS AND PROTOCOL

2.1 The Basis of the Experimental Design

This project was initiated to enable the Agency to progress the scientific basis upon which internal policies regarding optimisation of operational stocking exercises are based. For this study there were two 'factors' of primary interest:

- autumn stocking versus spring stocking;
- stocking with different ages of fish.

It was the influence of these factors on stocking success that needed to be estimated as precisely as possible.

However, there are a large number of other variables relating to any stocking exercise which may potentially affect stocking success. These include, for example:

- origin of stocked fish;
- year-to-year effects (e.g. climatic);
- site-to-site effects (e.g. habitat);
- mobility and shoaling of fish;
- reach-to-reach effects (e.g. habitat, water quality);
- river-to-river effects (e.g. broad river type, habitat, water quality);
- 'interactions' (between spatial and temporal effects);
- random variation;
- measurement error (e.g. from the removal method).

Although such factors could not be held constant or varied systematically, it was intended that their effects would be accounted for in the results analyses.

The original project proposals considered the use of 0+, 1+ and 2+ fish. However, it became apparent early in the discussions with the Project Board that the inclusion of 0+ fish within the stocking experiments would lead to the introduction of a series of additional pressures - both in terms of fish production and the practical implementation of the survey work. It was not felt to be practical to attempt to accommodate these pressures and, after in-depth discussion at the first Interim Meeting, it was decided that the study would concentrate on 1+ and 2+ fish, to the exclusion of 0+ fish.

It was also agreed that an earlier proposed experimental design would be modified to reflect this change, and to make best use of the stretches of river that had been identified by the Agency as being available and suitable for the study. The design that was ultimately adopted enabled a far more useful and robust analysis of results to be undertaken than would have be possible with alternative experimental designs that were considered.

Finally, it was also acknowledged that whilst the assessment of optimum stocking densities is (and remains) an important consideration in any proposed stocking exercise, this would not be specifically addressed as an intrinsic element of the experimental design.

Consequently, it was agreed that:

- the study would compare the success (*q.v.*) of stocking with one year-old and two year-old fish[2] introduced during autumn and spring (i.e. a total of four different stocking 'treatments');
- success would be assessed in terms of survival – more specifically 'the post-stocking persistence within the stocked reach over a 12-month post-stocking period';
- the response of the 'survival' estimates was to be analysed assuming 'season' and 'age' to be the treatments - assessed independently as [season] and [age]; and jointly as [season.age] - the design also allowed river and year to be handled as random effects - effectively accounting for the expected differences in post-stocking survival between rivers and between years;
- this analysis would represent the primary objective of the study and would serve to identify optimum stocking strategy in terms of age and season for fish introductions to riverine environments;
- additional information on production costs would be made available by the Agency and used in conjunction with information on mean survival rates for each stocking 'treatment' to undertake least-cost analyses on the range of four stocking options;
- post-stocking dispersal of fish outside of the stocked reach would be assessed only qualitatively;
- the study would be undertaken using three species of fish - chub, dace and roach;

[2] The designation as 'one year-old' or 'two year-old' is at odds with established aging nomenclature which relates more to growing seasons. This was intentional, as it facilitated both the development of the experimental design and its subsequent analysis and interpretation.
The following table indicates (for fish of the 1995 year-class) the relationship between the age of a fish relative to its nominal 'birthday' (termed 'designated age' in the table) and the age as it would be determined by scale analysis, i.e. its age relative to growing seasons (termed 'growth age' in the table).
In addition, the four separate stocking events that were undertaken using 1995 year-class fish during the course of the study are indicated in the table.

Year	1995				1996				1997				1998			
Season	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter
Designated age	0+				1+ (or one yr-old)				2+ (or two yr-old)				3+ (or three yr-old)			
Growth age	0+		1		1+		2		2+		3		3+		4+	
Stocking event							✓		✓		✓		✓			

- at least three study rivers[3] would be used with two distinct target reaches on each;
- surveys would be undertaken at four sites on each target reach, at one site upstream of the upper target reach, one site between the two target reaches and at one site downstream of the lower target reach;
- five sets of surveys would be carried out on each river – undertaken at roughly six-month intervals these surveys would, as the *de minimus*, provide information that could be used to assess survival rates within each target reach over the 12-month period following stocking.

	U/S reach		Middle reach		D/S reach	
→	**X**	**X X X X**	**X**	**X X X X**	**X**	→
		Upper stocked reach Reach A		Lower stocked reach Reach B		

NB ‘**X**’ represents survey site; flow direction left to right

Figure 2.1: Schematic representation of relationship between survey sites and reaches on each river

The above conditions represent the project specification agreed as between the Agency’s Project Board and WRc on the 7th March 1996 - with subsequent modifications as discussed and agreed with the Project Board and Project Leader at various meetings: 15th November 1996; 5th December 1996; 15th April 1997.

2.2 Field Site Selection

2.2.1 Selection criteria for study rivers

The selection of rivers, reaches and sites which were manageable in terms of manipulation, stocking and monitoring was of fundamental importance. In particular, the selection of sites that facilitated the generation of results that would be relevant to future restoration and rehabilitation stocking was important. Effectively, the type of river that was sought was one that would normally be the subject of stocking for rehabilitation after an historical pollution or a fishkill. Specifically, at the time of selection, a range of six basic criteria for the site selection process were identified (over):

3 As a result of several, inter-related developments (see Project Record for full information) an additional study river was sought and the experimental design modified such that it catered for four rivers. This development further improved the balance of the design, and provided a ‘safety net’ for the study (in that the overall experimental design could still be analysed even if the use of one of the four rivers had to be abandoned during the course of the study - due, for example, to a pollution incident).

Environmental quality

- The habitat of the river should be of a quality that would be expected to support reasonable populations of coarse fish (e.g. not steep gradient fast-flowing shallow streams).
- The cause of low densities should have been identified and should be known not to be an on-going problem, e.g. where the reduction in observed density has been the result of a single acute pollution incident and where chronic, background pollution (should it be in evidence) is not thought to limit coarse fish populations.

Current fish populations

- There should be negligible/zero populations of dace, chub and/or roach, such that there would be no need to mark fish prior to stocking in order to facilitate their positive identification during subsequent surveys. As an alternative, it may be possible to consider situations were stretches of river are operationally 'de-fished', although such operations would have to be highly efficient (especially when considering the need to remove 0+ fish).
- There should, at most, be only a limited natural recolonisation potential (e.g. where the only natural recolonisation that would be possible would be through upstream immigration from below the next confluence, but where this is effectively prevented by an impassable weir).

Experimental requirements

- Nominated rivers should be easily accessible (i.e. should have good bankside access along the majority of their length; fisheries staff should have good working relationships with riparian and fishery owners) and be of a width and depth that would permit (fully quantitative) electric fishing by wading with two anodes.
- Ideally there should be a reasonable length of river available (i.e. >2km), such that there is the possibility of setting up more than one experimentally stocked reach 'back-to-back'. However, it would still be useful to identify shorter stretches of river (i.e. one or two kilometres in length) that may be available.

2.2.2 River selection

The above criteria were circulated amongst (NRA) staff who nominated a number of rivers that were subsequently considered for inclusion in the study. Of these, four rivers (the River Alderbourne, Cherwell and Hogsmill in Thames Region and the River Lostock in North-West Region) were eventually considered suitable for use (see Project Record for further details on the selection process). Maps of the four study rivers are presented below as Figure 2.2 *et seq.*.

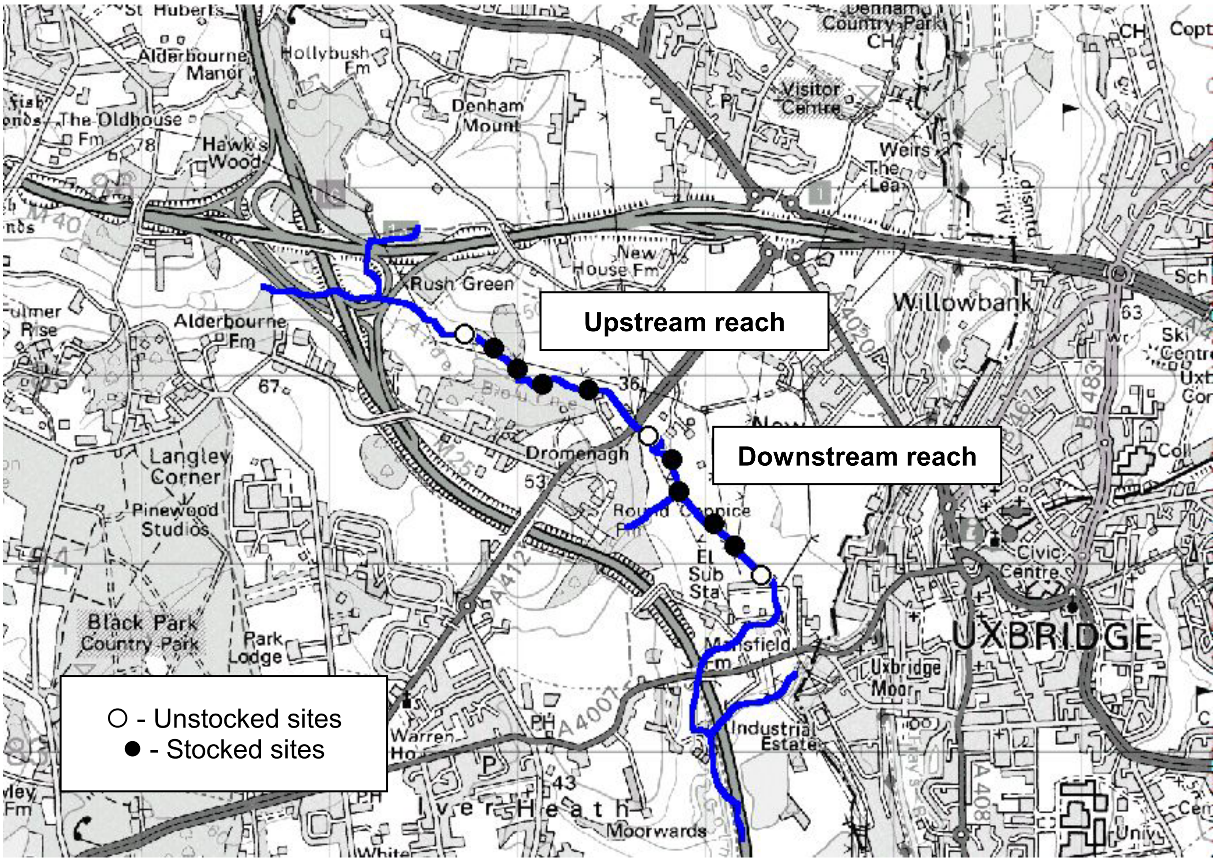


Figure 2.2: River Alderbourne near Uxbridge, West London - showing sites and reaches selected for the study

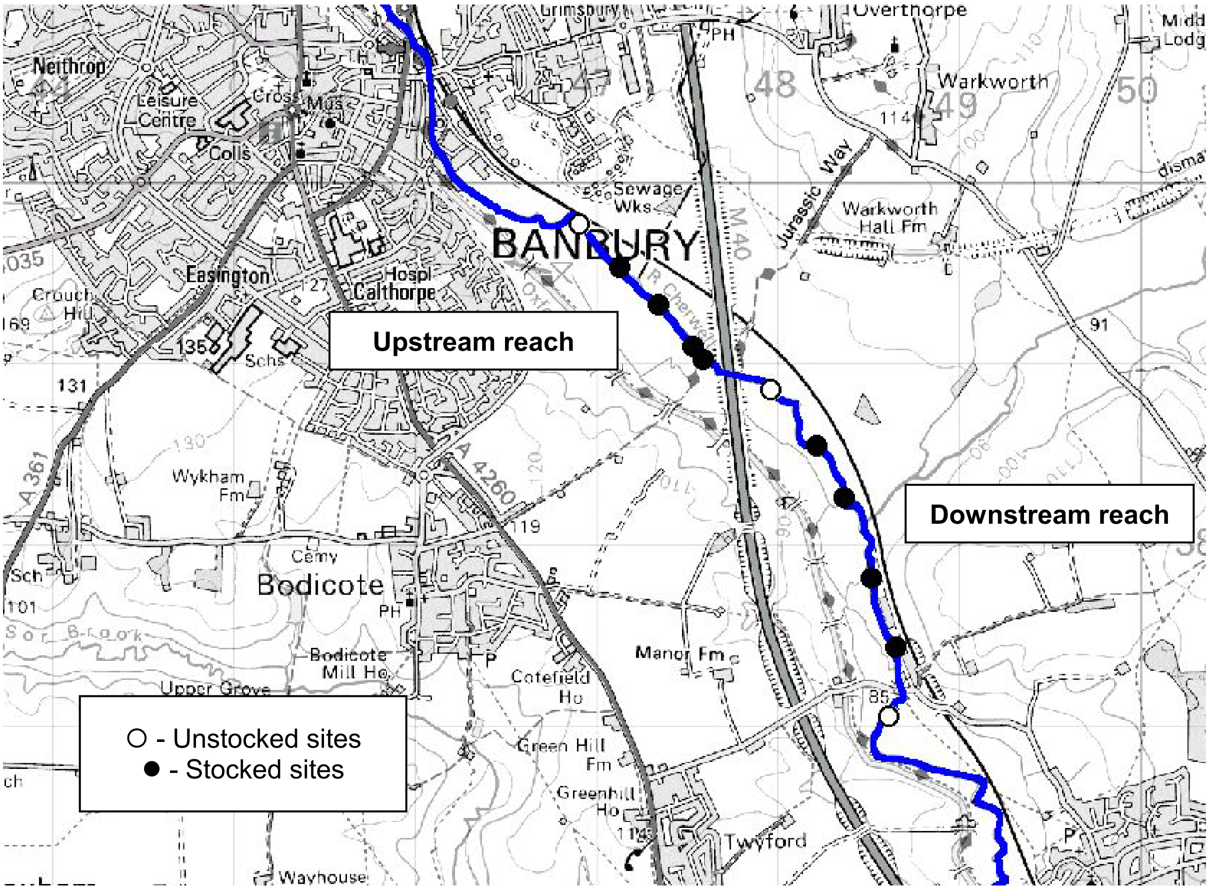


Figure 2.3: River Cherwell near Banbury, Oxfordshire - showing sites and reaches selected for the study

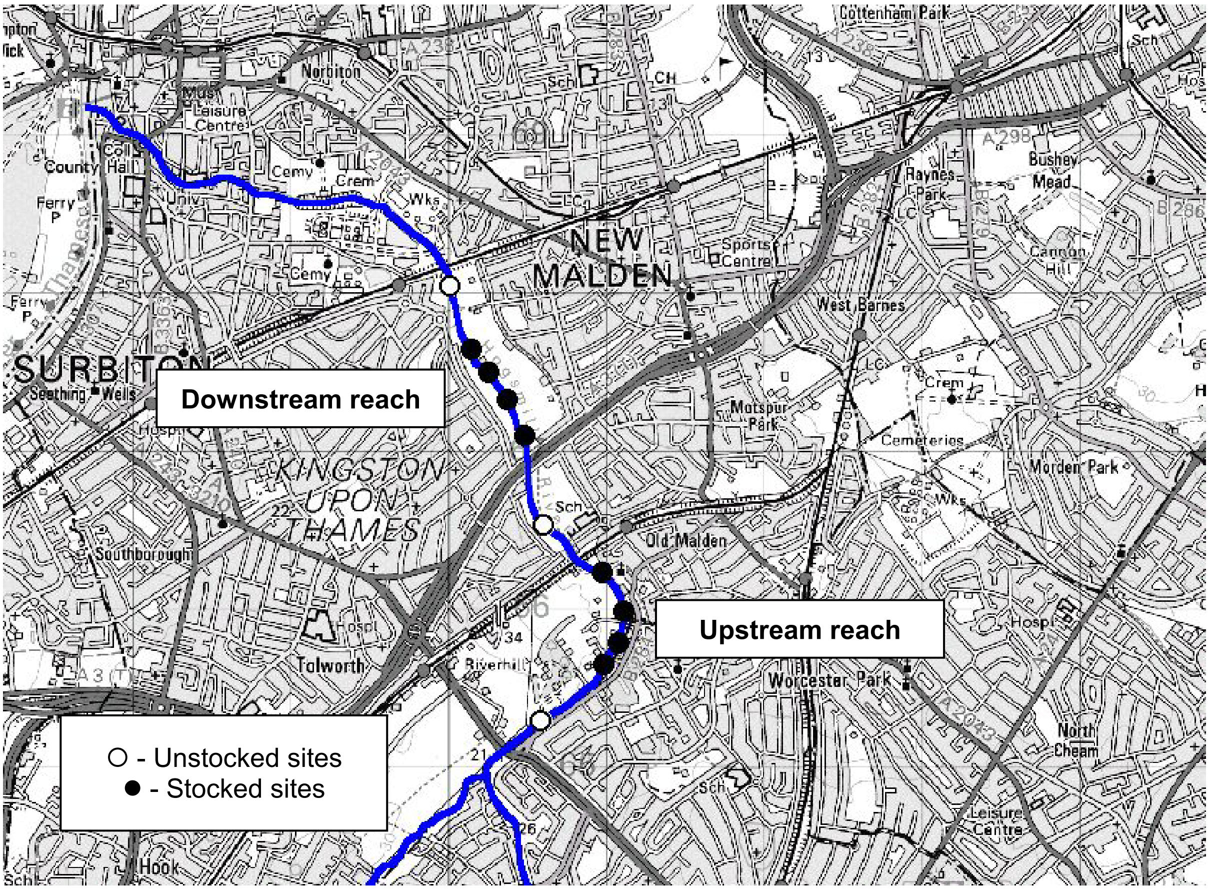


Figure 2.4: River Hogsmill near Surbiton / Kingston-upon-Thames - showing sites and reaches selected for the study

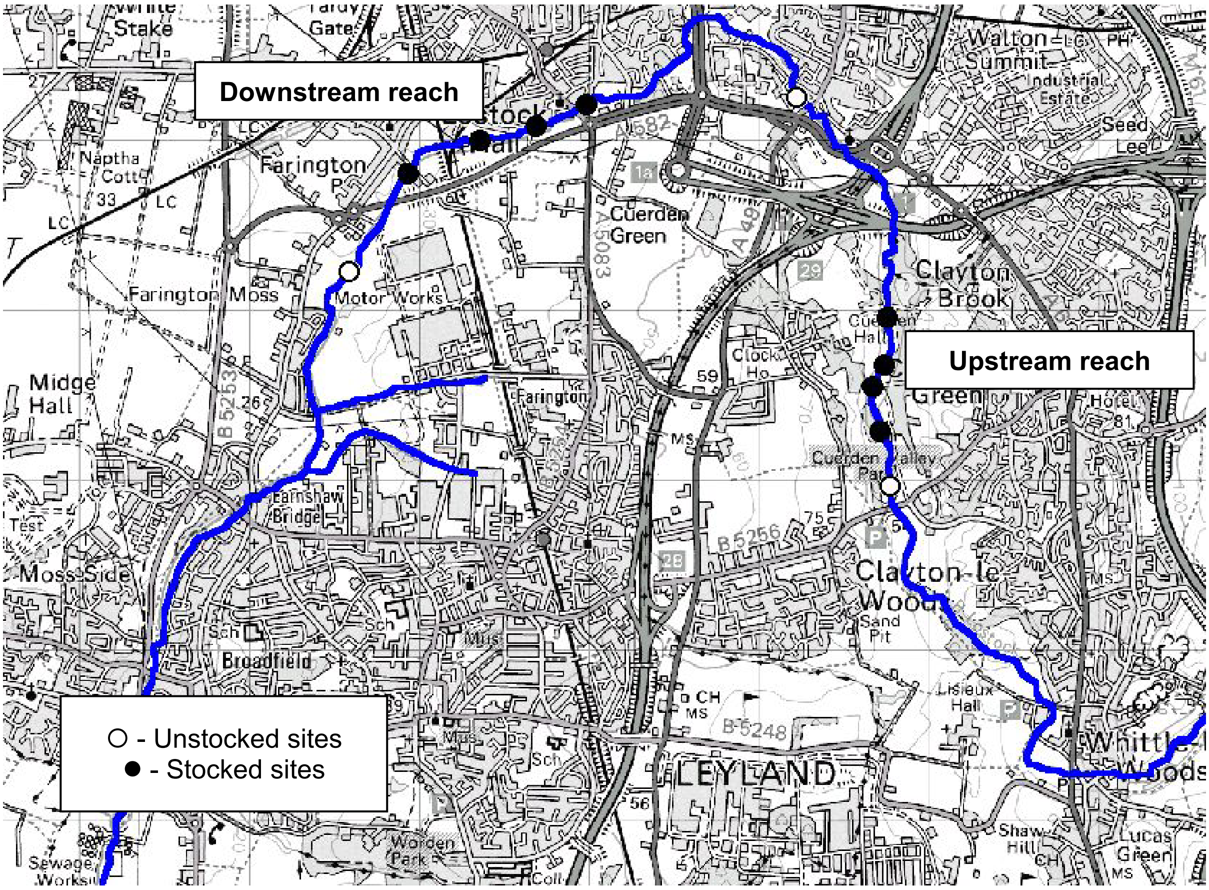


Figure 2.5: River Lostock near Preston, Lancashire - showing sites and reaches selected for the study

Of the four rivers selected for the study, only one (the River Cherwell) had been subject to a fish kill incident; the remaining three had very low fish populations due to more chronic problems.

Fish populations in the River Alderbourne had, historically, been limited largely by low flows (the river had suffered from drought conditions in preceding years). Although flow conditions in the river were no longer unfavourable the river's potential remained largely unfulfilled due to physical barriers to fish movement towards the (downstream) confluence with the Colne Brook (Richard Tyner, pers. comm.).

The River Hogsmill had suffered from extreme low flows in or before 1992 and, as a weir effectively prevented recolonisation from its downstream confluence with the River Thames, it remained (with the exception of minor species) essentially fishless.

The River Lostock had suffered from historical pollution although water quality was no longer thought to be a limiting factor (Darryl Clifton-Dey, pers. com.). An impassable weir at Faringdon (downstream of the proposed study reaches) prevented upstream colonisation. Fish populations downstream of the weir were healthy, supporting the view that water quality was not potentially limiting.

Other rivers that had been nominated were rejected for a range of reasons. In some instances, rivers were rejected because of physical characteristics (e.g. depth, width, degree of instream macrophyte growth) and the effects that these would have as regards electric fishing efficiency. In other cases, there was no evidence that the impact originally responsible for the suppression of natural fish populations had been alleviated. Also, some nominations related to sections of river that were felt to be too short (e.g. a total length of useable river of only ~1km) to be of use.

2.2.3 Initial status of fish populations

Existing survey information supplied by NRA staff indicated that the Rivers Alderbourne, Cherwell and Lostock supported very low populations of coarse fish (see Table 2.1 to Table 2.3, below). In addition, a fishery report was provided for the River Hogsmill which suggested that it was likely to fulfil the criteria for river selection. The river was described as a suitable candidate for stocking for rehabilitation although the report mentioned poor habitat quality at certain sites.

The data presented below are taken from surveys undertaken along the stretches of river considered for the study. It was anticipated that the densities of (native) fish present were so low as to preclude the need for stocked fish introduced as part of the proposed experimental work to be marked.

Table 2.1: Pre-stocking densities at selected sites on the River Alderbourne (November 1994)

	Site:		Number of fish caught:		
	length (m)	width (m)	chub	dace	roach
River Alderbourne - Site 1	85	2	0	0	0
Site 2	400	2.5	2	0	0
Site 3	110	3	2	0	0
Site 4	145	1.5	3	0	0
Site 5	115	2	2	0	0
Site 6	105	1.5	0	0	0
Total for sites surveyed	960	2.2	9	0	0
Density ($n.100m^{-2}$)			0.43	0	0

The chub that were caught on the River Alderbourne in 1994 were all of a similar size (19.0 to 26.5cm) and age (4 to 6 years old). It was believed that they had originated from an illegal introduction to the river (Richard Tyner, pers. comm.). No evidence of spawning or recruitment success for the chub population was found during the survey.

However, subsequent to the 1994 survey a trial stocking of chub and dace was undertaken on the river. Each of two sites were stocked with 25 panjet marked chub (30cm) and 500 panjet marked dace (12cm) in 1995. Consequently it was felt that, for the river to be used in the study, it was necessary to ensure that the resident populations of chub and dace that were likely to have become established since 1995 were reduced as far as possible. This removal exercise was undertaken in late 1996 (11 & 12 December). Approximately 330 dace and 20 chub were removed from the river. The nature of the operation (a relatively shallow river with excellent water clarity and use of efficient electric fishing equipment) was such that the removal exercise was believed to be very effective. No record was made of the capture (and susbsequent removal) of marked fish.

The detergent spill and associated fishkill on the River Cherwell (January 1995) left a much reduced coarse fish population in evidence. Post-fishkill, four NRA fishery surveys were undertaken on the stretch of river that was considered for use. The data from these surveys were used in the above table to provide an indication of the likely density of the fish population along the entire stretch.

In addition to the post-fishkill data for the River Cherwell (as presented above) minimum estimates of the fish populations prior to the fishkill were also made available by the NRA. These data implied that the River Cherwell had previously been a relatively healthy river, with the stretch identified for use in the current study supporting a density of ~16.3 individuals per $100m^2$ (equating to a biomass of ~$14.25g.m^{-2}$). The species composition over the stretch had consisted predominantly of roach, chub and dace, reinforcing its suitability as a study river.

Table 2.2: Pre-stocking densities at selected sites on the River Cherwell (October 1995)

	Site:		Number of fish caught:		
	length (m)	width (m)	chub	dace	roach
River Cherwell - Site 1	134	6.3	0	0	0
Site 2	241	7.3	1	0	0
Site 3	317	7.0	3	11	0
Site 4	297	4.1	0	0	4
Total for sites surveyed	989	6.175	4	11	4
Density (n.100m^{-2})			0.06	0.18	0.06

Table 2.3: Pre-stocking densities at selected sites on the River Lostock (1995)

	Site:		Number of fish caught:		
	length (m)	width (m)	chub	dace	roach
River Lostock - Site 1	50	3	0	0	1
Site 2	50	3	0	0	0
Site 3	50	6	0	0	6
Site 4	50	4	0	0	0
Site 5	50	3	0	0	0
Site 6	50	3.5	0	0	0
Total for sites surveyed	300	3.75	0	0	7
Average density (n.100m^{-2})			0	0	0.62

The seven roach that were caught on the River Lostock were unmarked and ranged between 10.5 and 22.5cm in length. No chub or dace were caught during the surveys which covered over 300m of river. The origin of the roach was unknown, although they apparently represented what was only a very sparse 'native' population. The survey results supported the belief of the fishery officer that there were no significant populations of roach, dace or chub present in the nominated reaches.

2.2.4 Site selection

On each river, four sites were identified along each of the reaches that were to be stocked during the course of the study. Three additional sites were also identified: one upstream of the upper stocked reach; one between the two stocked reaches; and one downstream of the lower stocked reach.

Survey sites were selected in spring 1997, during the first round of surveys. The 11 sites on each river were chosen at random, although some degree of pragmatism was necessary regarding access limitations and the nature of habitat being sampled. It was hoped that the range of sites selected represented an approximately stratified sampling programme as far as was possible using the electric fishing methods that were proposed. It was acknowledged that certain habitats (e.g. deep scoured pools on bends of the River Cherwell) would not be sampled and may provide a refuge for stocked fish. Such habitats could only be fished by boat and it was felt that the likely sampling efficiency using such techniques would be unacceptably low (especially given the nature of the size and age of fish that were being actively targeted). In addition, the three unstocked sites were, as far as practicable, positioned such that the information that would be produced on post-stocking movement would be pertinent (for example, the upstream site was not located too far upstream of the upstream limit of the upper stocked reach). The position of the sites on each study river are shown on Figure 2.2 *et seq.*. In addition, the location of each site (presented as the NGR of each site's NGR) are given as an appendix within the Project Record.

Together, the sites that were selected represented between 15% and 41% of the stocked reaches that they were taken to represent (see Appendix A). This, taken together with the fact that the sites covered the range of habitat types observed on each reach, increased general confidence regarding the extent to which the results observed at the sites that were surveyed typified the actual situation prevailing within the reach as a whole.

2.3 Stocking Methodology

2.3.1 Species combinations

Fisheries which are to be stocked for restoration or rehabilitation are invariably stocked with a combination of fish species. Therefore, in many cases, inter-specific competition, as well as the effect that age at stocking may have on such inter-specific effects, are likely to be important. Ideally therefore the success of autumn versus spring stocking should be examined through a series of controlled experiments which, together, employ all of the principal combinations of species and age. However, not only is it obvious that the associated manpower requirements would be excessive, but the need to ensure adequate replication of experimental conditions renders this approach impractical.

The three species of interest were therefore stocked in approximately equal numbers into each experimental treatment, with each stocking treatment being applied in a similar manner to each species. Although it was not possible to establish the influence of inter-specific effects on the success of different stocking regimes using this approach, it did permit the principal objectives of the project (i.e. the identification of the optimum fish age and season for stocking) to be met in a cost-effective manner.

2.3.2 Timing and method of release

The stocking programme (showing age and year-class of stocked fish) for the agreed experimental design was as indicated below (Table 2.4). Note that, for each river, two of the four stocking events involved the same year-class of fish (shown as bold text in Table 2.4). A conscious decision was made to arrange the stocking programme such that the first stocking of the duplicated year-class was undertaken to the lower reach and, in terms of time, was separated from the second stocking as far as possible.

	River and reach							
	Alderbourne		Cherwell		Hogsmill		Lostock	
Stocking date	A (u/s)	B (d/s)	A (u/s)	B (d/s)	A (u/s)	B (d/s)	A (u/s)	B (d/s)
Autumn '96	2+ ('94)		2+ ('94)			**1+('95)**		**1+('95)**
Spring '97		**1+ ('95)**		**1+ ('95)**	2+('94)		2+('94)	
Autumn '97		1+ ('96)		1+ ('96)	**2+('95)**		**2+('95)**	
Spring '98	**2+ ('95)**		**2+ ('95)**			1+('96)		1+('96)
Fish supplied by :	Calverton		Calverton		Calverton		Leyland	

Table 2.4: Schematic of agreed stocking programme on final selected study rivers

It was decided by the Project Board that, in general, fish would not be marked prior to stocking. Exceptions to this were those instances where the 1995 year class of fish was being stocked into a river for the second time. It was intended that the second batch of 1995 year class fish would be marked to facilitate their positive identification. However, in practice, these were not the only marking exercises that were undertaken (see Section 2.3.4).

Fish were not stocked into waters which were believed to be in an unsuitable state to receive them (e.g. in flood). Such adverse conditions necessitated a postponement of stocking. Similarly, and as survey work was scheduled to precede stocking exercises (see footnote on page 4), delays in the completion of survey work would necessarily delay the planned stocking.

Actual stocking dates were as shown in Table 2.5.

Table 2.5: Stocking dates

River	Autumn 1996	Spring 1997	Autumn 1997	Spring 1998
Alderbourne	17-Dec-96	09-Apr-97	29-Oct-97	28-May-98
Cherwell	31-Oct-96	21-Mar-97	30-Oct-97	29-May-98
Hogsmill	06-Nov-96	08-Apr-97	04-Nov-97	04-Jun-98
Lostock	20-Nov-96	07-May-97	08-Dec-97	24-May-98

2.3.3 Stocking densities

In operational practice a number of factors need to be taken into account when determining stocking densities for rehabilitation or restoration, including:

- the age of the stocked fish;
- the season;
- the carrying capacity of the river habitat;
- the number of species being stocked;
- the species present and abundance of resident populations;
- the speed at which the fishery is to be restored.

A further critical consideration of especial importance when undertaking experimental studies to assess the survival and dispersal of stocked fish is to ensure that stocking densities provide a statistically meaningful sample of fish throughout the post-stocking monitoring.

For this study, stocking densities were varied between time of year and age of stocking (to reflect natural mortality, a 20% mortality rate being assumed for each 6-month period[4]).

The stocking densities used in the experimental design were based on two criteria:

- the stock density was of the same order of magnitude as the population that would be expected in the same river but under non-impacted conditions; and
- the stock density was not grossly dissimilar to that used in standard operational practice by the Agency.

In practice, the actual density of stocked fish was based on pre-impact population estimates for the River Cherwell. Data for the reach, derived from surveys undertaken some months before the fishkill, were made available by the NRA. These data are presented as an appendix within the Project Record.

Increasing the number of fish being stocked over and above the levels indicated by pre-impact studies, in an attempt to produce a situation where more fish remained in the stocked reach (so giving higher population estimates) would have the associated risks of:

- introducing density-dependent effects that could not easily be estimated and which could mask the 'true' persistence rates; and
- providing experimental results that cannot easily be matched back to operational procedures.

The target densities for the four stocking treatments were as shown in Table 2.6.

[4] Whilst this 6-month mortality rate may be low (compared to some studies of natural systems) it was not intended to be a direct reflection of the actual mortality rates experienced by the stocked fish. The nominal 20% 6-month mortality rate (which equates to a 36% annual mortality rate) was simply used to provide a consistent means of determining the number of successive age groups of fish that were being stocked. Had a higher mortality rate been assumed, the numbers of fish of the younger age groups that would have been required would have would have been impracticably high and the total number of fish required by the project would have exceeded the number that were available.

Table 2.6: Target densities

Treatment - season and age	Overall density ($n.100m^{-2}$)	Density per species ($n.100m^{-2}$)
Autumn 1+	66.3	22.1
Spring 1+	53.0	17.7
Autumn 2+	42.4	14.2
Spring 2+	34.0	11.3

In order to calculate the number of fish required for each stocking exercise the area of each reach had to be estimated. This was done using an approximation of the channel width of each reach (taken from preliminary site visits) and estimates of reach lengths as taken from 1:10,000 OS maps. Subsequently, refined estimates of reach areas were produced, again using overall reach lengths estimated from OS maps, but substituting a mean channel width as calculated from site measurements recorded during the first round of surveys. The two values for each reach were, generally, in reasonable agreement (see Table 2.7) although some discrepancies were in evidence. The nominal average densities actually achieved by the stocking exercises (assuming no emigration of stocked fish outside of the nominally defined reach) were as given in Table 2.8. All subsequent analyses were based on population densities as calculated using the refined reach area estimates.

Table 2.7: Reach areas

River	Reach	Anticipated area (m^2)	Estimated actual area (m^2)
Alderbourne	Upper stocked reach (reach A)	2,713	2,403
	Lower stocked reach (reach B)	2,800	2,381
Cherwell	Upper stocked reach (reach A)	7,280	7,375
	Lower stocked reach (reach B)	9,870	10,486
Hogsmill	Upper stocked reach (reach A)	4,000	4,950
	Lower stocked reach (reach B)	3,800	5,613
Lostock	Upper stocked reach (reach A)	6,000	4,592
	Lower stocked reach (reach B)	7,200	9,057

On each occasion fish were, as far as practicable, stocked throughout the target reaches (as opposed to being 'spot-planted'). In addition, each stocking exercise was undertaken in a single operation (i.e. there was no 'trickle-stocking').

Table 2.8: Stocking densities achieved

River	Age	Season	Reach	Number stocked (per species)	Nominal mean density (per species; n.100m^{-2})
Alderbourne	1+	Autumn	Lower stocked reach (reach B)	619	26.0
	1+	Spring	Lower stocked reach (reach B)	495	20.8
	2+	Autumn	Upper stocked reach (reach A)	384	16.0
	2+	Spring	Upper stocked reach (reach A)	307	12.8
Cherwell	1+	Autumn	Lower stocked reach (reach B)	2,182	20.8
	1+	Spring	Lower stocked reach (reach B)	1,745	16.6
	2+	Autumn	Upper stocked reach (reach A)	1,030	14.0
	2+	Spring	Upper stocked reach (reach A)	824	11.2
Hogsmill	1+	Autumn	Lower stocked reach (reach B)	840	15.0
	1+	Spring	Lower stocked reach (reach B)	672	12.0
	2+	Autumn	Upper stocked reach (reach A)	566	11.4
	2+	Spring	Upper stocked reach (reach A)	453	9.2
Lostock	1+	Autumn	Lower stocked reach (reach B)	1,591	17.6
	1+	Spring	Lower stocked reach (reach B)	1,273	14.1
	2+	Autumn	Upper stocked reach (reach A)	849	18.5
	2+	Spring	Upper stocked reach (reach A)	679	14.8

2.3.4 Problems encountered with the stocking programme

Responses / operational solutions

The range of reactive measures adopted in response to ongoing operational problems are detailed in Table 2.9 below.

In order to facilitate the identification of the 'source' of fish that were introduced through the stocking programme, other marking exercises (additional to those outlined in the Table 2.1) were undertaken. Specifically:

- all of the 2+ ('94 year class) chub, dace and roach that were stocked to the River Lostock from Leyland in Spring 1997 were (Panjet) batch-marked at the base of the pelvic fins;
- all of the 2+ ('95 year class) chub and dace that were stocked to the Rivers Alderbourne and Cherwell from Calverton in Spring 1999 were batch-marked with a dye injection at the base of the pelvic fins.

Table 2.9: Reactive measures adopted in response to operational problems with stocking programme

Problem	Response
Lack of 2+ roach (R.Hogsmill - Spr.'97)	*Larger 1+ roach ('95 y.c.) from Calverton were used for the stocking exercise.* All of these fish were batch-marked with a dye injection on the belly.
Mix of 1+ & 2+ dace (R.Hogsmill - Spr.'97)	*Larger dace from a mix of 1+ and 2+ ('95 and '94 y.c.) from Calverton were used for the stocking exercise.* These fish, the majority of which were thought to be 2+, were batch-marked with a dye injection on the ventral surface, posterior to the anal fin. Scale samples were taken from a sub-sample of these fish to indicate the proportions of 1+ and 2+ fish - and hence the likely number of 2+ fish introduced. NB all 2+ chub remained unmarked.
Limited number of 2+ dace (R.Lostock - Aut.'97)	*2+ dace from Calverton were used to supplement the limited number that were available from Leyland.* All Leyland fish (including the full quota of chub and roach) were (Panjet) batch-marked at the base of one of the pectoral fins. The supplementary 2+ dace from Calverton were batch-marked with an additional dye injection at the base of the pelvic fins.
Lack of 2+ roach (R.Alderbourne - Spr.'98)	*No replacement was found.*
Lack of 2+ roach (R.Cherwell - Spr.'98)	*No replacement was found.*

2.4 Survey Methodology

All sites were surveyed by (pulsed DC) electric fishing; fished by wading using either using generator-powered (twin anode) equipment or backpack (single anode) equipment. All sites were isolated using stop nets. In general, multiple removals were undertaken although the use of only two removals was accepted as a reasonable strategy given the small contribution of measurement error to coarse fish surveys (in most coarse fish surveys the error associated with the removal method is usually small, e.g. less than 1%; see Table 2.10). Exceptions to this were occasions when no 'target species' (i.e. fish that could have originated from earlier stocking activities) were caught in the first run and occasions where prevailing conditions (flow conditions, light conditions, etc.) prevented subsequent runs being undertaken despite a low number of target species having being caught in the first run.

Table 2.10: Variance partitioning for roach in a lowland river - after Barnard & Wyatt, 1996

	<10cm		>10cm	
Source of error	**Variance**	**Percentage**	**Variance**	**Percentage**
Spatial	0.000	0.0	0.328	17.5
Temporal	0.796	60.3	0.000	0.0
Interaction and mobility	0.521	39.4	1.533	81.8
Measurement	0.003	0.3	0.013	0.7
Total	1.320	100.0	1.873	100.0

As noted above (Section 0) surveys in a given season were undertaken prior to that season's stocking exercise. Survey dates are given in Appendix B.

All fish were identified to species and measured (standard fork length). Where appropriate, fish were examined for Panjet marks. A subset of fish were scaled to provide data to provide information to assist with subsequent confirmation of age and source (i.e. whether stocked or native).

In addition to basic fisheries data as described above, simple site measurements (site length and channel width at three points along the site) were recorded. All site measurements are presented as Appendix A.

2.5 Practical Constraints to Survey Work

2.5.1 Access agreements

River Alderbourne

In spring 1998 the riparian owner for two of the sites on the upper stocked reach (Reach A) on the River Alderbourne withdrew his support for the project. Without the necessary access permissions from the riparian owner it was not possible to undertake any further surveys at the two sites in question. Consequently, surveys for spring and autumn 1998 and for spring 1999 could only be undertaken on two of the original four sites on Reach A. Access to the other two sites on the reach and to the other seven sites on the river, remained unaffected.

2.5.2 Adverse conditions

River Cherwell

In autumn 1998 the River Cherwell flooded and the planned surveys at all 11 sites had to be abandoned. The river could not be fished safely or effectively. Access was not possible as all fields adjacent to the river remained severely waterlogged.

In spring 1999 the survey of one site on the upper stocked reach of the River Cherwell (Reach A) had to be abandoned. The site was on bend in the river, and excessive scour during the previous season's flood event had deepened the site such that it could no longer be effectively or safely surveyed.

Also in spring 1999, surveys of the middle site (i.e. the site between the upper and lower stocked reaches) and all four of the sites within the lower stocked reach (Reach B) were abandoned. Fields adjacent to the river (many of which had been under water for several weeks) remained severely waterlogged and access permissions to the river were withheld by the riparian owner.

River Hogsmill

In autumn 1998 the survey of one site on the downstream stocked reach (Reach B) of the River Hogsmill had to be abandoned due to high flows.

In spring 1999 the survey of one site on the upper reach (Reach A) of the River Hogsmill had to be abandoned. A pool mid way along the site had been excessively deepened (presumably by the scour effects of high flows due to high run-off levels during the preceding winter) and could no longer be surveyed efficiently or safely.

3. SURVEY RESULTS AND ANALYSIS

3.1 Post-Stocking Persistence of Target Species

3.1.1 Data processing

Removal data for the three target species were bulked prior to population estimates. Population estimates were produced for multiple run data using the Maximum Weighted Likelihood method of Carle and Strub (Carle and Strub, 1978). Where removal data was only available from a single run, the number of fish that were caught was multiplied by the estimated probability of capture for surveys at adjacent sites to generate a population estimate.

The lengths of all chub, dace and roach were used to generate length-frequency histograms for each reach on each survey occasion (see Figure 3.1 for an example; all such histograms are presented as an appendix within the Project Record). In combination with length-frequency data for stocked fish at the time of stocking, as recorded by staff at Calverton and Leyland (see Figure 3.2 for an example; again, all such histograms are presented as an appendix within the Project Record) this data was used to assign each chub, dace and roach that was caught to one of five groups: ‘native’ or stocked from one of the four possible ‘age.season’ combinations. Confirmation of the source of a recaptured fish was possible in a limited number of cases by reference to Panjet marks.

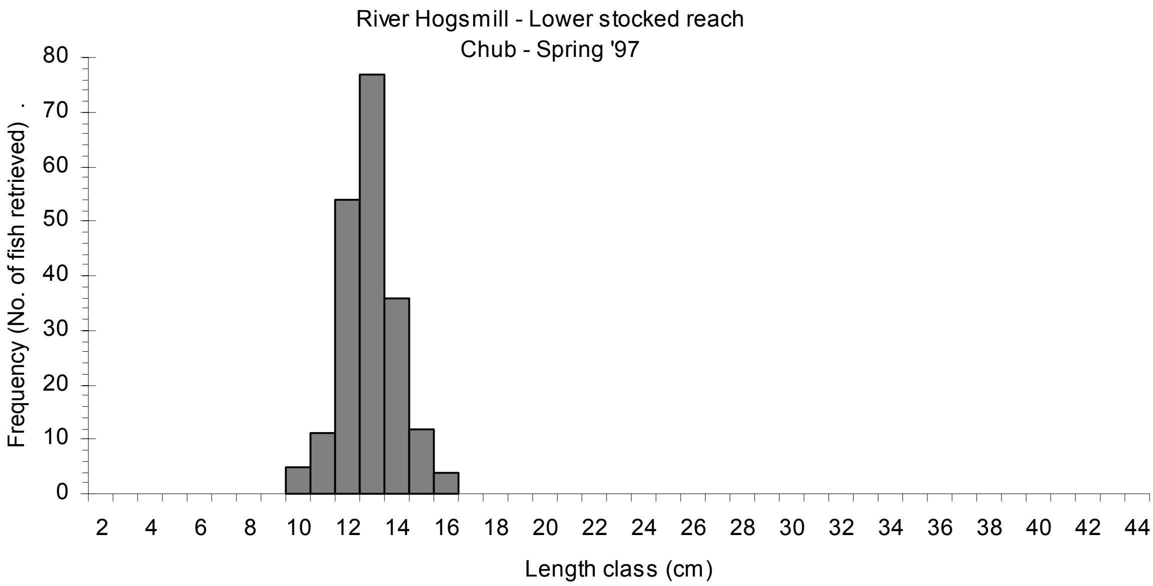


Figure 3.1: Example of length frequency histogram of fish caught from a target reach

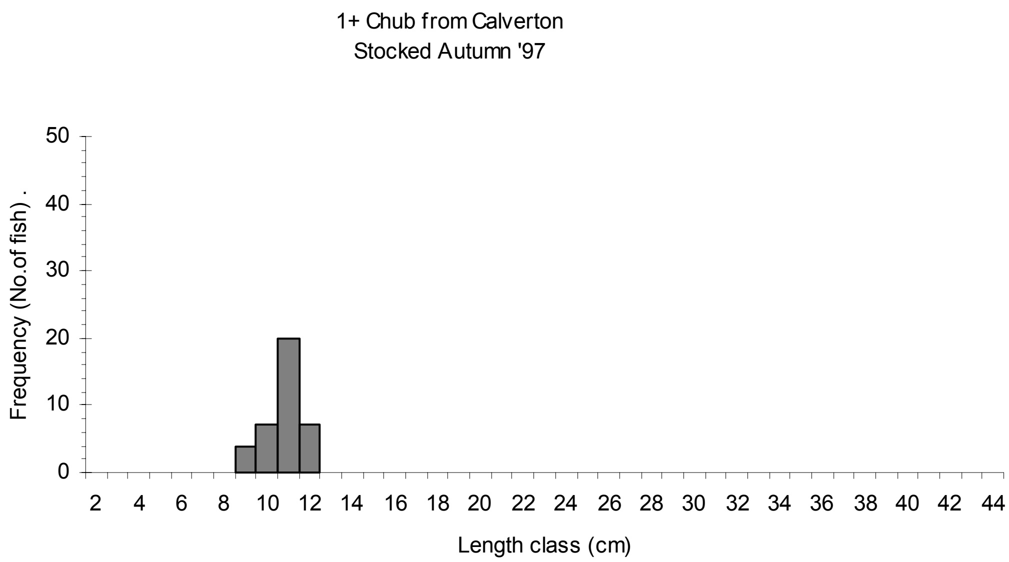


Figure 3.2: Example of length frequency histogram of stocked fish at time of stocking

It had been intended to make use of scale data to ascribe fish to likely source. However, analysis of scale samples taken from recovered Panjet marked fish (i.e. fish of known origin) displayed apparent discrepancies between the age as judged from scales and the 'true' age as of the stock as inferred by their identifying marks. Histograms demonstrating these discrepancies are reproduced below (Figure 3.3 to Figure 3.6).

The (bulk) population estimates for each survey were then apportioned across the three target species and the five possible sources according to the relative numbers of each species.source combination that had been observed. These site-specific population estimates for fish derived from a given stocking treatment (which are presented as an appendix within the Project Record) were then combined (using site areas as weighting factors) to derive mean population densities for the reach. This exercise was repeated for all surveys to generate data for plots indicating post-stocking persistence within each stocked reach. An example of these plots is given as Figure 3.7 - the full set of figures are given as Appendix C.

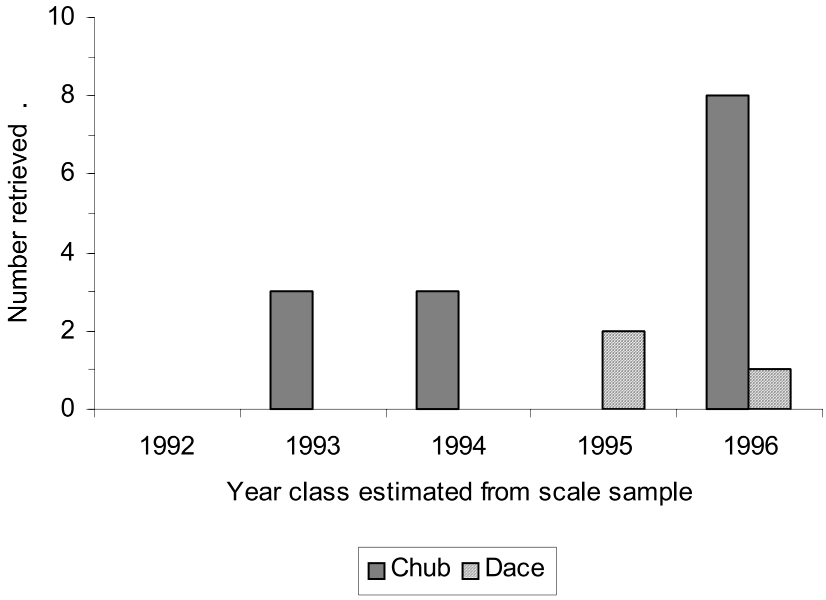


Figure 3.3: Assessment of scale reading results for marked fish retrieved from River Alderbourne; marked as 1995 year class

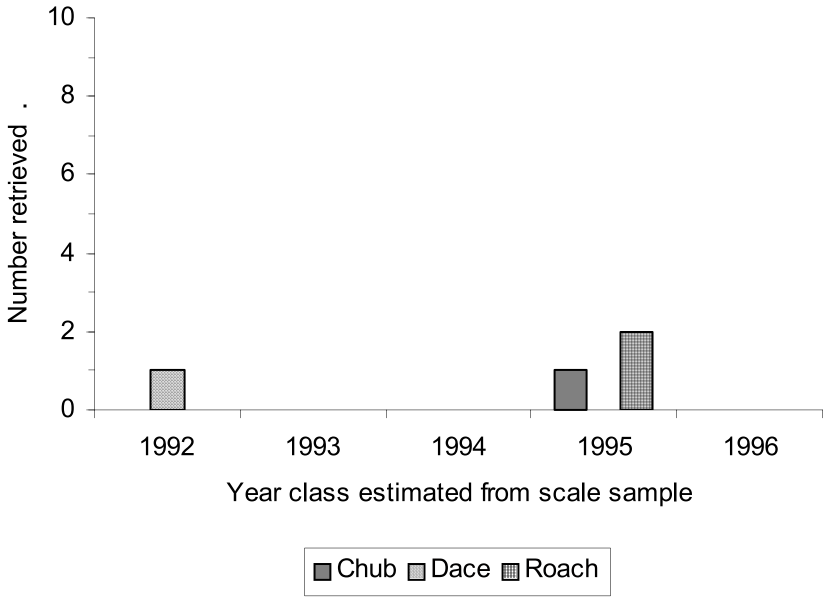


Figure 3.4: Assessment of scale reading results for marked fish retrieved from River Hogsmill; marked as 1994 year class

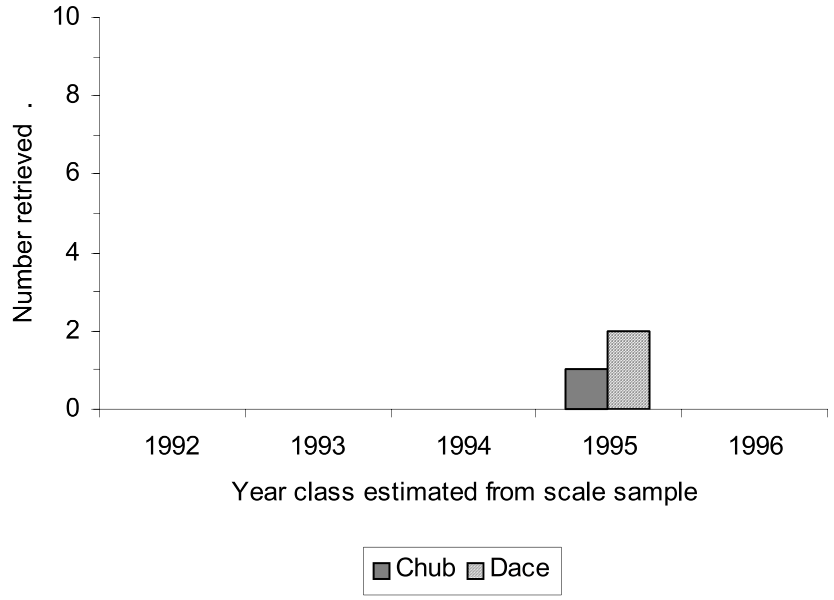


Figure 3.5: Assessment of scale reading results for marked fish retrieved from River Lostock; marked as 1994 year class

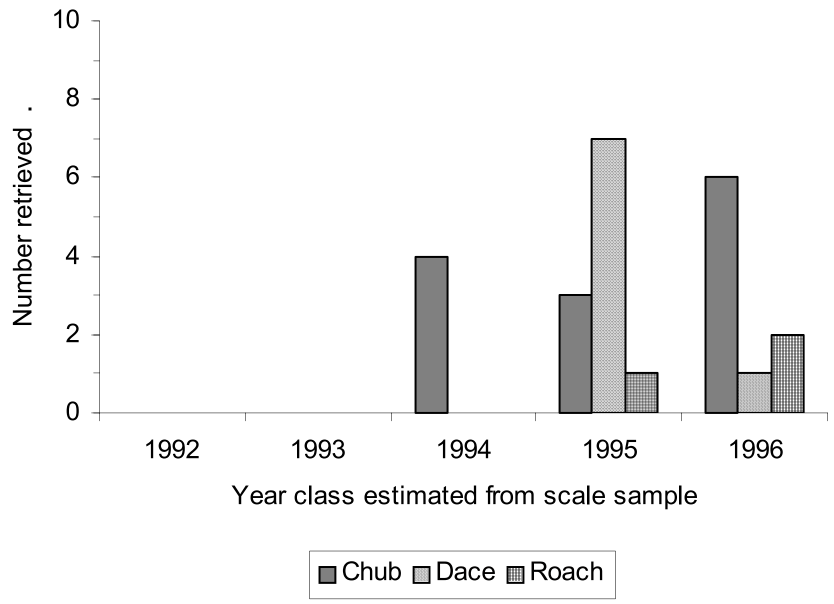


Figure 3.6: Assessment of scale reading results for marked fish retrieved from River Lostock; marked as 1995 year class

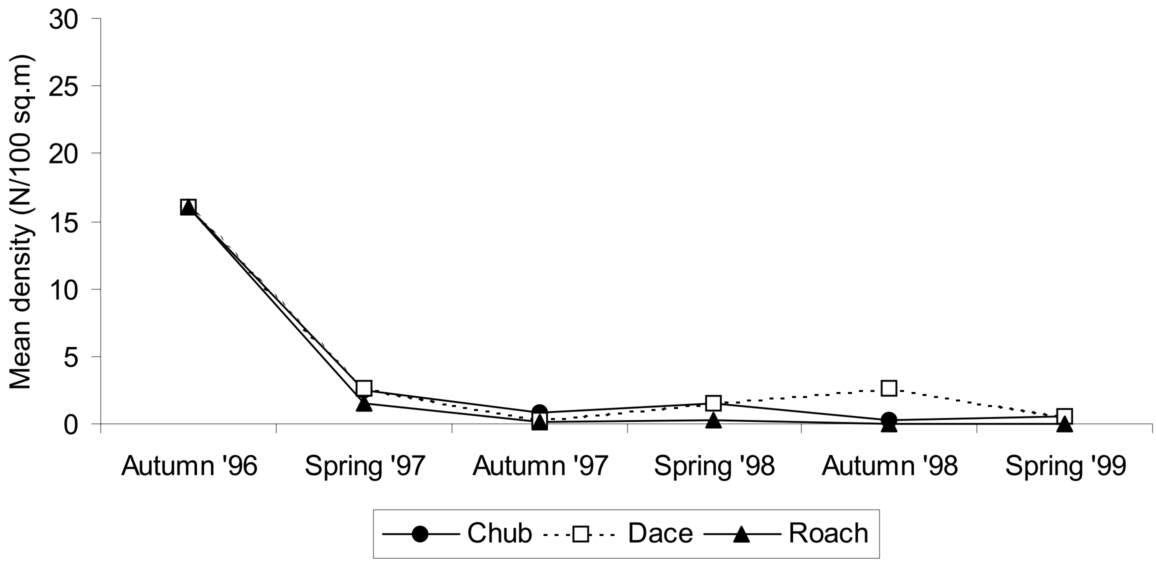


Figure 3.7: Example of plot showing persistence of stocked fish (in this case for fish stocked as Autumn 2+ to the River Alderbourne)

3.1.2 Data analysis

Estimating the persistence rate

The available data set was truncated to exclude all data with 'days elapsed' >400 (i.e. the data was restricted to population estimates over the first 1 months post-stocking). Site specific population estimates were then fitted to a 'decay' model to produce 64 estimates of persistence rates for each species (i.e. separate estimates of persistence rates for each combination of river, site and treatment). The model that was originally used was:

$N = N_0 * exp^{-Bt}$

or

$\ln(N) = \ln(N_0) - B*t$ Model (1)

where:

D = Days elapsed since stocking;

t = D/100;

N_0 = the initial number of fish at D=0;

N = the (estimated) number of fish remaining after D days; and

B = a 'decay rate' constant that varies according to the various experimental factors.

NB The adjustment to the time measure (D/100 rather than D) was done simply to make the estimates of B a more sensible size.

Initially two different methods of fitting Model (1) were attempted:

- a log-link model with offset $\ln(N_0)$ and Poisson error; and
- a log-link model including the D=0 case along with the other 'y' values but giving it a very high weight (to force the model through the initial point).

Both options worked fine with dummy data, but the analysis routines for both methods were unable to handle the real data sets (which contained typically only 2 or 3 data points, with one of them sometimes zero). This problem was addressed by transforming the raw data (i.e. using 'N + 1'), enabling ordinary weighted regression to be applied to the log-log data. Thus the model became:

$N = (N_0+1)*exp^{-Bt} - 1$ Model (2)

Reciprocals of the measurement errors for the population estimates (i.e. the reciprocal of the errors associated with the removal method) where used as the weighting factors for these regressions.

Clearly this approach is not wholly satisfactory, as the predicted N dips below zero for t values greater than $\ln(N_0+1)/B$. However, it was an objective procedure and, in cases where the data was well-behaved, provided no worse a fit to the data over the observed range than did Model (1). On this basis therefore, 64 estimates of persistence rates[5] (BHat) were produced for each of the three fish species (presented as an appendix within the Project Record).

Analysis of persistence rate estimates

It was originally envisaged that persistence rates would be analysed by ANOVA techniques using 'River' as a blocking term within the analysis. However, for two of the fish species there was a strong 'River.Age' interaction which effectively prevented the use of 'River' as a blocking factor.

Accordingly an alternative approach, using stepwise regression, was adopted. This approach had the additional advantage of facilitating a weighted regression to be effected (with weights equal to $1/s_i^2$, where s_i is the standard error of the i^{th} BHat value). Main factors were introduced one by one, followed by the interactions. Non-significant terms were dropped one by one until only statistically significant terms remained. This process was undertaken separately for each species.

The resultant regression models were then used to estimate the percentage of the initial population remaining 6 months and 12 months post-stocking for each combination of significant factors.

[5] Persistence rate estimates (BHat values) produced in this way are, by definition, effectively the slopes (on a per 100 day basis) of log-log 'survival' plots.

Accounting for levels of the 'year' factor

The basic experimental design made use of a stocking and monitoring programme that covered more than one year in an attempt to account for the influence of temporal effects on stocking success (for example the influence of between-year climatic differences).

The situation was complicated by the fact that there were two methods of accounting for differences between years within the analyses that were applied. In essence, these two methods can be thought of as manifestations of two alternative hypotheses relating to the stresses experienced by stocked fish. Over the stocking programme, four distinct times of stocking were used: autumn 1996; spring 1997; autumn 1997; and spring 1998. The diagram below (Figure 3.8) shows these four stocking times and indicates the 12-month post-stocking monitoring period associated with each time of stocking.

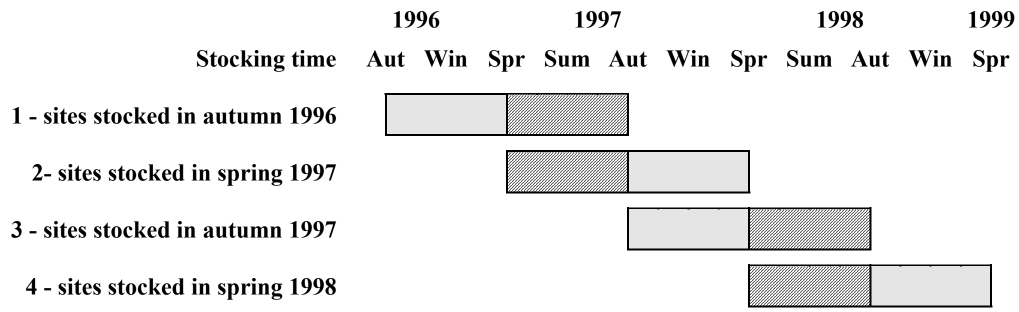


Figure 3.8: 12 month post-stocking monitoring periods for the four different times of stocking used in the study

Quite clearly, there are two different 'summer' periods encompassed by the four monitoring periods (summer 1997 and 1998) but there are three different 'winter' periods (winter 1996, 1997 and 1998). Consequently, subsequent analyses need to assume that it is either the over-summer or the over-winter survival that is the more important temporal factor that needs to be accounted for.

Where is felt that it is more important to differentiate between the results that are generated across different summer periods, two levels need to be used to account for temporal factors (i.e. two levels of the 'summer year' factor). Alternatively, where is felt that it is more important to differentiate between the results that are generated across different winter periods, three levels must be used to account for temporal factors (i.e. three levels of the 'winter year' factor).

The Project Board gave a positive steer on this matter, and directed the analysis to consider the 'winter year' factor.

Analysis results for post-stocking persistence - chub

Stepwise regression analysis on the estimated persistence rates for the chub data produced a model that accounted for 49% of the overall variability seen in the data. Statistically significant factors within the model were:

- River ($P<0.001$); and
- River.Age interaction ($P<0.001$)

No other factors were significant ($P>0.1$).

Estimates of mean persistence (presented as a rate as defined in Model (2) above and as the percentage of the initial stocked population remaining after 6 and 12 months post-stocking) are given for each combination of the model's significant factors in the table below. As noted above, persistence rates are effectively the slope (on a per 100 day basis) of log-log 'survival' plots. Consequently, as the population size decreases from the time of stocking, all of the persistence rates quoted are negative. A high negative value would therefore indicate very poor persistence – reflected by relatively low values for percentage persistence at 6 and 12 months.

Table 3.1: Persistence results for chub stocking

		Stocked age	
River	**Statistic**	**1+**	**2+**
Alderbourne	Persistence rate	-0.579	-1.106
	6 month persistence	33.8 %	11.9 %
	12 month persistence	10.6 %	0.1 %
Cherwell	Persistence rate	-1.901	-1.304
	6 month persistence	1.5 %	7.8 %
	12 month persistence	0.0 %	0.0 %
Hogsmill	Persistence rate	-1.237	-0.856
	6 month persistence	9.0 %	19.7 %
	12 month persistence	0.0 %	2.8 %
Lostock	Persistence rate	-1.248	-1.346
	6 month persistence	8.8 %	7.1 %
	12 month persistence	0.0 %	0.0 %

As discussed above the temporal factor included in the analysis was 'winter year'. An alternative analysis was undertaking using 'summer year' as the temporal factor. Despite this, the same set of significant explanatory factors were selected by the stepwise regression, resulting in the same overall model.

Analysis results for post-stocking persistence - dace (i)

Stepwise regression analysis on the estimated persistence rates for the dace data using winter year as the temporal factor produced a model that accounted for 68% of the overall variability seen in the data. Statistically significant factors within the model were:

- River ($P<0.001$);
- Age ($P<0.001$);
- River.Age interaction ($P<0.001$); and
- Winter year ($P<0.001$).

No other factors were significant ($P>0.1$).

Estimates of mean persistence (presented as a rate as defined in Model (2) above and as the percentage of the initial stocked population remaining after 6 and 12 months post-stocking) are given for each combination of the model's significant factors in the tables below.

Table 3.2: Persistence results for dace stocking - 'winter year' factor = 1996

		Stocked age	
River	**Statistic**	**1+**	**2+**
Alderbourne	Persistence rate	-1.0374	-1.2339
	6 month persistence	13.7 %	9.1 %
	12 month persistence	0.6 %	0.0 %
Cherwell	Persistence rate	-2.4409	-1.221
	6 month persistence	0.0 %	9.4 %
	12 month persistence	0.0 %	0.0 %
Hogsmill	Persistence rate	-1.5917	-1.2512
	6 month persistence	4.0 %	8.8 %
	12 month persistence	0.0 %	0.0 %
Lostock	Persistence rate	-1.4601	-1.6566
	6 month persistence	5.5 %	3.3 %
	12 month persistence	0.0 %	0.0 %

Table 3.3: Persistence results for dace stocking - 'winter year' factor = 1997

		Stocked age	
River	Statistic	1+	2+
Alderbourne	Persistence rate	-0.7651	-0.9616
	6 month persistence	23.6 %	16.0 %
	12 month persistence	4.6 %	1.4 %
Cherwell	Persistence rate	-2.1686	-0.9487
	6 month persistence	0.3 %	16.4 %
	12 month persistence	0.0 %	2.0 %
Hogsmill	Persistence rate	-1.3194	-0.9789
	6 month persistence	8.0 %	15.5 %
	12 month persistence	0.0 %	1.2 %
Lostock	Persistence rate	-1.1878	-1.3843
	6 month persistence	10.0 %	6.5 %
	12 month persistence	0.0 %	0.0 %

Table 3.4: Persistence results for dace stocking - 'winter year' factor = 1998

		Stocked age	
River	Statistic	1+	2+
Alderbourne	Persistence rate	-0.7166	-0.9131
	6 month persistence	25.9 %	17.6 %
	12 month persistence	5.8 %	2.0 %
Cherwell	Persistence rate	-2.1201	-0.9002
	6 month persistence	0.5 %	18.1 %
	12 month persistence	0.0 %	2.0 %
Hogsmill	Persistence rate	-1.2709	-0.9304
	6 month persistence	8.0 %	17.0 %
	12 month persistence	0.0 %	1.7 %
Lostock	Persistence rate	-1.1393	-1.3358
	6 month persistence	11.1 %	7.3 %
	12 month persistence	0.0 %	0.0 %

Analysis results for post-stocking persistence - dace (ii)

As for chub an alternative analysis was undertaking using ‘summer year’ as the temporal factor. Unsurprisingly (given that the winter year factor had been significant) the summer year temporal factor was found to be significant. Stepwise regression analysis using summer year as the temporal factor again produced a model that accounted for 68% of the overall variability seen in the data. Statistically significant factors within the model were:

- River (P<0.001);
- Age (P<0.001);
- River.Age interaction (P<0.001);
- Summer year (P<0.005);
- Stocking season (P<0.05); and.

No other factors were significant (P>0.1).

Estimates of mean persistence (presented as a rate as defined in Model (2) above and as the percentage of the initial stocked population remaining after 6 and 12 months post-stocking) are given for each combination of the model’s significant factors in the tables below.

Table 3.5: Persistence results for dace stocking - ‘summer year’ factor = 1997 and ‘stocking season’ = autumn

		Stocked age	
River	**Statistic**	**1+**	**2+**
Alderbourne	Persistence rate	-0.9251	-1.2339
	6 month persistence	17.2 %	9.1 %
	12 month persistence	1.8 %	0.0 %
Cherwell	Persistence rate	-2.3309	-1.221
	6 month persistence	0.0 %	9.4 %
	12 month persistence	0.0 %	0.0 %
Hogsmill	Persistence rate	-1.5917	-1.1395
	6 month persistence	4.0 %	11.1 %
	12 month persistence	0.0 %	0.0 %
Lostock	Persistence rate	-1.4601	-1.5445
	6 month persistence	5.5 %	4.4 %
	12 month persistence	0.0 %	0.0 %

Table 3.6: Persistence results for dace stocking - 'summer year' factor = 1997 and 'stocking season' = spring

River	Statistic	Stocked age 1+	Stocked age 2+
Alderbourne	Persistence rate	-0.7951	-1.1039
	6 month persistence	22.3 %	12.0 %
	12 month persistence	3.9 %	0.1 %
Cherwell	Persistence rate	-2.2009	-1.091
	6 month persistence	0.2 %	12.3 %
	12 month persistence	0.0 %	0.0 %
Hogsmill	Persistence rate	-1.4617	-1.0095
	6 month persistence	5.0 %	14.5 %
	12 month persistence	0.0 %	0.9 %
Lostock	Persistence rate	-1.3301	-1.4145
	6 month persistence	7.4 %	6.1 %
	12 month persistence	0.0 %	0.0 %

Table 3.7: Persistence results for dace stocking - 'summer year' factor = 1998 and 'stocking season' = autumn

River	Statistic	Stocked age 1+	Stocked age 2+
Alderbourne	Persistence rate	-0.7343	-1.0431
	6 month persistence	25.0 %	13.6 %
	12 month persistence	5.3 %	0.6 %
Cherwell	Persistence rate	-2.1401	-1.0302
	6 month persistence	0.4 %	13.9 %
	12 month persistence	0.0 %	1.0 %
Hogsmill	Persistence rate	-1.4009	-0.9487
	6 month persistence	6.0 %	16.4 %
	12 month persistence	0.0 %	1.5 %
Lostock	Persistence rate	-1.2693	-1.3537
	6 month persistence	8.4 %	7.0 %
	12 month persistence	0.0 %	0.0 %

Table 3.8: Persistence results for dace stocking - 'summer year' factor = 1998 and 'stocking season' = spring

		Stocked age	
River	**Statistic**	**1+**	**2+**
Alderbourne	Persistence rate	-0.6043	-0.9131
	6 month persistence	32.2 %	17.6 %
	12 month persistence	9.5 %	2.0 %
Cherwell	Persistence rate	-2.0101	-0.9002
	6 month persistence	1.0 %	18.1 %
	12 month persistence	0.0 %	2.0 %
Hogsmill	Persistence rate	-1.2709	-0.8187
	6 month persistence	8.0 %	21.2 %
	12 month persistence	0.0 %	3.5 %
Lostock	Persistence rate	-1.1393	-1.2237
	6 month persistence	11.1 %	9.3 %
	12 month persistence	0.0 %	0.0 %

Analysis results for post-stocking persistence - roach

Stepwise regression analysis on the estimated persistence rates for the roach data produced a model that accounted for only 8% of the overall variability seen in the data. The only significant factor within the model was:

- River ($P<0.1$);

No other factors were significant ($P>0.1$).

This model made use of winter year although no change in the outputs of the stepwise regression model were seen when summer year was substituted as the temporal factor.

Estimates of mean persistence (presented as a rate as defined in Model (2) above and as the percentage of the initial stocked population remaining after 6 and 12 months post-stocking) are given in the table below.

Table 3.9: Persistence results for roach stocking

		Stocked age	
River	**Statistic**	**1+**	**2+**
Alderbourne	Persistence rate	-1.0386	-1.0386
	6 month persistence	13.7 %	13.7 %
	12 month persistence	0.6 %	0.6 %
Cherwell	Persistence rate	-1.5334	-1.5334
	6 month persistence	4.6 %	4.6 %
	12 month persistence	0.0 %	0.0 %
Hogsmill	Persistence rate	-1.1849	-1.1849
	6 month persistence	10.1 %	10.1 %
	12 month persistence	0.0 %	0.0 %
Lostock	Persistence rate	-1.1947	-1.1947
	6 month persistence	9.9 %	9.9 %
	12 month persistence	0.0 %	0.0 %

3.1.3 Persistence: results summary

'River' was a significant factor in the persistence analyses performed for all three species. Both 'age' and 'river.age interaction' were significant factors in the analyses performed for chub and dace. For dace, where a year factor was included 'winter year' became a further significant factor. In the alternative analysis (using 'summer-year' as the year factor) 'summer year' and 'season' were inextricably linked and were both significant factors for dace. For roach, there were no significant factors other than 'river'.

Inspection of the results presented in Tables 3.1-3.9 (above) shows a wide range in persistence rates estimated for the three target species across the range of significant factors identified by the analyses. The lowest persistence rates (i.e. the most negative ones) are such that the resultant 12-month percentage persistence estimates are, in many cases, effectively zero. Consequently it is more reasonable to look at the 6-month percentage persistence across the significant factors as an indicator of the relative success of each treatment.

The relative performance of the two levels of the 'age' factor (i.e. age 1+ and age 2+) followed the same pattern for chub and dace, although the pattern was not consistent across the four levels of the significant 'river' factor (i.e. across the four rivers). For dace the pattern was also consistent across all three levels of the 'winter-year' factor. Where the 'summer-year' factor was considered (and the 'stocking season' factor became significant) the same relative performance of the two levels of the 'age' factor was seen across all four combinations of levels for the 'winter-year' and 'stocking season' factors.

The results of the analyses can therefore be summarised – by considering only the optimum level of the 'age' factor on each river. Only for dace does another factor ('year') need to be considered. Following the direction of the Project Board the 'winter year' factor is considered in this summary and the results relating to the use of the 'summer year' factor are excluded. Accordingly, the highest 6 month percentage persistence rates for each species are reproduced in the table below (Table 3.10).

Table 3.10: Summary of 'optimum' 6 month percentage persistence estimates

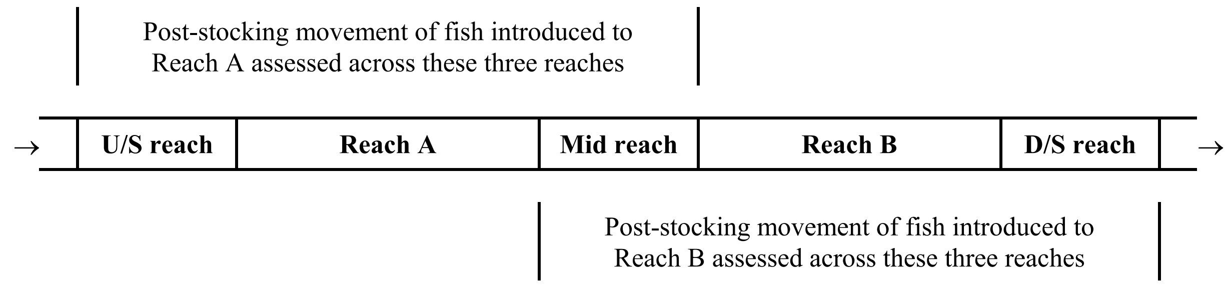
		River and level of 'stocked age' factor			
Species	**Other significant factors** †	**Alderbourne 1+**	**Cherwell 2+**	**Hogsmill 2+**	**Lostock 1+**
Chub	None	33.8 %	7.8 %	19.7 %	8.8 %
Dace	'Winter year': level = 1996	13.7 %	9.4 %	8.8 %	5.5 %
	'Winter year': level = 1997	23.6 %	16.4 %	15.5 %	10.0 %
	'Winter year': level = 1998	25.9 %	18.1 %	17.0 %	11.1 %
Dace	Mean value (across all 'winter year' levels)	21.1%	14.6 %	13.8 %	7.0 %
Roach	NB: age NOT significant	13.7 %	4.6 %	10.1 %	9.9 %

† see preceeding text for detail on significant factors

3.2 Movement of Target Species out of Stocked Reaches

The movement of stocked fish out of the stocked reach was assessed only qualitatively. Population estimates for each target species in the three unstocked reaches on each study river (i.e. the upstream reach, the middle reach and the downstream reach) were compared to the estimated mean population densities in the stocked reaches such that limited movement up- and downstream could be assessed.

For each stocked reach, the changes in estimated mean reach population density were compared, through time, against the two unstocked reaches immediately up and downstream (see Figure 3.9, below).



NB: flow is from left to right

Figure 3.9 Schematic representation of reaches considered in post-stocking movement assessments on each river

Figures showing the range of upstream and downstream movement of stocked fish during the six month period post-stocking are given as Appendix D. An example of these plots is presented below as Figure 3.10. In addition, a qualitative summary of the observed upstream/downstream movement is presented as Table 3.11.

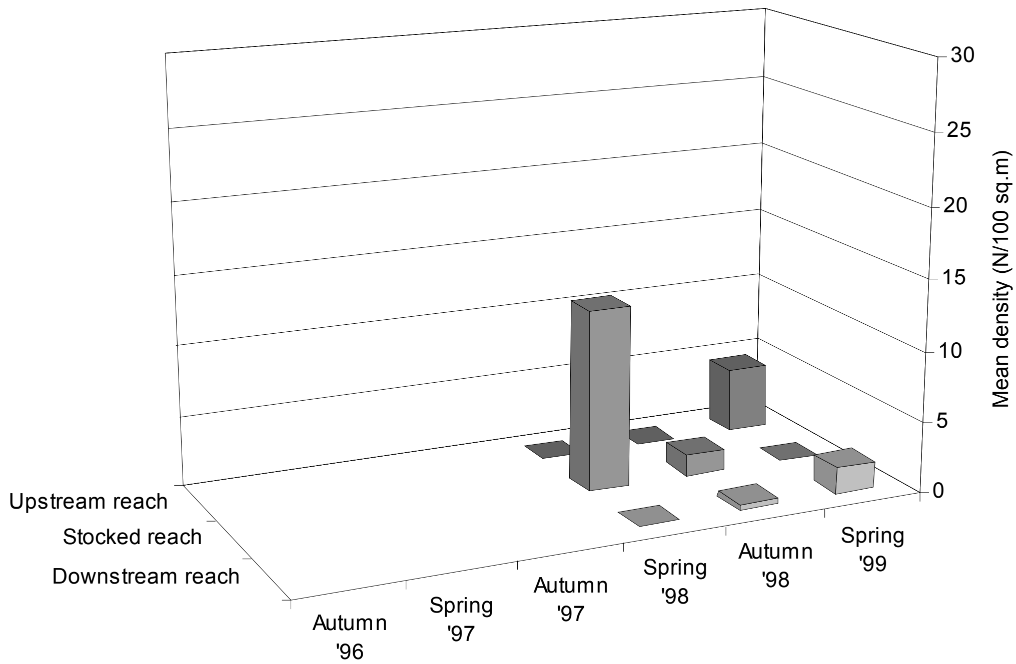


Figure 3.10: Example of plot showing persistence & dispersal of stocked fish (in this case for dace stocked as Spring 2+ to the River Alderbourne)

Table 3.11: Persistence and dispersal: a qualitative summary

		Stocking season & age			
River	**Species**	**Autumn 1+**	**Spring 1+**	**Autumn 2+**	**Spring 2+**
Alderbourne	Chub	↓	↓	↑↑	↑↑
	Dace	↓	↓	↑↑	↔
	Roach	↓	↔	↑↑	No stocking
Cherwell	Chub	↔	↔	↔	↔
	Dace	↔	↔	↔	↔
	Roach	↔	↔	↔	No stocking
Hogsmill	Chub	↔	↓	↓	↓
	Dace	↔	↔	↓	↓
	Roach	↔	↓	↓	↔
Lostock	Chub	↓	↔	↑	↔
	Dace	↓	↓	↔	↔
	Roach	↓↓	↓↓	↓	↔

Key to symbols: ↓ ......slight downstream dispersal apparent
↓↓....downstream dispersal strongly in evidence
↔.....no significant dispersal apparent
↑ ......slight upstream dispersal apparent
↑↑....upstream dispersal strongly in evidence

3.3 Non-Target Fish

3.3.1 Native chub, dace and roach

In addition to stocked chub, dace and roach (see Section 3.1.1) estimates of population densities for what were believed to be native (i.e. non stocked) chub, dace and roach were also produced for each reach and for each of the five sets of surveys. Plots showing how the population densities for these non-stocked fish varied through time are given as Appendix E.

It is recommended that the plots showing the post-stocking persistence of stocked fish (Appendix C) are assessed alongside the plots for native fish given in Appendix E. Note that on the upper reach (Reach A) of the River Lostock only stocked fish were caught (i.e. none of the fish caught were believed to be native in origin) - consequently no plot is reproduced for this particular reach.

These data are of importance in that they provide a safeguard against unintentionally writing-off certain of the stocking treatments. The methodology used to ascribe each fish that was caught to one of five possible sources could have resulted in a situation where stocked fish were mistakenly identified as ‘natives’. An error of this nature would result in the apparent success of the stocking activity being underestimated. Such an error would be made more obvious should the persistence of stocked fish appear to fall alongside a concomitant rise in the population of supposed 'native' fish.

3.3.2 Pike

A number of pike were caught during surveys on the River Alderbourne and the River Cherwell. As the presence of predators is likely to influence the survival (and hence the perceived persistence) of stocked chub, dace and roach it was felt relevant to present the basic data on observed pike populations. Whilst population estimates were not calculated for pike, the numbers caught on each set of surveys on the Alderbourne and the Cherwell are shown below (Table 3.12 and Table 3.13 respectively). Length frequencies for the fish that were caught are also presented (Appendix F).

Table 3.12: Numbers of pike caught - River Alderbourne

Reach / site	Year	Season	Number caught
Lower stocked reach (Reach B)	97	S	0
	97	A	0
	98	S	0
	98	A	1
	99	S	3
Downstream site	97	S	1
	97	A	0
	98	S	0
	98	A	0
	99	S	0

Table 3.13: Numbers of pike caught - River Cherwell

Reach / site	Year	Season	Number caught
Upstream site	97	S	1
	97	A	0
	98	S	7
	98	A	0
	99	S	8
Upper stocked reach (reach A)	97	S	15
	97	A	2
	98	S	18
	98	A	n/a
	99	S	9
Middle site	97	S	2
	97	A	4
	98	S	3
	98	A	n/a
	99	S	n/a
Lower stocked reach (reach B)	97	S	2
	97	A	12
	98	S	8
	98	A	n/a
	99	S	n/a
Downstream site	97	S	4
	97	A	2
	98	S	1
	98	A	n/a
	99	S	0

3.3.3 Other species

A small number of other species were also caught on the surveys that were undertaken. These again were limited to the Rivers Alderbourne and Cherwell, and included perch, tench, golden rudd, bream and brown trout. Relative to the three stocked species the numbers caught were low. No population estimates were made; the numbers of each species caught are shown below in Table 3.14 and **Table 3.**15.

In addition, minor species were encountered at all sites (see **Table 3.**16). The information presented in this table is not exhaustive or definitive, as effort during the surveys was directed specifically at the three 'target' species; chub, dace and roach. Nonetheless, in the absence of any target species, casual observation of minor species at virtually every site on every occasion was taken as being an indication that water quality problems were unlikley to be a limiting factor.

Table 3.14: Numbers of non-target species caught - River Alderbourne (excludes pike and minor species)

Reach / site	Year	Season	Perch	Brown trout
Upstream site	97	S	2	-
	97	A	-	-
	98	S	-	-
	98	A	1	-
	99	S	1	-
Lower stocked reach (reach B)	97	S	-	-
	97	A	-	-
	98	S	2	-
	98	A	2	-
	99	S	-	-
Downstream site	97	S	-	3
	97	A	-	-
	98	S	-	1
	98	A	3	1
	99	S	-	1

Table 3.15: Numbers of non-target species caught - River Cherwell (excludes pike and minor species)

Reach / site	Year	Season	Bream	Golden rudd	Perch	Tench
Upstream site	97	S	-	-	-	5
	97	A	-	-	-	-
	98	S	-	-	-	7
	98	A	n/a	n/a	n/a	n/a
	99	S	-	-	1	1
Upper stocked reach (reach A)	97	S	-	-	-	2
	97	A	-	-	-	-
	98	S	-	-	4	8
	98	A	n/a	n/a	n/a	n/a
	99	S	2	-	1	5
Middle site	97	S	-	-	-	-
	97	A	-	-	-	-
	98	S	-	-	-	2
	98	A	n/a	n/a	n/a	n/a
	99	S	n/a	n/a	n/a	n/a
Lower stocked reach (reach B)	97	S	-	-	-	-
	97	A	-	-	-	-
	98	S	-	2	1	-
	98	A	n/a	n/a	n/a	n/a
	99	S	n/a	n/a	n/a	n/a
Downstream site	97	S	-	-	-	-
	97	A	-	-	-	-
	98	S	-	-	-	2
	98	A	n/a	n/a	n/a	n/a
	99	S	-	-	-	-

Table 3.16: Minor species encountered

River	Bullhead	Gudgeon	Stoneloach	Minnow
Alderbourne	✓		✓	✓
Cherwell		✓		✓
Hogsmill			✓	✓
Lostock		✓		

4. ECONOMIC APPRAISAL

4.1 Introduction

This section presents and discusses an economic appraisal of the alternative stocking strategies that could be supported by Calverton Fish Farm. This appraisal was undertaken during the period November 2000 to March 2001 and included a number of visits to Calverton to collect data on the production process, costs and outputs for both the present situation and potential alternative (stocking) strategies.

4.2 Approach

An economic appraisal of alternative stocking strategies can be undertaken from a number of perspectives. A distinction can be drawn between:

- an economic analysis of stocking – which would appraise both the costs of stocking and the benefits (to the environment, anglers, etc.) to determine whether, and at what level, stocking should be undertaken; and
- an economic analysis of different stocking strategies – which would appraise the outputs and costs of alternative stocking strategies to determine which is most preferable, given Agency objectives.

It was recognised early in the project that problems in placing a monetary value to any potential benefits of achieving a given target meant that a classical cost benefit analysis would be inappropriate. Indeed the purpose of this project is not to determine whether stocking is worthwhile but what is the most appropriate (i.e. the optimum) stocking strategy. Consequently, this economic appraisal deals with the second type of assessment and the benefits of alternative stocking treatments (e.g. in terms of improving anglers' exploitation rates or fish 'catchability') are not considered.

There are a variety of end points which could be examined in the cost analysis. For example costs could be expressed in terms of:

- angler-catchable fish;
- fish of spawning age; or
- fish surviving in the target reach.

Whilst the first two options have obvious benefits from a fishery management point of view it was agreed that the current project could only offer robust information on the third. In addition it would be possible to express the costs in terms of fish biomass or numbers. It was recognised that while the project could deal most effectively with numbers of fish, much of the Agency's work is undertaken in terms of biomass (e.g. the targets in Fisheries Classification System). The inherent problem in converting numbers to biomass is that performance of stocked fish (in terms of growth) is likely to differ between rivers. It is possible that, in certain situations, the relative merits of a set of given stocking treatments may be reversed if growth and biomass are included in the evaluation.

It was therefore concluded that the outputs from the project should be expressed as numbers of fish persisting for a set period of time after stocking (e.g. 6 or 12 months), and as part of the implementation, fisheries officers should be offered guidance as to the possible scenarios resulting from differing growth performance of the stocked fish, which in turn would influence the case for what age and season of introduction would best suit their particular river.

An issue arises in terms of the differentiation between fish species. Calverton currently produces eight species of fish and there are plans to produce an even greater variety. However, only three of these species (chub, dace and roach) were the subject of the field trials. In addition, certain species of fish would not react well to changes in the stocking treatments because of the additional need for over-wintering in tank systems. Of the species studies in this project, only chub would be considered robust enough to cope with the over-wintering required by alternative stocking strategies. As a result it was not considered appropriate to undertake the economic appraisal at the level of individual species, although the implications of stocking strategies on the type of fish produced is an additional consideration in terms of selecting alternative treatments.

Furthermore it must be recognised that there is not an infinite variety of alternative stocking strategies which are worthwhile investigating. There are limits on the stocking strategies which can be pursued given the constraints of the current fish farm operations. Hence the interest is not in the costs of alternative hypothetical stocking strategies but rather in the incremental costs of changing operations from the current system to the alternatives. The alternatives selected for investigation were:

- the age of the fish to be stocked; and
- the stocking season.

The central question to be addressed by the economic appraisal was identified as being:

"What are the costs inherent in a move to a production system that is geared solely to producing ***n*** fish of age ***t*** to be stocked in season ***s*** ?"

The economic appraisal was therefore required to determine the costs of four 'scenarios' based on the age of the fish and the stocking season.

Scenario	Stocking Season	Age of Output
Scenario 1 (current)	Autumn	1+ (F2)
Scenario 2	Spring	Mainly 1+ (F2)
Scenario 3	Autumn	2+ (F3)
Scenario 4	Spring	Mainly 2+ (F3)

Scenarios 2, 3 and 4 were expected (a priori) to involve additional capital and operational costs. The central issue that is raised by the study is therefore whether the additional costs associated with the possible alternative scenarios can be justified given the improvements (or otherwise) in the post-stocking survival of the fish.

4.3 Production Economics of the Fish Farm

4.3.1 The production system

In undertaking the economic appraisal of the alternative stocking strategies it was necessary to determine the basic fish production situation at the fish farm. Data were collected and discussions undertaken that enabled the construction of a detailed flow chart of operations on the fish farm. The main activities can be broken down into the following typical cycle (which is presented graphically as Figure 4.1):

- broodfish collection takes place in March to May with larva placement taking place in April or May;
- in January the F1 fish are harvested and transferred to tanks for over-wintering;
- the following May, these F1 fish have aged one year (i.e. they become F2) and are placed in outdoor ponds;
- in October or November the majority of the F2 are harvested for stocking out;[6]
- a proportion of the F2 are retained (to become F3) and transferred to tanks for wintering;
- once the F2 become F3 (May) they are placed in outdoor ponds;[7]
- in October or November the F3 are stocked out.[8]

A full cycle therefore takes a maximum of 3 years to complete and at any one time there are fish at the farm in each of three concurrent cycles.

An essential aspect of these cycles is the over-wintering of fish in tanks. This allows the outdoor ponds to be dried out and maintained over the winter months, and to be prepared for

[6] Fish being stocked at this stage in the cycle are F2 and equate to the autumn 1+stocking that was used in the current study

[7] Fish being stocked at this stage in the cycle are mainly F2 and equate to the spring 1+stocking that was used in the current study

[8] Fish being stocked at this stage in the cycle are F3 and equate to the autumn 2+stocking that was used in the current study

the intake of newly hatched and yearling fish in the Spring. The winter dry-out of ponds promotes natural productivity within the ponds and boosts their natural invertebrate production; this effectively provides a cheaper, better feeding strategy for the fish than the alternative of reliance on pellet foods (which are not considered ideal for cyprinid species). Whilst this practice is considered to be essential for the viability of the fish farm, it creates a requirement for additional equipment and an adequate borehole water supply to enable fish to be held in tanks until the outdoor ponds have been refilled in the spring.

The demands for tank storage space and water increase with a move from autumn to spring stocking, because additional fish need to be held over the winter in Swedish tanks to allow for pond maintenance. Producing F3 fish for spring stocking greatly exacerbates this problem because the fish are larger and need more space per individual.

4.3.2 Costs and outputs

Calverton fish farm has a variety of fixed and variable costs. Fixed costs include infrastructure, land, and labour. Labour in this case is regarded as a fixed cost because the quantities of labour required vary little with total numbers and sizes of fish produced. Much of the labour requirement at peak times is currently free (e.g. students on work experience) though if many more were to be employed then more accommodation may need to be provided.

Obvious variable costs include power and artificial food, which is relied upon to a much greater extent for the older age groups of fish. The current running costs of Calverton are estimated to be £226k - a breakdown of which is provided in the following table (Table 4.1).

Table 4.1: Cost breakdown for Calverton fish farm

Cost item	**£k**
Manpower	105
Transport and plant	14
Equipment, building maintenance	70
Office	13
Fish Food	22
Pond bottom maintenance	2
Total	**226**

In the alternative production scenarios considered the main impact on these costs would be in terms of purchased fish food and the equipment and building maintenance costs. Additional fish food is required under the different treatments because of the longer period over which the fish are held on farm and because the fish are larger and therefore consume more food per capita. Equipment and maintenance costs would also increase in order to provide sufficient additional over-wintering storage.

A typical annual output of F2 and F3 fish is summarised in the following table (Table 4.2).

Table 4.2: Typical output of Calverton Fish Farm

F2 Fish	F3 Fish	Total stocked out
172,659	89,450	262,109

Any change in the stocking strategy would have an impact on the total number of fish that could be produced. F3 fish obviously require a larger amount of space than F2 fish. Given the space limitations it must therefore be recognised that a move to producing more F3 fish would inevitably consume some of the space which could otherwise have been used to produce F2 fish. As a result there is an opportunity cost of moving to F3 production. Hypothetically this could be resolved by creating extra pond space but this is not considered possible given current site limitations. The opportunity costs are mitigated slightly by the additional unit revenue associated with F3 fish. Currently the average market price of F3 fish (all species combined) is £1.55 compared to £0.78 for F2 fish (Alan Henshaw, personal communication).

4.4 Impact on Cost and Output of the Alternative Stocking Strategies

As discussed above, the economic appraisal is focused on determining the incremental costs associated with moving from the current situation to one of the three alternative scenarios. The main impacts of these scenarios are characterised below.

4.4.1 Scenario 2

Under this scenario there is a switch to spring stocking of F2 (1+) fish. The impact of this change in terms of the fish production process is illustrated in Figure 4.1. The main impacts that have be identified are:

- additional costs of fish food given the need to feed the fish during the added retention period from Autumn to the following spring (estimated at £8,400 – this in addition to the £22,000 costs for fish food identified under the base case);
- additional tanks needed for the over-wintering of the fish for the additional (autumn to spring) retention period (a total cost, including supply and installation, of £40,200) - assuming the tanks and associated equipment (pumps, pipework, etc.) have an average life-span of 20 years, this expenditure would have an equivalent annual cost (at 6%) of £3,143.

The total additional annual costs of moving to a spring stocking of what would be mainly F2 fish would therefore be £11,543.

4.4.2 Scenario 3

Under this scenario there is a move to stocking of older, F3 (2+) fish, stocking in autumn. The impact of this change in terms of the fish production process is illustrated in Figure 4.1. The main impacts that have been identified are:

- additional costs of fish food given the need to feed the larger, older fish (estimated at £20,200 – this in addition to the £22,000 costs for fish food identified under the base case);

- additional tanks needed for over-wintering a higher proportion of older, larger fish (a total cost of £40,200) – again, assuming an average life-span of 20 years, this expenditure would have an equivalent annual cost (at 6%) of £3,143.
- loss of revenue from the reduced output of fish (a greater space is needed by the larger fish) - it is estimated that the total number of F3 fish which could be produced would be 120,000 (compared to 262,000 as a mixture of F2/F3 fish currently produced) which, at current prices, would mean an effective revenue loss of £87,321.

The total additional annual costs of moving to a autumn stocking of mainly F3 fish would therefore be £110,625.

4.4.3 Scenario 4

Under this scenario there is a move to stocking of older, F3 (2+) fish together with a move to spring stocking. The impact of this change in terms of the fish production process is illustrated in Figure 4.1. The main impacts that have been identified are:

- additional costs of fish food given the need to feed larger, older fish during the added retention period from autumn to the following spring (estimated at £28,600 – this in addition to the £22,000 costs for fish food identified under the base case);
- additional tanks needed for holding older, larger fish for a second over-winter period (a total cost of £55,400) – assuming an average life-span of 20 years, this expenditure would have an equivalent annual cost (at 6%) of £4,332;
- loss of revenue from the reduced output of fish (a greater space is needed by the larger fish) – again, it is estimated that the total number of F3 fish which could be produced would be 120,000 (compared to 262,000 as a mixture of F2/F3 fish currently produced) which, at current prices, would mean an effective revenue loss of £87,321.

The total additional annual costs of moving to a spring stocking of what would be mainly F3 fish would therefore be £120,254.

These results are summarised in the following table (Table 4.3).

Table 4.3: Total annual costs of moving to the alternative stocking strategies (all figures as £ per annum)

Scenario	Fish food	Equipment (tanks, etc.)	Opportunity cost	Total cost (over base case)
Scenario 2	£8,400	£3,143	£ 0	£ 11,543
Scenario 3	£20,200	£3,143	£ 87,321	£ 110,624
Scenario 4	£28,600	£4,332	£ 87,321	£ 120,253

4.5 Discussion

In Scenario 2 a move to a spring stocking has a relatively minor impact and is mainly due to the costs of additional fish food. However, it should be noted that stocking strategy involves a relatively narrow time window between the early spring (when the fish should ideally be stocked out) and brood fish collection, which needs to start almost straight afterwards.

Successful and timely completion of both of these activities can be jeopardised by spring floods. Such risks have not been accounted for in this analysis.

In Scenarios 3 and 4 the main impact is the opportunity cost of the reduced output given the space constraints on the fish farm. These options also present risks that have not been examined in detail. For example, in Scenario 4 in addition to the narrow time window between stocking and brood fish collection there are also the additional health and disease risks which are inherent in keeping larger, older fish in tanks for a second over-winter period in preparation for spring stocking.

By making assumptions regarding the relative space used by F2 and F3 fish on the farm at present it is possible to produce a first estimate of the total number of F2 fish that could be produced given no changes to the current system at Calverton. Assuming F2 require 6/16 of the space taken by F3, Calverton's current 'capacity' *for F2 only* is given by:

current F2 plus current F3 x (16/6)

= 172,659 + (89450 x (16 /6))

= 411,192

By combining this estimate with the production and figures and costs outlined above (Section 4.4) the following costs per fish can be derived (Table 4.4).

Table 4.4: Estimates of cost per fish for production processes geared to different stocking scenarios

Scenario	Age	Stocking season	Total cost	Number of fish produced	Cost per fish
Scenario 1	F2 [1+]	autumn	£ 226,000	411,192	£ 0.55
Scenario 2	(mainly) F2 [1+]	spring	£ 237,543	411,192	£ 0.58
Scenario 3	F3 [2+]	autumn	£ 336,624	120,000	£ 2.81
Scenario 4	(mainly) F3 [2+]	spring	£ 346,253	120,000	£ 2.89

The figures from Scenarios 1 and 2 as presented above agree well with the market values of £0.78 for F2 fish. Whilst the cost estimates for F3 fish (under Scenarios 3 and 4) are significantly higher than the market price of £1.55 for F3 fish, this is because the costs estimated here reflect altering the production process to concentrate solely on F3 production. The F3 costs therefore include the likely additional investment costs and reflect the reduced level of output that would be anticipated. Consequently, whilst the estimated costs for the older fish are obviously higher than current rates, the range of estimates provided in Table 4. are probably reasonably accurate estimates of the cost differentials that would arise from the changes in the fish husbandry regimes inherent in the production scenarios under consideration.

The extent to which the increased costs associated with the production of older fish can be considered to be 'value for money' depends on the relative survivability of the fish being stocked. This is discussed further in Section 5.

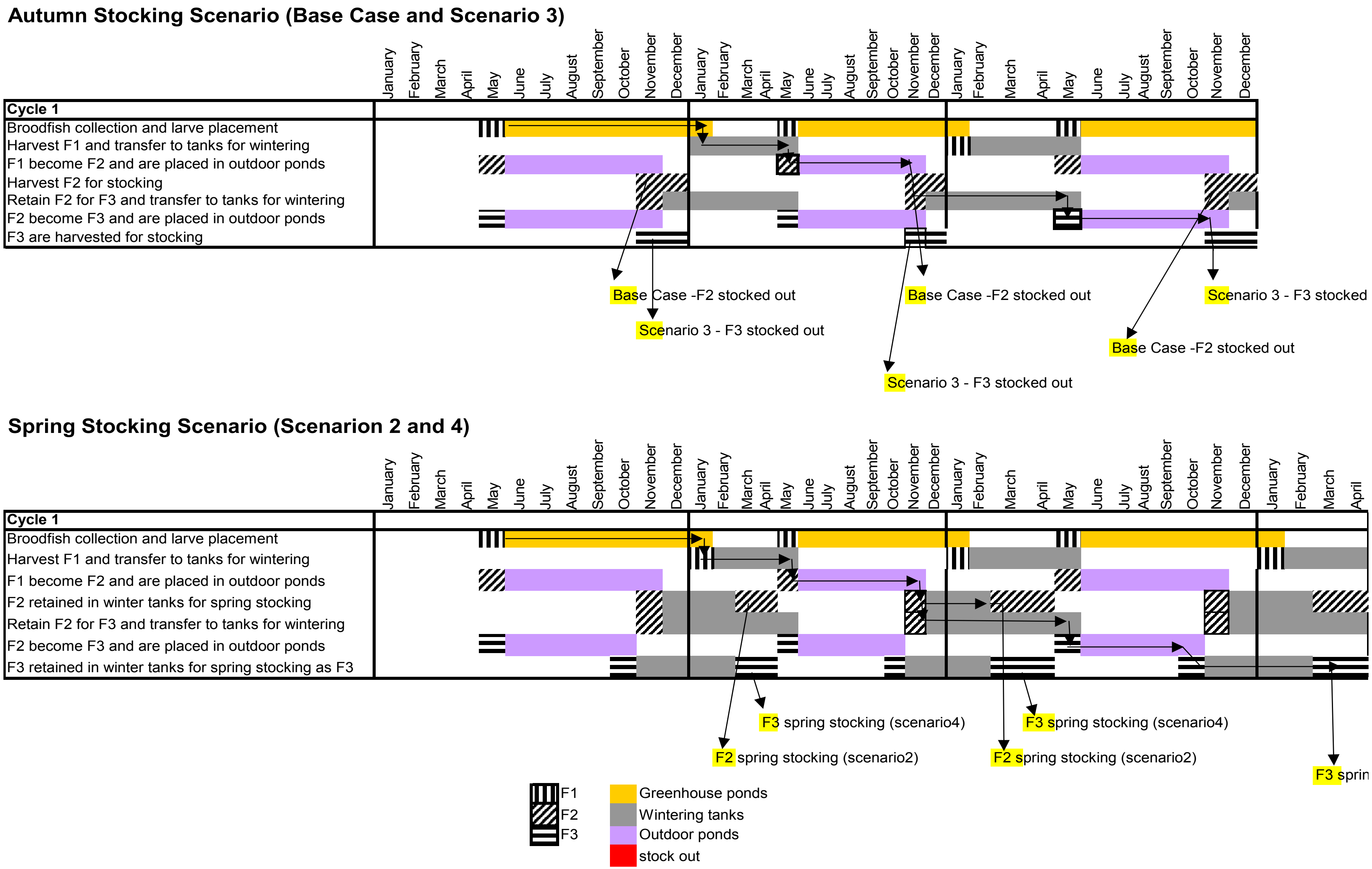


Figure 4.1: Production processes at Calverton under current and alternative stocking scenarios

5. DISCUSSION

5.1 The Experimental Design

5.1.1 Site selection

It is acknowledged that there were certain underlying problems with the study sites that were selected for the project. However, as the project was instigated within a relatively tight timescale and site selection was necessarily driven by availability this situation was essentially unavoidable. Notwithstanding this the study rivers were, at the time, said to be representative of sites that would be subject to (operational) stocking; consequently, despite their apparent shortcomings, it was felt reasonable to consider them.

On each of the four study rivers there were potential sites that could not be accessed or sampled effectively (e.g. deep pools that could not be electric fished by wading). However it was felt that, at the time of the surveys (normal or low flow conditions), stocked fish would not be making use of these habitat types to the extent that the survey results garnered would be greatly biased.

5.1.2 Stocked fish identification

Early meetings of the Project Board directed the project not to mark stocked fish. Subsequent operational problems in differentiating stocked fish from ‘native’ non-stocked fish, or fish of the same year-class but from a different stocking highlighted the shortcomings of this decision. With hindsight it would have been appropriate to mark all stocked fish in order to facilitate their subsequent positive identification.

Although subjective in nature and somewhat labour intensive the use of length-frequency distributions to identify the ‘origin’ of fish caught during post-stocking surveys provided a pragmatic and acceptable solution to the problem of identifying the ‘origin’ of all fish caught.

5.1.3 Sampling efficiency

It is possible that poor sampling efficiency throughout the course of the study could underestimate populations of stocked fish still resident within the stocked reaches, so leading to an underestimate of the overall post-stocking persistence. However, qualitative assessment of the sampling efficiencies observed suggest that this was not likely to have been an issue. The rivers selected for the study afforded themselves to relatively efficient sampling by electric fishing (wading) techniques. Inevitably, the conditions prevailing at the time of the survey would dictate actual efficiency ‘on the day’ but, as far as possible, the scheduling of surveys was carried out such that sampling conditions were optimised.

As fish were being released into what were believed to be barren waters it was decided to stock to recreate population densities within the target reaches that were representative of pre-existing or exepected populations whilst not exceeding the likely carrying capacity. As discussed in Section 0 stocking densities for the study were effectively based on pre-impact densities for the River Cherwell. It was felt that, for all four study rivers, these density targets were of the same order of magnitude as the population densities that would have been expected under non-impacted conditions and were not too dissimilar to stocking densities used in standard operational practice by the Agency. However, stocking at higher densities was considered during the experimental design phase. It was thought that, by starting with higher initial densities, the likelihood of having a greater number of fish left in the reach after six and twelve months would be increased. It was argued that this in turn would increase the ability of the study to discern between the effects of the age and season treatments that were applied. It was concluded that, if fish were to be introduced at densities substantially higher than the likely carrying capacity of the target reach, it would not subsequently be possible to separate out the effect of the age and season factors and the effects of habitat availability and potential intra-species competition. The latter effects would be likely to be both uncontrolled and unaccountable for). In addition, and on a more practical level, using more fish (in order to stock at higher initial densities) was not a valid option as, in many cases, the fish were not available from either the Calverton or Leyland fish production facilities.

5.1.4 Predation

In addition to movement outside of the stocked reach, predation (e.g. by pike or herons) will account for a proportion of the overall observed post-stocking persistence rate. Where such predation pressures are high post-stocking persistence will be reduced. Although the level of predation pressure experienced by a population of stocked fish will vary both spatially and temporally it represents only one of many factors that it was not possible to control in the study.

In the analyses that were applied to the data, non-controlled factors that may have affected survival on any given river (flow conditions, predation, habitat, water quality, etc.) were each assumed to be constant for all reaches on that river. Consequently, although one river may be prone to, for example, additional predation pressure by pike, the effects of this additional factor acting upon survival were effectively lost in the 'river effect' accounted for in each of the regression models.

Furthermore, where fish populations have been severely reduced through pollution incidents (such as was the case on the River Cherwell) different fish species are likely to display different rates of recolonisation from natural 'reservoir' stocks. The fact that a predatory species such as pike appears to be a successful recolonising species is, in itself, an interesting issue.

Following a fish kill incident, where stocking is to be used as a remediation tool, it would not be standard operational practice to undertake a detailed assessment of the predation pressures that are likely to be operating on the system. Nor would it be standard operational practice to undertake active predator management post-stocking. Consequently, the prevailing scenario on the River Cherwell (and, to a lesser extent, the River Alderbourne) with the potential for predation by pike, is likely to be representative of 'normal' conditions and is representative of what may be encountered operationally. Indeed, the observed densities of pike were within (although perhaps towards the upper end of) the range that would normally be expected in such riverine environments (Graeme Peirson, pers. comm.).

5.2 Post-Stocking Persistence

5.2.1 Estimated persistence rates

The estimated persistence rates presented in Section 3.1 appear to be low and would, in isolation, bring the efficacy of stocking as an operational practice into question. However it is important to remember that, due to the nature of the adopted experimental design, the figures presented refer specifically to *post-stocking persistence within the stocked reach* and not to 'survival' as it may be more loosely interpreted. Comparable figures are not widely available in the literature, although Steel *et al*. (1998) suggest that 30% may be a realistic annual survival rate for hatchery reared coarse fish stocked into large river systems (although they do not cite any specific studies to support this figure). When additional loss due to emigration out of a stocked reach is taken into account, the 30% rate suggested by Steel *et al*. may well be of the same order of magnitude as the apparently lower (persistence) rates seen in this R&D.

Persistence rates can be seen to vary between rivers ('river' as factor being significant in all of the models applied to the survey data). This serves to underline the importance of habitat in determining the apparent success of stocking activities. Also, for a given river, the estimated persistence rate differs across the three species stocked. However, in terms of post-stocking persistence the River Alderbourne appeared, qualitatively, to perform best out of the four study rivers.

The post-stocking persistence of chub in the River Alderbourne was the highest rate seen for any river and any species in the study (with nearly 34% of the stocked fish remaining after 6 months). Similarly on the River Hogsmill chub were the most persistent species, with nearly 20% of stocked remaining after 6 months. However, on the River Cherwell dace performed best (an average of 14.6% of the stocked fish remaining after 6 months) whilst on the River Lostock roach were the more persistent (with 9.9% remaining after 6 months).

This variability limits the degree to which specific operational guidance may be drawn from the results. It is nevertheless a useful exercise to take the estimate survival rates (and derived estimates of persistence after 6 months) and draw up a table indicating the stocking requirements for each species on each of the study rivers given a nominal target population size. By way of example this was done for a nominal 6 month post-stocking target population density of 10 fish.100m^{-2}. These figures are given below (Table 5.1). To simplify the table, the three sets of estimates produced for dace (relating to the three levels of the 'winter year' factor experienced during the course of the study) have been combined to give a single average figure. Whilst, statistically speaking, it is inappropriate to combine these three estimates in this way it is only intended that the figures be used as a guideline and be taken only as first estimates against which the estimates for chub and roach may be compared.

These requirement estimates were then combined with the 'cost per fish' figures presented in Table 4.4 to produce a first estimate of the cost (for each river and for each species) of fish production inherent in each of the four stocking strategies that were considered. These estimates are presented below as Table 5.1.

Table 5.1: Estimates of numbers of fish.100m^{-2} required to achieve a nominal target density of 10 fish.100m^{-2} remaining in stocked reach 6 months post-stocking

		Stocking strategy			
		1+		2+	
Species	**River**	**Autumn**	**Spring**	**Autumn**	**Spring**
Chub	Alderbourne	30	30	84	84
	Cherwell	667	667	128	128
	Hogsmill	111	111	51	51
	Lostock	114	114	141	141
Dace †	Alderbourne	45	45	70	70
	Cherwell	3750	3750	68	68
	Hogsmill	150	150	73	73
	Lostock	142	142	217	217
Roach	Alderbourne	73	73	73	73
	Cherwell	217	217	217	217
	Hogsmill	99	99	99	99
	Lostock	101	101	101	101

Table 5.2: Estimates of fish production costs 100m^{-2} incurred in achieving a nominal target density of 10 fish.100m^{-2} remaining in stocked reach 6 months post-stocking

		Stocking strategy			
		1+		2+	
Species	**River**	**Autumn**	**Spring**	**Autumn**	**Spring**
Chub	Alderbourne	£16	£17	£236	£243
	Cherwell	£367	£386	£360	£371
	Hogsmill	£61	£64	£143	£147
	Lostock	£62	£66	£396	£407
Dace †	Alderbourne	£26	£28	£197	£203
	Cherwell	£2063	£2175	£192	£197
	Hogsmill	£82	£87	£204	£210
	Lostock	£78	£82	£611	£628
Roach	Alderbourne	£40	£42	£205	£211
	Cherwell	£120	£126	£611	£628
	Hogsmill	£54	£57	£278	£286
	Lostock	£55	£59	£284	£291

† (both tables) - figures presented for dace are based on the average persistence over six months taken across all three levels of the 'winter year' factor - see text for details.

As can be seen in Table 5.2 the cost of the fish required for stocking in order to produce a population density of 10 fish.100m^{-2} after a period of 6 months varies dramatically from £16 per 100m^2(1+ chub stocked into the River Alderbourne in autumn) to £2175 per 100m^2(1+ dace stocked into the River Cherwell in spring).

The results suggest that, with the exception of dace on the River Cherwell, the most cost-effective option for each species:river combination is to stock with 1+ fish in the autumn. On the River Cherwell for dace there is a more than 15-fold difference in the cost of stocking with 2+ and stocking with 1+ fish.

In interpreting the above figures it must be remembered that the analyses applied to the field data sought to estimate persistence over a 6 month period - and not persistence in-river to a given age. For example, the fish production costs associated with stocking 1+ chub into the River Hogsmill such that a target population density of 10 fish.100m^{-2} is realised after 6 months are estimated at £61 per 100m^2 for fish stocked in the autumn. Although this is substantially less than the £143 estimated for 2+ fish stocked in the autumn, the former action would result in a population consisting of age 2+ fish whilst the latter would result in a population consisting of age 3+ fish. When this difference in age in the desired target population is taken into account the relative merits of the different stocking strategies may be altered. This may be especially true given likely in-river survival rates subsequent to the 12 month period that was assessed as part of this study. Further analysis, to make measures of 'cost per fish remaining in the stocked reach' directly comparable across all four stocking strategies, for example by assessing in-river persistence to a given (age defined) end-point, is beyond the scope of this project. Consequently the costs presented above in Table 5.2 should be interpreted with caution.

5.2.2 Native populations

With the exception of roach on the upper reach of the River Hogsmill populations of 'native' chub, dace or roach were absent or observed only at relatively low levels (less than three individuals per 100m^2) on each of the stocked reaches. These results imply that either natural recolonisation occurred at very low rate or that there were underlying water quality or physical habitat limitations that effectively limited the population that could be supported within each reach. Personal observation (of both stocked fish and 'minor' species within the stocked reaches) would tend to refute the water quality/habitat explanation.

On the upper reach of the River Hogsmill there was an apparent increase in the roach population. The River Hogsmill has a largely urban catchment; heavy rainfall, giving rise to high river levels and localised flooding, may have resulted in the effective displacement of fish from either private ornamental ponds or natural backwaters higher in the catchment into the main river system. A similar process was undoubtedly responsible for the presence of golden rudd in the upper reach of the River Cherwell.

5.3 Movement out of Stocked Reaches

5.3.1 General

Casual observation of the data reveals no clear pattern of dispersal, although it is evident that the apparent low persistence rates may be explained in part by the emigration of stocked fish out of the stocked reach.

Notwithstanding the above, there is some suggestion from the data that the younger fish (1+) rarely displayed a tendency to move upstream, In contrast the older (2+) fish did, on occasions, show quite marked upstream movement.

5.3.2 Movement to favourable habitats

The perceived within-reach persistence rate is obviously a function of both dispersal and survival; a high incidence of dispersal will give rise to low within-reach persistence. Dispersal out of the stocked reach and into areas with more favourable habitats during the days, weeks and months following stocking will be an important factor in moderating the perceived within-reach persistence rate. Because of the potential to 'lose' fish from a stocked reach it is important to ensure that the habitat of the receiving water is suitable (if not optimum) for the stocked fish. Indeed, the question of habitat quality is of key importance and the application of habitat improvement techniques should, in the first instance, be considered as a potential alternative to stocking (i.e. 'consideration of alternative management options' within the decision framework presented as Figure 1.1).

5.3.3 Potamadromous movements

In addition to movement due to 'day to day' habitat requirements within-river migration due to spawning requirements may be another factor giving rise to apparent losses from the stocked reach. For example, in their study on the movements of barbel (*Barbus barbus*), chub, dace and roach in the Ouse catchment, Lucas *et al*. (2000) concluded that migration by coarse fish in lowland rivers is an important component of the life cycle. The movement of fish from the stocked reaches in this present study may, in part, be the result of spawning requirements. It is not possible to relate the observed movements in this study to spawning activity as both the spatial and temporal aspects of the sampling programme were too limited.

6. RECOMMENDATIONS

6.1 Guidance for Stocking Activities

6.1.1 Experimental results

The results from the post-stocking persistence analyses infer that there were no significant differences between the four treatments that can be considered ‘across the board’. Any differences between the four treatments only become significant once ‘river’ is accounted for, suggesting that the quality or nature of the receiving water was, in some way, not constant across the four rivers selected. The rivers were, however, chosen as being suitable for receiving fish and as being representative of the type of waters that would be operationally stocked by the Agency.

This dependence on an (unidentified) aspect of river or reach ‘quality’ presents a very real barrier to deriving definitive advice on best practice and precludes the provision of specific guidance within the scope of this project.

However, results from this project do suggest that within-reach post-stocking persistence is generally low. A consequence of this is that, if only ‘within-reach’ persistence is considered, unfeasibly large numbers of fish need to be stocked to meet relatively modest short-term targets. In turn this suggests that large numbers of fish would need to be stocked to replace a fishery if a total loss of stock had occurred, or even to supplement missing year-classes on large river systems. The process of natural mortality of stocked fish coupled with the inevitable dispersal through the river system make stocking impractical in most large river systems. Nevertheless, the use of stocking as means of ‘jump-starting’ (rather than re-creating) a fishery or as a means of introducing key age-classes of fish needs to be considered, and it is perhaps in these terms that stocking has its real value.

It is recommended that, where the objective is the re-creation of a fishery within a relatively restricted reach of river (for example 5km or less) the Agency considers methods other than stocking. In such instances, the ‘within-reach’ benefits of stocking (in terms of the persistence of stocked fish) are likely to be very limited.

6.2 Guidance for Fish Production

6.2.1 Economic considerations

The economic assessments that were undertaken demonstrated the marked increase in costs associated with moving from the production of 1+ fish to the production of 2+ (i.e. a move from F2 to F3 fish). When combined with the estimates of within-reach persistence generated by the analyses of the post-stocking survey data there is the suggestion that stocking 1+ (i.e. F2) fish in the autumn represents the most cost effective means of attaining population density targets over a 6 month timescale.

Therefore, should the Agency wish to continue with operational stocking, it is recommended that fish culture should concentrate on 1+ (i.e. F 2) production - with stocking-out of fish being undertaken in the autumn. However at the same time it is important to recognise the continued importance of the market demand for the older, larger fish that are produced at the Agency's fish production facilities. It is recommended that the current flexibility in production enjoyed by the Agency's fish production facilities be maintained.

6.3 Guidance Relating to the Dispersal of Stocked Fish

This study has produced extensive quantitative information on post-stocking dispersal. Although the experimental design was not developed to allow dispersal to be quantitatively assessed the results generated suggest that dispersal may in some cases be a significant, if not major, factor affecting the apparent within-reach survival of stocked fish.

Casual observation revealed no clear patterns of dispersal. Consequently it is not possible to make substantive recommendations regarding the likely patterns (and subsequent implications) of dispersal.

6.4 Recommendations for Further Work

Four areas of further work are identified as potentially providing useful information to feed into the management decisions that should underpin stocking activities within the Agency. These relate to:

- stocking densities;
- dispersal;
- the potential for natural recovery; and
- the potential for habitat improvement works as an alternative, or supporting, management strategy.

Whilst more detail on these four areas of research is given below, it is recommended that all four areas be considered for inclusion within the production of a 'Fish stocking Technical Manual' within the Agency's Fisheries Function.

6.4.1 Stocking densities

As discussed in Section 5.1.3 stocking densities in this study were selected so as to minimise the potential effects of other factors (e.g. competition for available habitat). However, the potential for adjusting the stocking density as a means of optimising post-stocking persistence remains an outstanding issue. In operational practice, for example, one of two possible alternative strategies may be adopted:

- 'kick starting' the system with a high stock density at or above the anticipated carrying capacity of the reach; and
- lower level stocking to augment natural recolonisation and to help the system regenerate semi-naturally.

The choice of strategy may well be influenced by operational need. For example, as the former approach is likely to provide more instantaneous results than the latter it is likely that, where a reach is managed as a recreational fishery, a 'kick-start' type strategy may be favoured. However, it would be important to factor-in the relative long-term benefits of the alternative strategies. Notwithstanding this, in order to prevent fish being stocked to excessive densities whilst, at the same time, ensuring that sufficient fish are introduced to meet the medium- to long-term objectives of the stocking exercise, there is a real and pressing need to establish optimum stocking densities.

It is recommended that research be carried out to assess the success of stocking to different densities and to derive guidance on stocking densities for operational practices.

6.4.2 Dispersal

It is apparent from this study that dispersal is an important factor affecting the apparent success of stocking exercises. Little information is currently available within the literature on the post-stocking movements of stocked fish.

R&D on dispersal is currently being promoted as a research project within the Agency Fisheries Function's R&D programme. This findings from this study underline the importance of undertaking this work and it is recommended that its inception be promoted.

6.4.3 Potential for natural recovery following fish-kills

Although this study did not demonstrate *significant* increases in native populations through the course of the monitoring programme, the contributions to post-kill fish population densities that accrue through natural recolonisation need to be considered within the framework of a stocking strategy. Evidence from the current study suggested that natural events, such as flooding, may be responsible for the redistribution of fish within a catchment. In addition certain species, such as pike on the River Cherwell, appear to be good 'colonisers' following fish-kills.

It is widely accepted that fish-kills rarely affect the entire population within a given river system. Avoidance behaviour can result in a number of fish surviving through an incident whilst the presence of populations within unaffected backwaters and confluent streams can provide a source for recolonisation.

Whilst it is recognised that stocking to replace older age groups of key species may be an appropriate policy in important recreational fisheries, the overall contribution to recovery that can be made by native fish through redistribution/recolonisation should be considered. **It is recommended that, as part of the development of the Function's Technical Manual on fish stocking, information be collated on 'natural' recoveries following fish-kill incidents.** If sufficient information is available it may be possible to provide guidance on the likely level of recovery that may be expected without the need for stocking. As well as forming part of the proposed Technical Manual it would probably be appropriate to submit the findings of such an exercise to the peer-reviewed literature.

6.4.4 Habitat improvement works

As well as for restoration following fish-kills, the need for stocking may also lie in the (real or perceived) under-performance of recreational fisheries. However, it is important for fishery managers to see stocking as only one of a range of management actions that are available to them within an integrated and holistic framework of stock management.

Although the practical aspects of coarse fish habitat improvement have, in general terms, been dealt with in available manuals (e.g. FAO, 1996) the relative benefits of habitat improvement works as an alternative, or supporting, management strategy to the use of stocking as a management tool could be usefully highlighted.

It is recommended that the potential benefits of habitat improvement works as a viable alternative to stocking be given appropriate consideration within the planned Technical Manual on fish stocking.

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APPENDIX A REACH DIMENSIONS

Table A.1: Proportion of individual target reaches surveyed

River	Target reach	Total length (m)	Average width (m)	Total reach area (m^2)	Total area surveyed (m^2)	Proportion surveyed
Alderbourne	A - upper reach	775.00	3.10	2,402.50	901.80	0.38
	B - lower reach	750.00	3.18	2,381.25	979.13	0.41
Cherwell	A - upper reach	1,000.00	7.38	7,375.00	2,461.77	0.33
	B - lower reach	1,714.29	6.12	10,485.71	1,558.13	0.15
Hogsmill	A - upper reach	1,125.00	4.40	4,950.00	1,381.73	0.28
	B - lower reach	1,036.36	5.42	5,613.64	2,112.93	0.38
Lostock	A - upper reach	1,187.50	3.87	4,591.67	1,517.93	0.33
	B - lower reach	1,937.50	4.68	9,057.81	1,929.53	0.21

Table A.2: Site dimensions - River Alderbourne

Site code	Site length (m)	Width (m) at: top of site	mid-point	bottom of site	Average width (m)	Area (m^2)
AUS	32	2.9	2.6	2.7	2.7	87.5
AA1	64	2.8	2.3	3.9	3.0	192.0
AA2	71	2.4	3.5	2.5	2.8	198.8
AA3	75	3.7	3.6	2.9	3.4	255.0
AA4	80	3.0	3.0	3.6	3.2	256.0
AMI	72	4.2	2.8	4.1	3.7	266.4
AB1	56	3.8	3.4	3.7	3.6	203.5
AB2	60	3.9	3.9	3.0	3.6	216.0
AB3	113	4.3	2.6	2.8	3.2	365.4
AB4	87	2.7	1.8	2.2	2.2	194.3
ADS	105	3.0	2.5	5.2	3.6	374.5

Table A.3 Site dimensions - River Cherwell

Site code	Site length (m)	Width (m) at: top of site	mid-point	bottom of site	Average width (m)	Area (m^2)
CUS	76	6.3	8.3	6.7	7.1	539.6
CA1	108	6.2	5.3	5.9	5.8	626.4
CA2	87	8.0	7.7	7.6	7.8	675.7
CA3	75	9.3	10.0	7.3	8.9	665.0
CA4	70	7.3	7.0	6.9	7.1	494.7
CMI	95	7.1	7.7	5.1	6.6	630.2
CB1	63	5.4	3.1	5.0	4.5	283.5
CB2	63	4.2	5.4	5.7	5.1	321.3
CB3	77	7.0	5.2	6.3	6.2	474.8
CB4	55	8.7	8.6	8.8	8.7	478.5
CDS	90	6.9	9.0	9.0	8.3	747.0

Table A.4: Site dimensions - River Hogsmill

Site code	Site length (m)	Width (m) at: top of site	mid-point	bottom of site	Average width (m)	Area (m^2)
HUS	81	5.9	6.0	6.9	6.3	507.6
HA1	72	6.1	4.6	5.4	5.4	386.4
HA2	60	5.5	2.4	3.4	3.8	226.0
HA3	75	3.2	3.6	3.1	3.3	247.5
HA4	101	5.6	5.0	4.9	5.2	521.8
HMI	74	5.8	4.5	4.4	4.9	362.6
HB1	73	8.4	5.5	6.3	6.7	491.5
HB2	105	5.8	4.6	5.0	5.1	539.0
HB3	102	6.0	5.0	4.6	5.2	530.4
HB4	120	3.0	5.0	5.8	4.6	552.0
HDS	64	2.9	5.7	5.9	4.8	309.3

Table A.5: Site dimensions - River Lostock

Site code	Site length (m)	Width (m) at: top of site	mid-point	bottom of site	Average width (m)	Area (m^2)
LUS	89	4.4	3.1	3.6	3.7	329.3
LA1	92	5.3	3.0	3.9	4.1	374.1
LA2	111	6.3	2.8	3.3	4.1	458.8
LA3	99	2.6	2.7	3.6	3.0	293.7
LA4	91	3.0	4.0	5.9	4.3	391.3
LMI	120	3.1	4.4	3.4	3.6	436.0
LB1	107	5.7	3.9	5.2	4.9	527.9
LB2	75	2.6	4.8	5.4	4.3	320.0
LB3	128	4.9	3.7	4.4	4.3	554.7
LB4	102	5.2	4.8	5.5	5.2	527.0
LDS	128	3.1	3.7	5.3	4.0	516.3

APPENDIX B SURVEY DATES

Table B.1: Survey dates - River Alderbourne

	Survey year and season				
Site	**Spring 97**	**Autumn 97**	**Spring 98**	**Autumn 98**	**Spring 99**
AUS	25/03/97	17/10/97	11/05/98	10/11/98	22/04/99
AA1	25/03/97	16/10/97	11/05/98	10/11/98	23/04/99
AA2	25/03/97	16/10/97	11/05/98	10/11/98	23/04/99
AA3	25/03/97	16/10/97	n/a	n/a	n/a
AA4	25/03/97	16/10/97	n/a	n/a	n/a
AMI	24/03/97	15/10/97	11/05/98	09/11/98	22/04/99
AB1	24/03/97	15/10/97	11/05/98	09/11/98	22/04/99
AB2	24/03/97	15/10/97	14/04/98	27/10/98	22/04/99
AB3	24/03/97	15/10/97	14/04/98	27/10/98	21/04/99
AB4	24/03/97	15/10/97	14/04/98	27/10/98	21/04/99
ADS	24/03/97	03/09/97	14/04/98	27/10/98	21/04/99

Table B.2: Survey dates - River Cherwell

	Survey year and season				
Site	**Spring 97**	**Autumn 97**	**Spring 98**	**Autumn 98**	**Spring 99**
CUS	13/03/97	10/09/97	06/05/98	n/a	26/05/99
CA1	12/03/97	10/09/97	06/05/98	n/a	26/05/99
CA2	12/03/97	10/09/97	06/05/98	n/a	n/a
CA3	13/03/97	10/09/97	07/05/98	n/a	27/05/99
CA4	13/03/97	10/09/97	07/05/98	n/a	27/05/99
CMI	17/03/97	12/09/97	08/05/98	n/a	n/a
CB1	17/03/97	12/09/97	08/05/98	n/a	n/a
CB2	14/03/97	11/09/97	08/05/98	n/a	n/a
CB3	14/03/97	11/09/97	07/05/98	n/a	n/a
CB4	14/03/97	11/09/97	07/05/98	n/a	n/a
CDS	17/03/97	11/09/97	07/05/98	n/a	28/05/99

Table B.3: Survey dates - River Hogsmill

Site	Survey year and season				
	Spring 97	Autumn 97	Spring 98	Autumn 98	Spring 99
HUS	n/a	19/09/97	08/04/98	13/11/98	01/06/99
HA1	n/a	19/09/97	08/04/98	13/11/98	01/06/99
HA2	n/a	19/09/97	08/04/98	13/11/98	n/a
HA3	n/a	19/09/97	08/04/98	13/11/98	01/06/99
HA4	n/a	19/09/97	08/04/98	13/11/98	01/06/99
HMI	n/a	19/09/97	07/04/98	13/11/98	01/06/99
HB1	03/04/97	18/09/97	07/04/98	12/11/98	25/05/99
HB2	03/04/97	18/09/97	07/04/98	12/11/98	25/05/99
HB3	03/04/97	18/09/97	07/04/98	12/11/98	25/05/99
HB4	03/04/97	18/09/97	07/04/98	12/11/98	25/05/99
HDS	03/04/97	18/09/97	07/04/98	12/11/98	25/05/99

Table B.4: Survey dates - River Lostock

Site	Survey year and season				
	Spring 97	Autumn 97	Spring 98	Autumn 98	Spring 99
LUS	18/04/97	24/09/97	21/04/98	19/11/98	30/04/99
LA1	18/04/97	24/09/97	21/04/98	19/11/98	30/04/99
LA2	18/04/97	24/09/97	21/04/98	19/11/98	30/04/99
LA3	17/04/97	24/09/97	21/04/98	19/11/98	30/04/99
LA4	17/04/97	24/09/97	21/04/98	19/11/98	30/04/99
LMI	17/04/97	24/09/97	20/04/98	19/11/98	29/04/99
LB1	17/04/97	23/09/97	20/04/98	18/11/98	29/04/99
LB2	16/04/97	23/09/97	20/04/98	18/11/98	29/04/99
LB3	17/04/97	23/09/97	20/04/98	18/11/98	29/04/99
LB4	16/04/97	23/09/97	20/04/98	18/11/98	29/04/99
LDS	16/04/97	23/09/97	20/04/98	17/11/98	28/04/99

APPENDIX C POST STOCKING PERSISTENCE OF STOCKED FISH

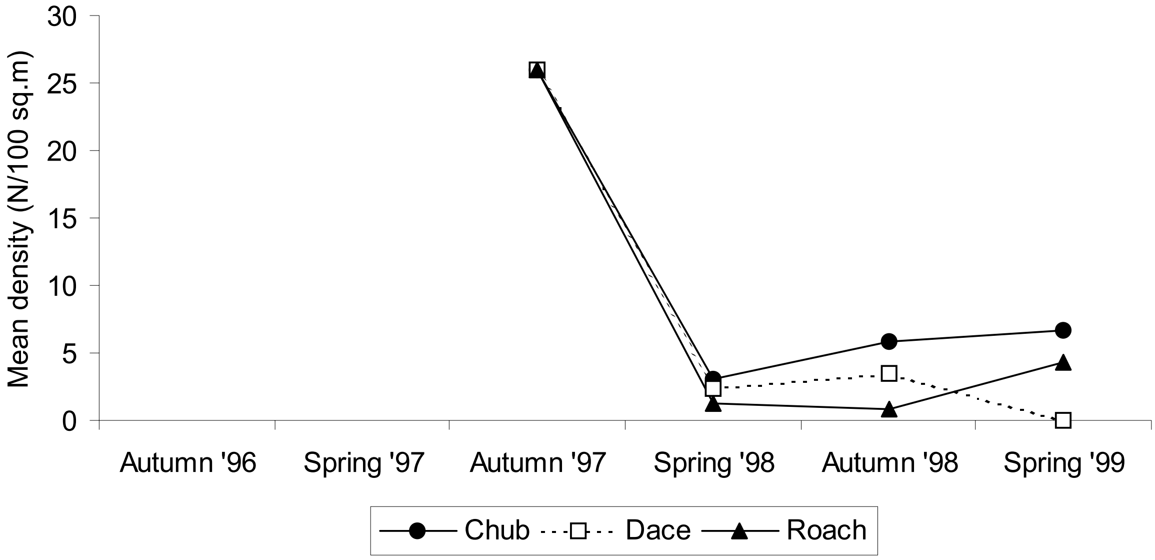

Figure C.1: Persistence of stocked fish in River Alderbourne; fish stocked as Autumn 1+

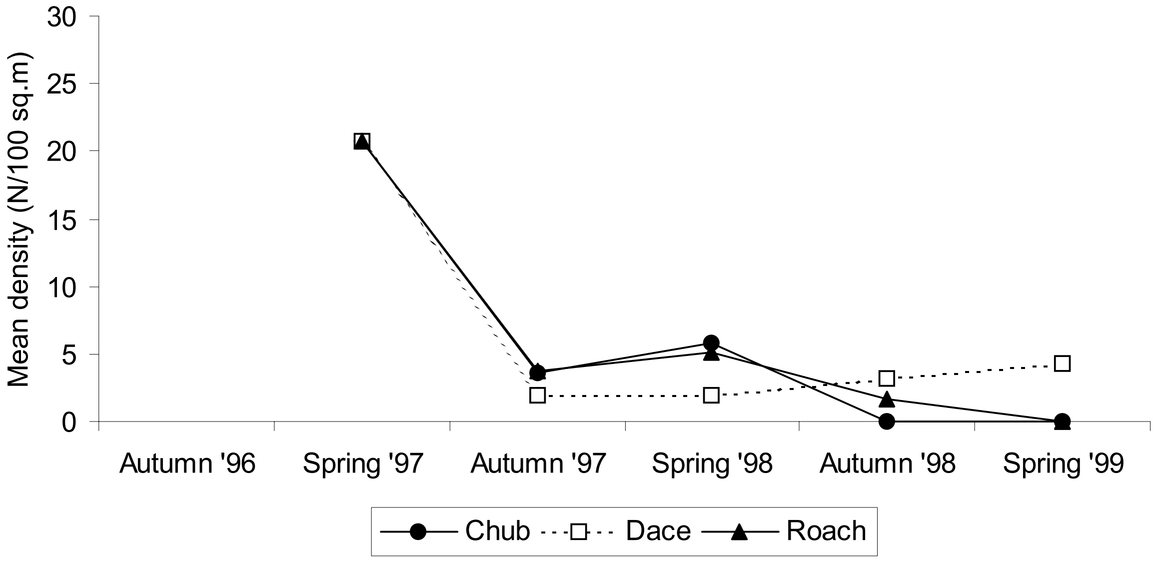

Figure C.2: Persistence of stocked fish in River Alderbourne; fish stocked as Spring 1+

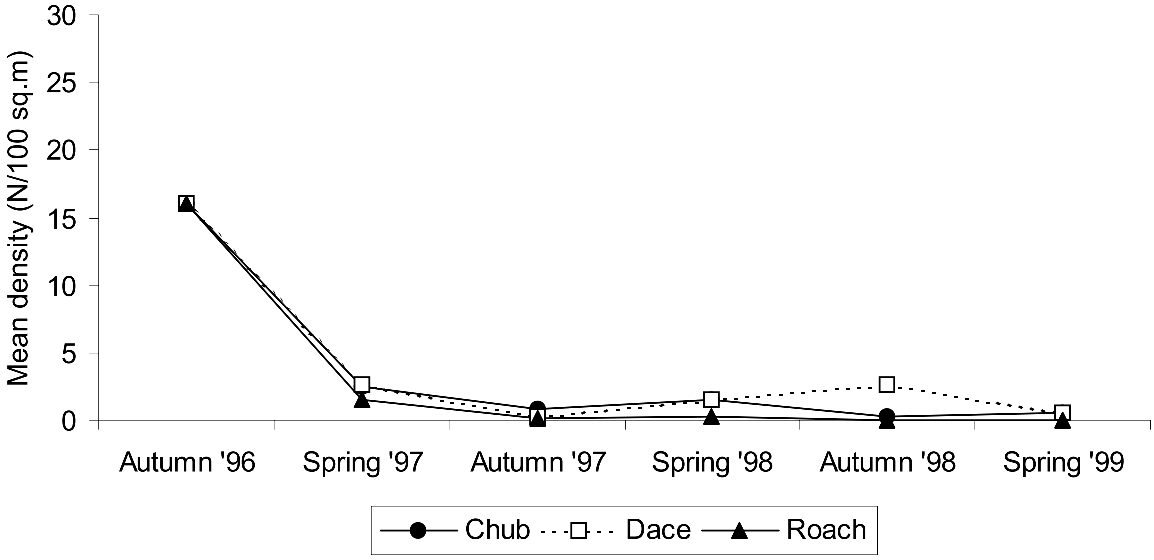

Figure C.3: Persistence of stocked fish in River Alderbourne; fish stocked as Autumn 2+

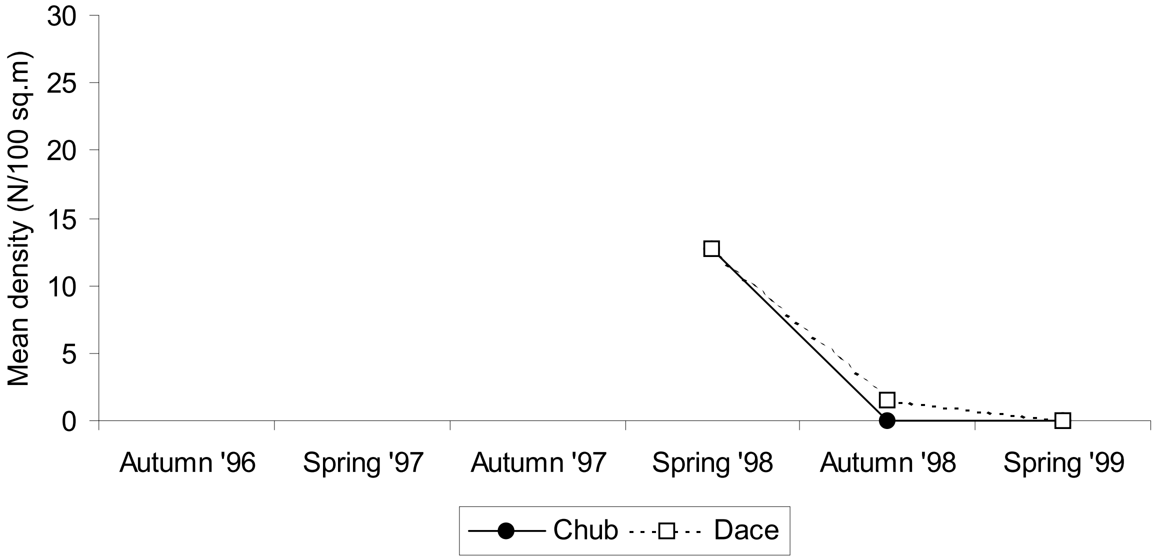

Figure C.4: Persistence of stocked fish in River Alderbourne; fish stocked as Spring 2+

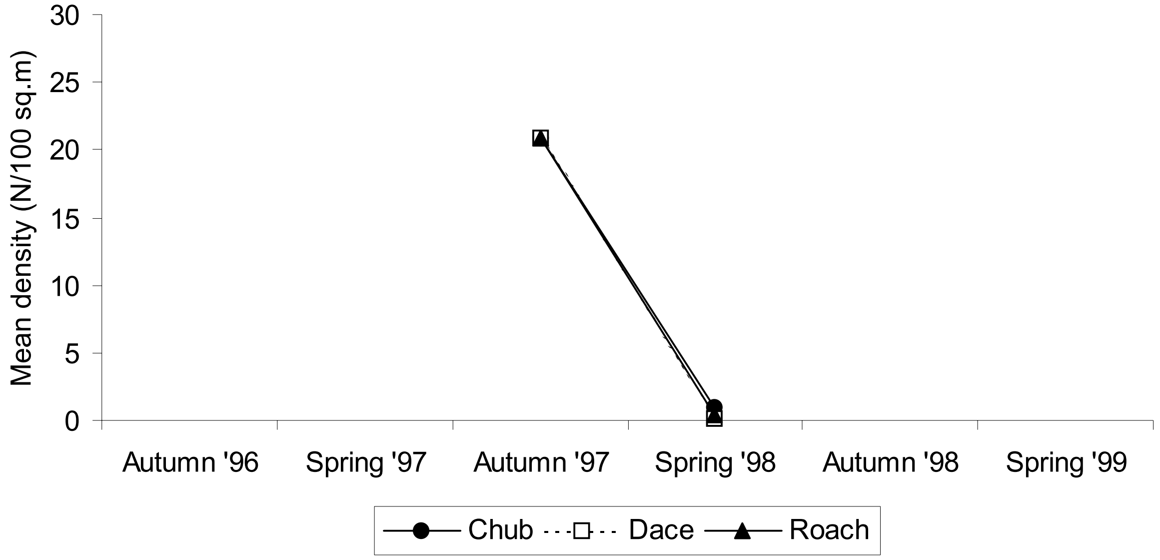

Figure C.5: **Persistence of stocked fish in River Cherwell; fish stocked as Autumn 1+**

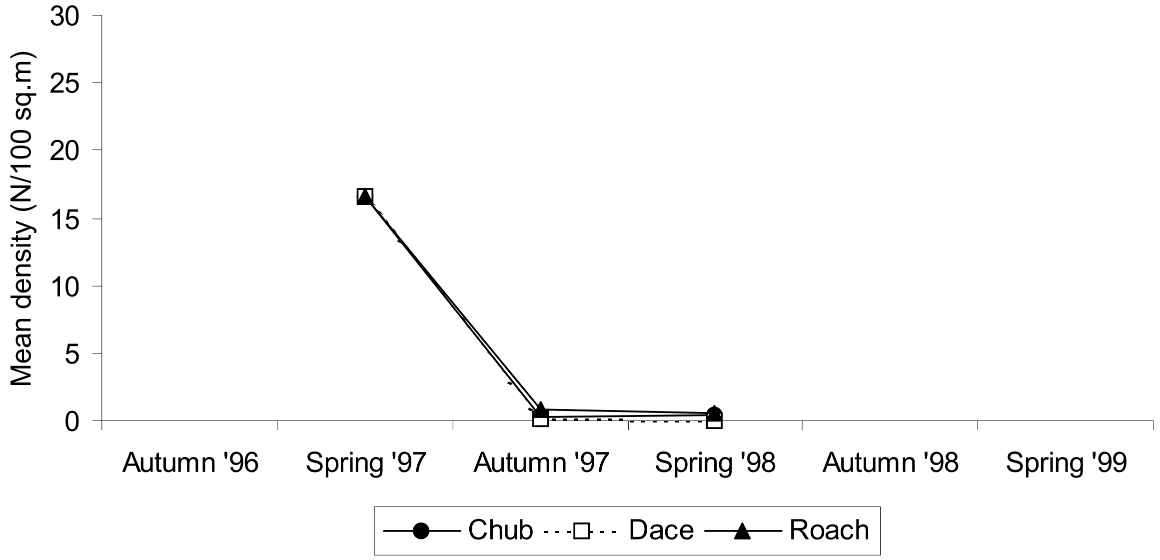

Figure C.6: **Persistence of stocked fish in River Cherwell; fish stocked as Spring 1+**

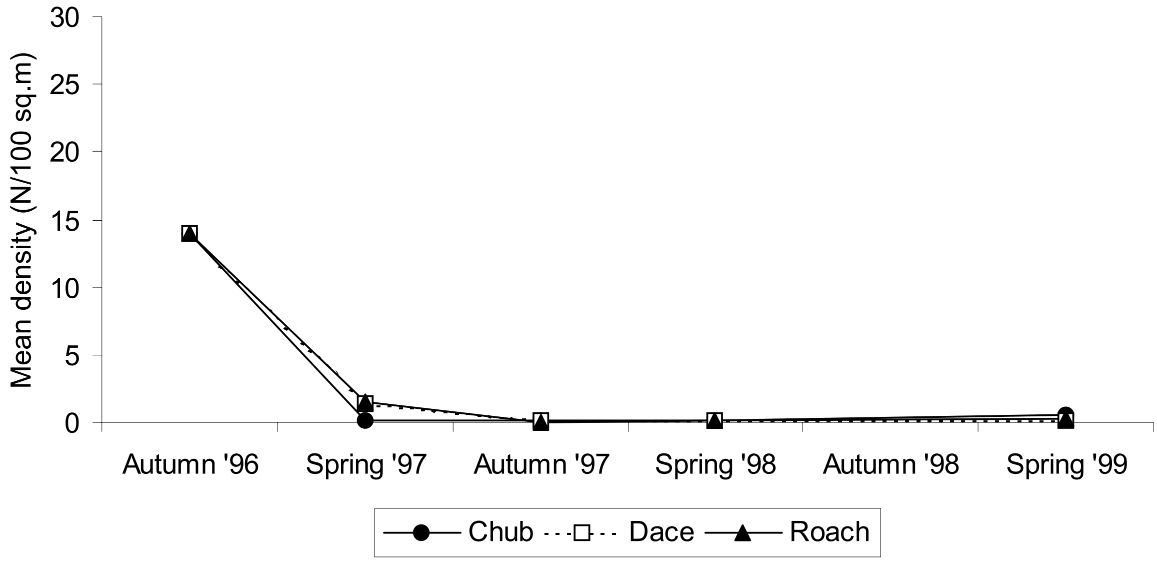

Figure C.7: **Persistence of stocked fish in River Cherwell; fish stocked as Autumn 2+**

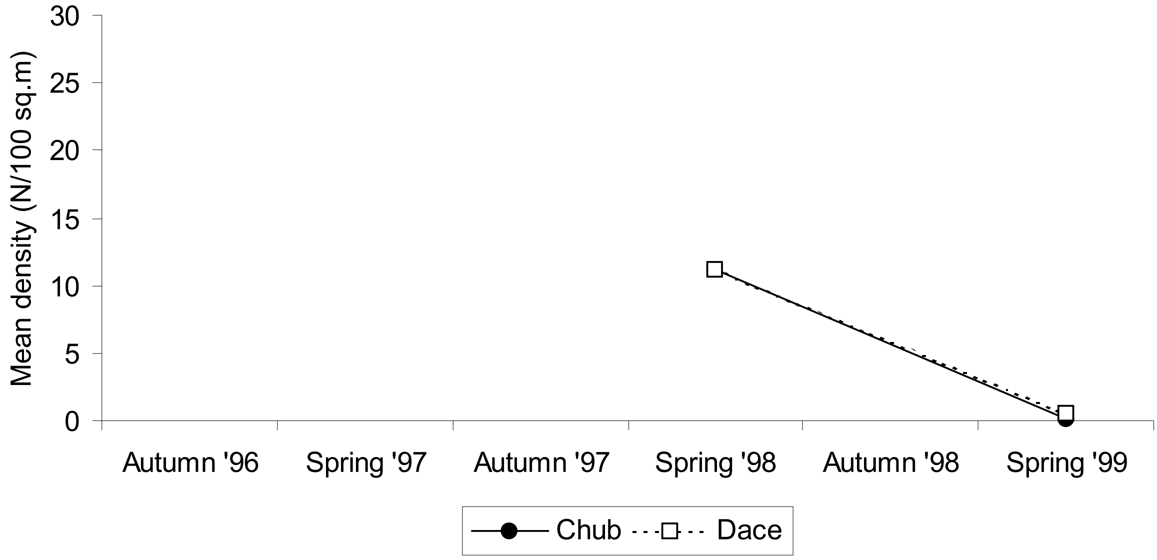

Figure C.8: **Persistence of stocked fish in River Cherwell; fish stocked as Spring 2+**

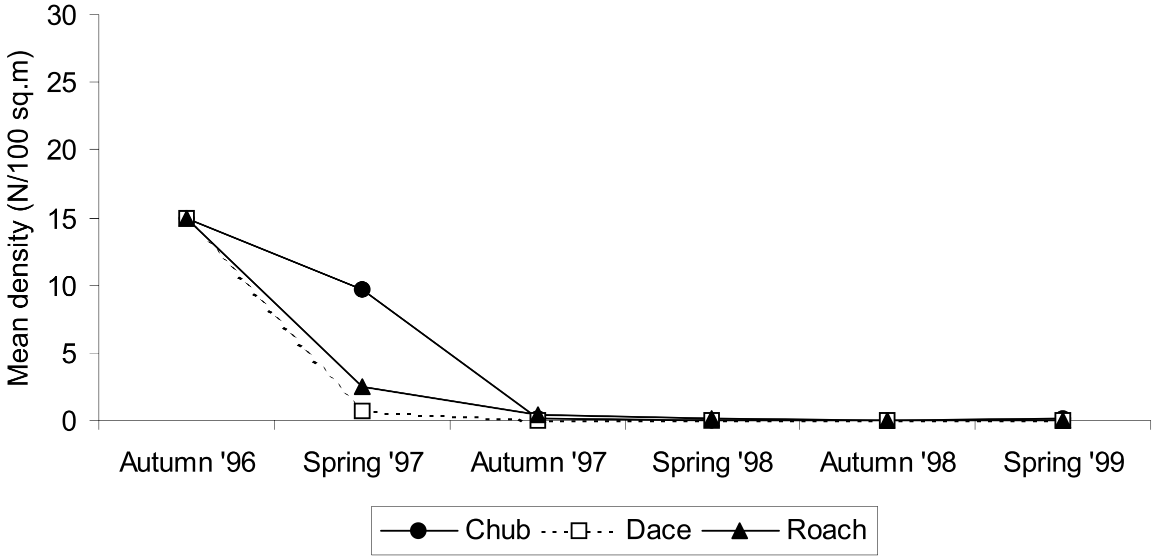

Figure C.9: Persistence of stocked fish in River Hogsmill; fish stocked as Autumn 1+

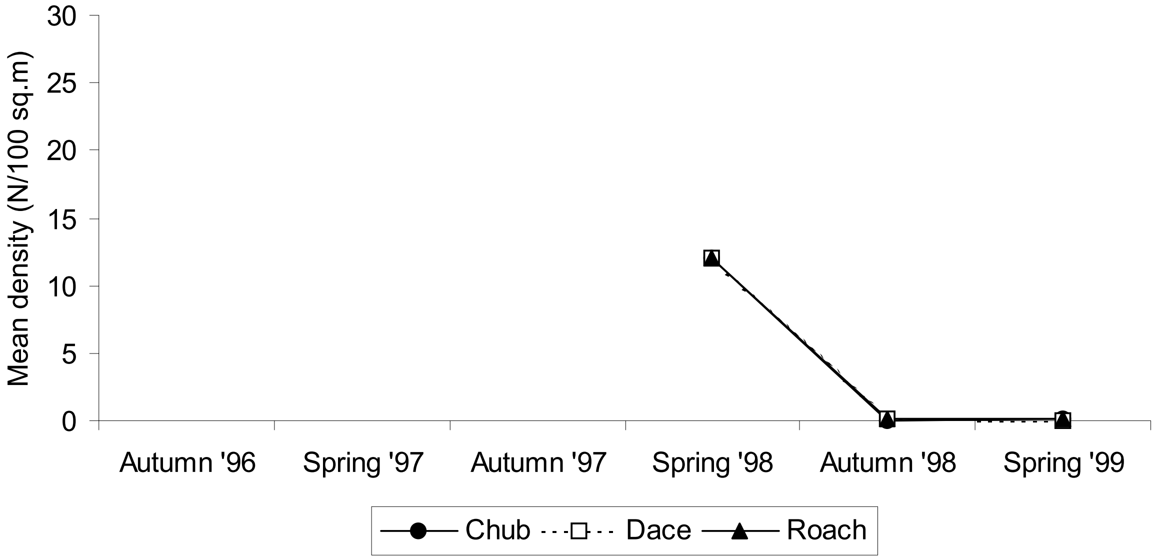

Figure C.10: Persistence of stocked fish in River Hogsmill; fish stocked as Spring 1+

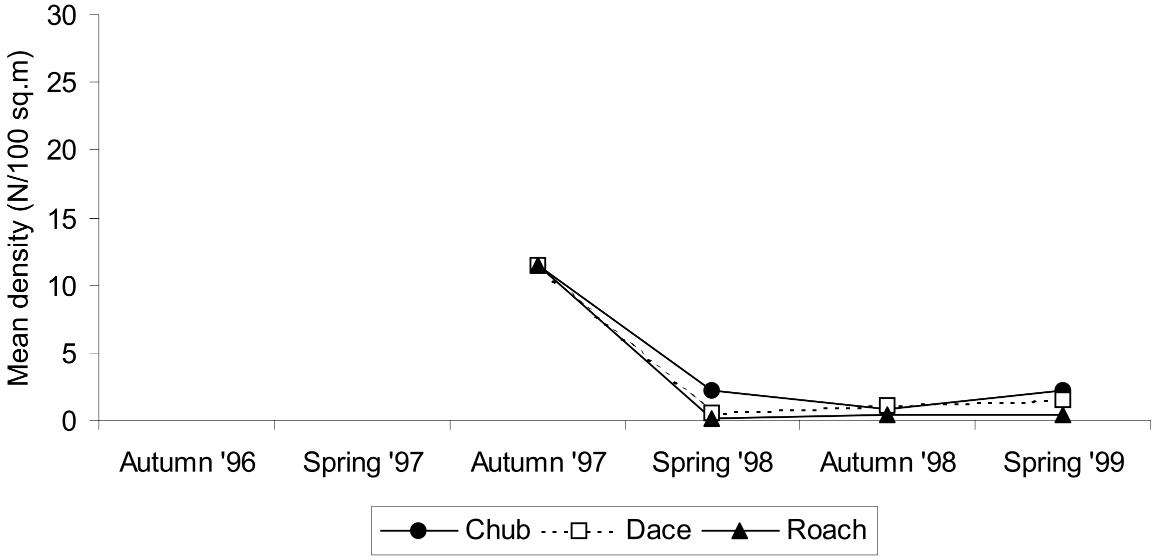

Figure C.11: Persistence of stocked fish in River Hogsmill; fish stocked as Autumn 2+

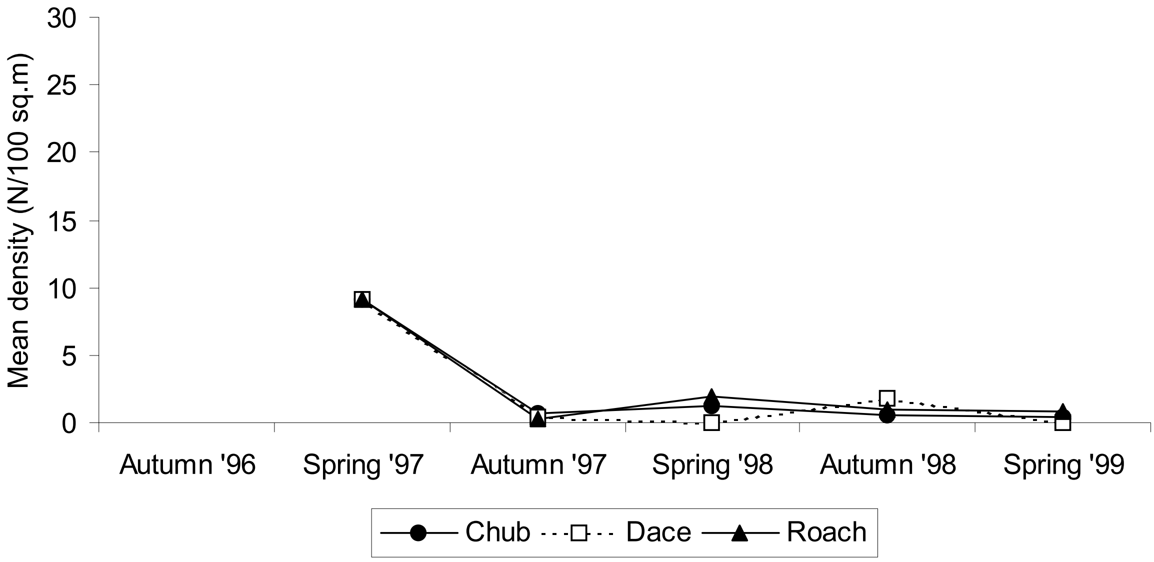

Figure C.12: Persistence of stocked fish in River Hogsmill; fish stocked as Spring 2+

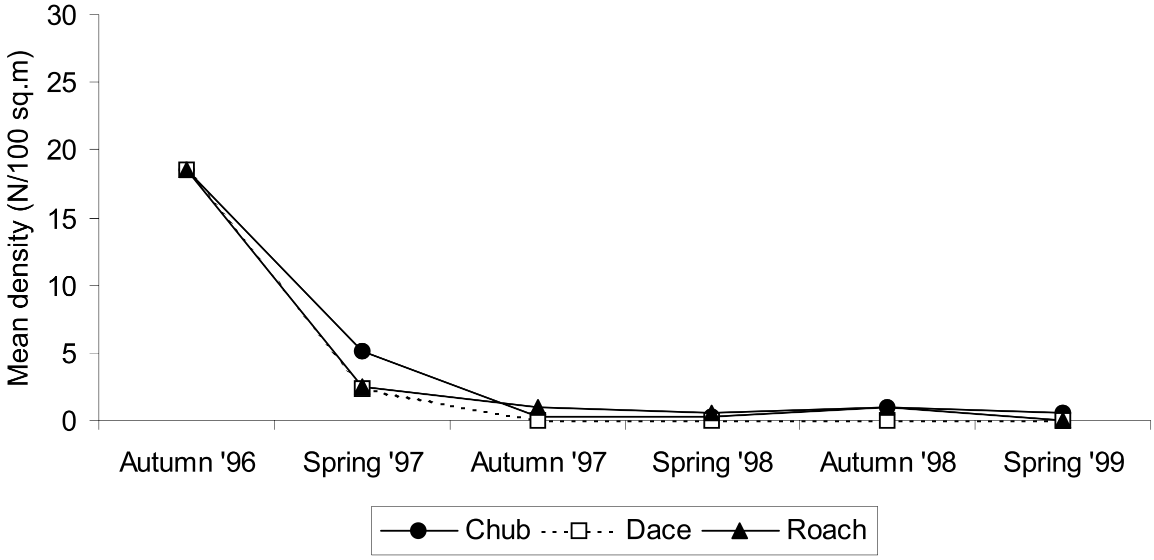

Figure C.13: **Persistence of stocked fish in River Lostock; fish stocked as Autumn 1+**

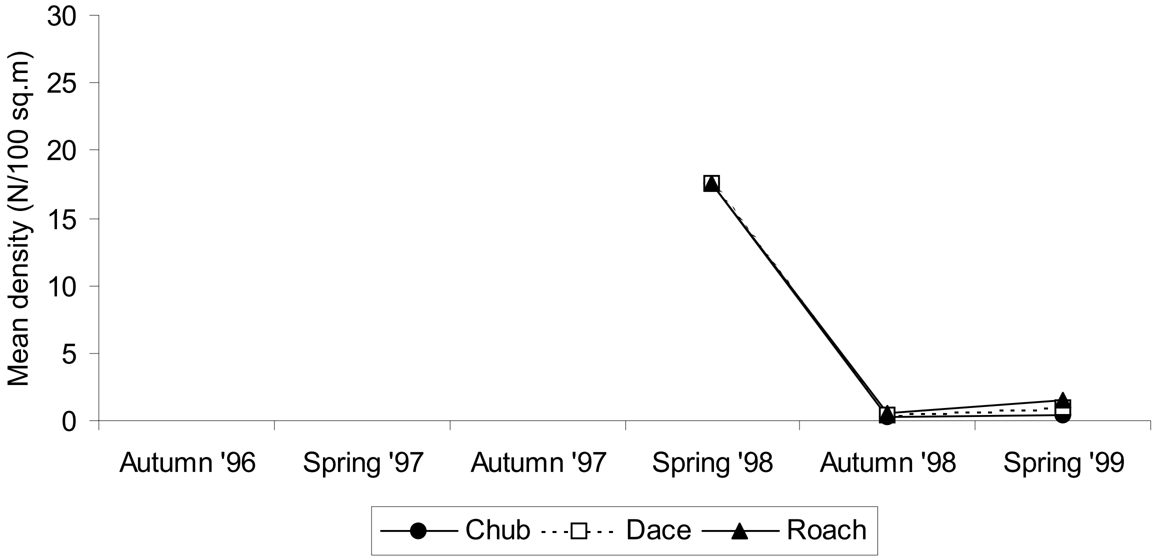

Figure C.14: **Persistence of stocked fish in River Lostock; fish stocked as Spring 1+**

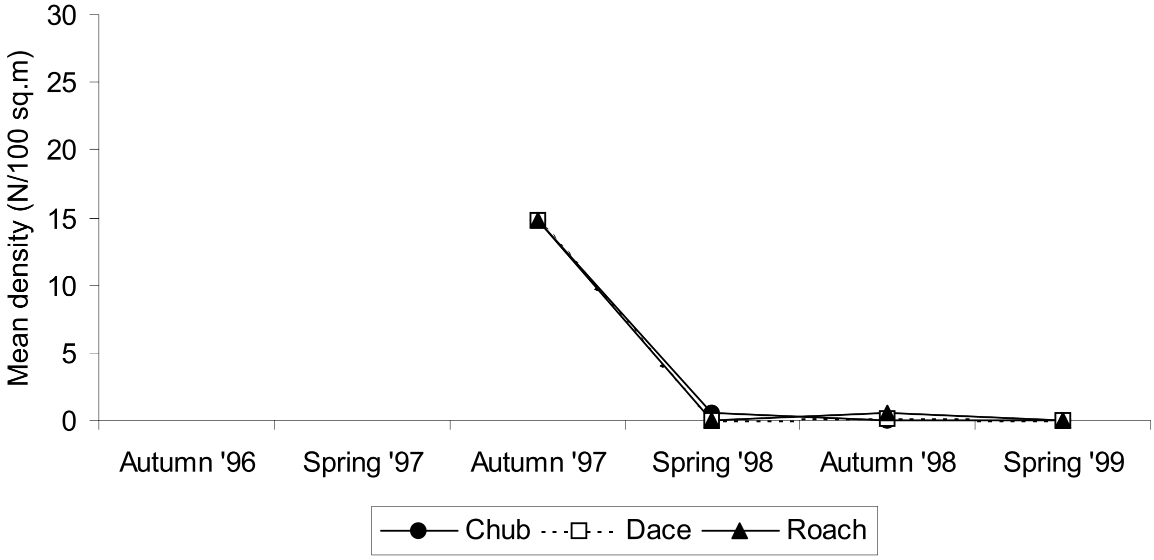

Figure C.15: Persistence of stocked fish in River Lostock; fish stocked as Autumn 2+

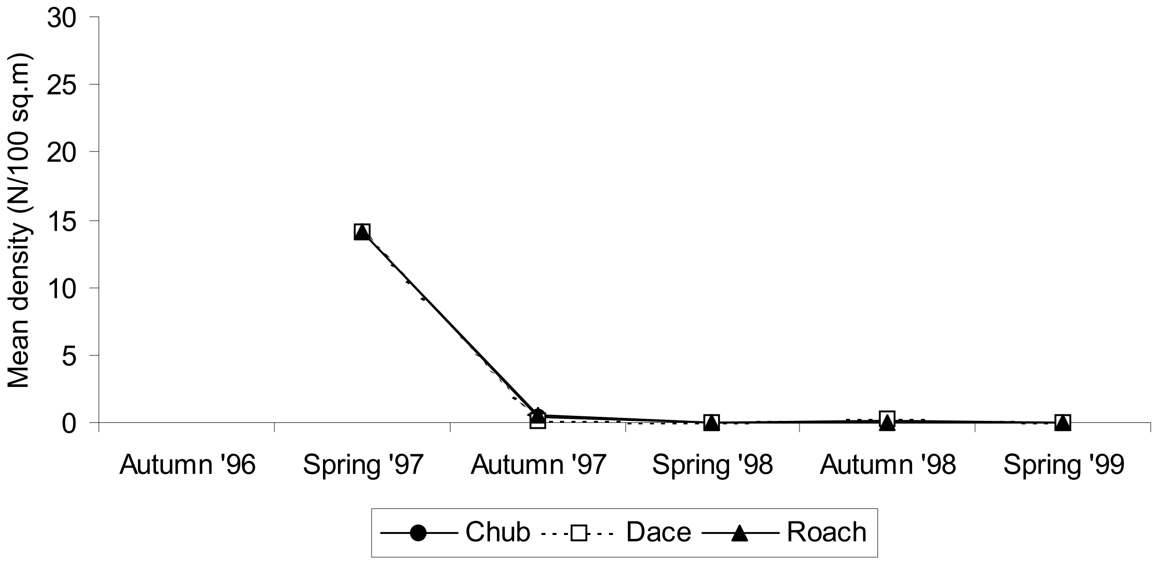

Figure C.16: Persistence of stocked fish in River Lostock; fish stocked as Spring 2+

APPENDIX D PERSISTENCE AND DISPERSAL OF STOCKED FISH

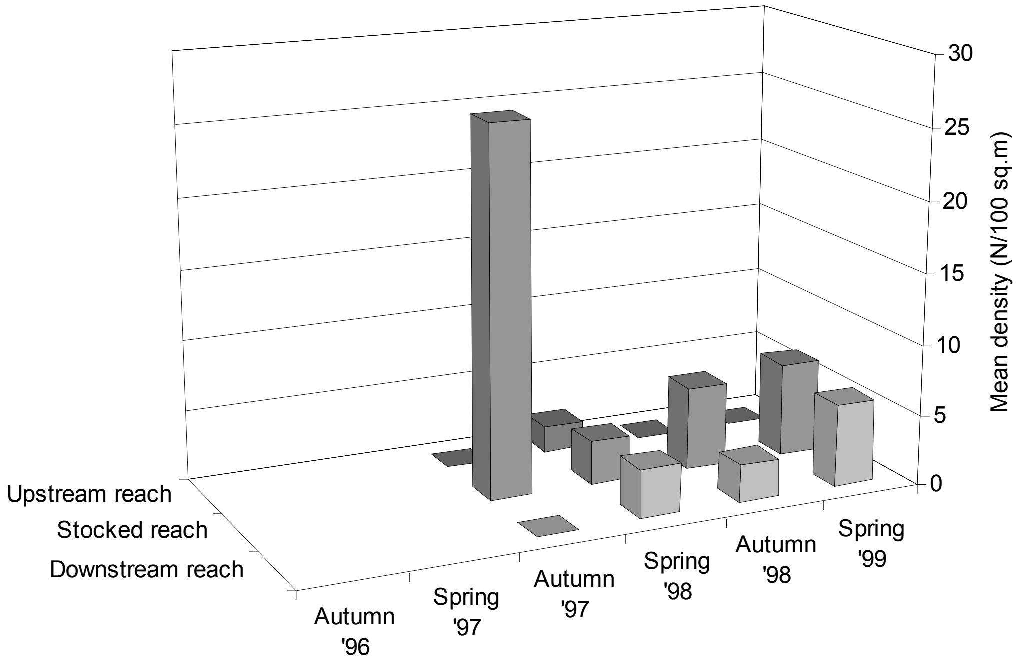

Figure D.1: **Persistence & dispersal of stocked fish in River Alderbourne; Chub stocked as Autumn 1+**

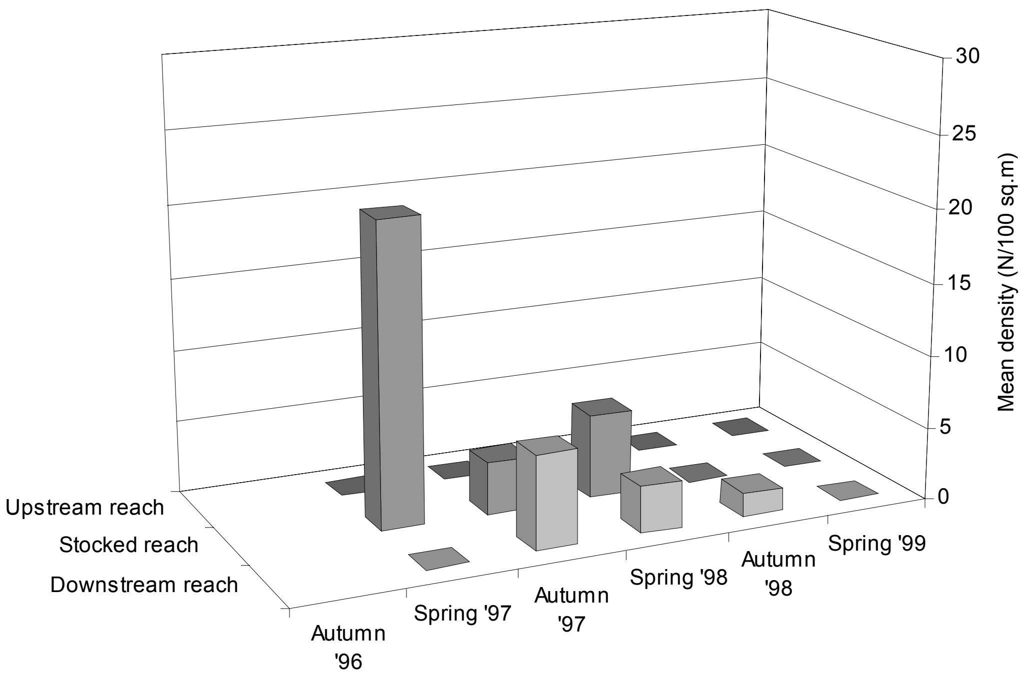

Figure D.2: **Persistence & dispersal of stocked fish in River Alderbourne; Chub stocked as Spring 1+**

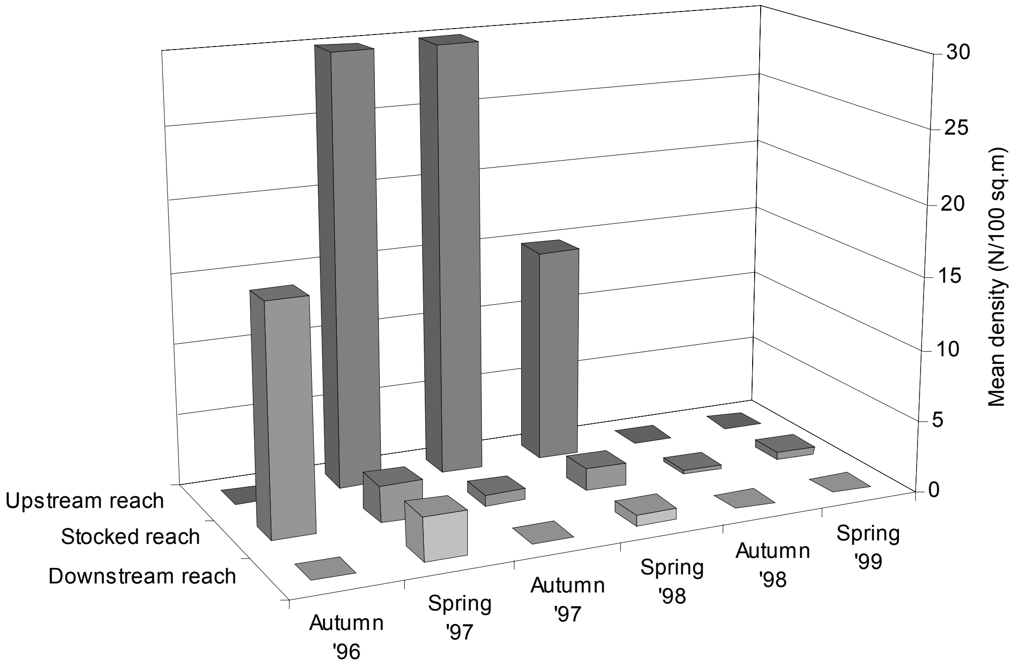

Figure D.3: **Persistence & dispersal of stocked fish in River Alderbourne; Chub stocked as Autumn 2+**

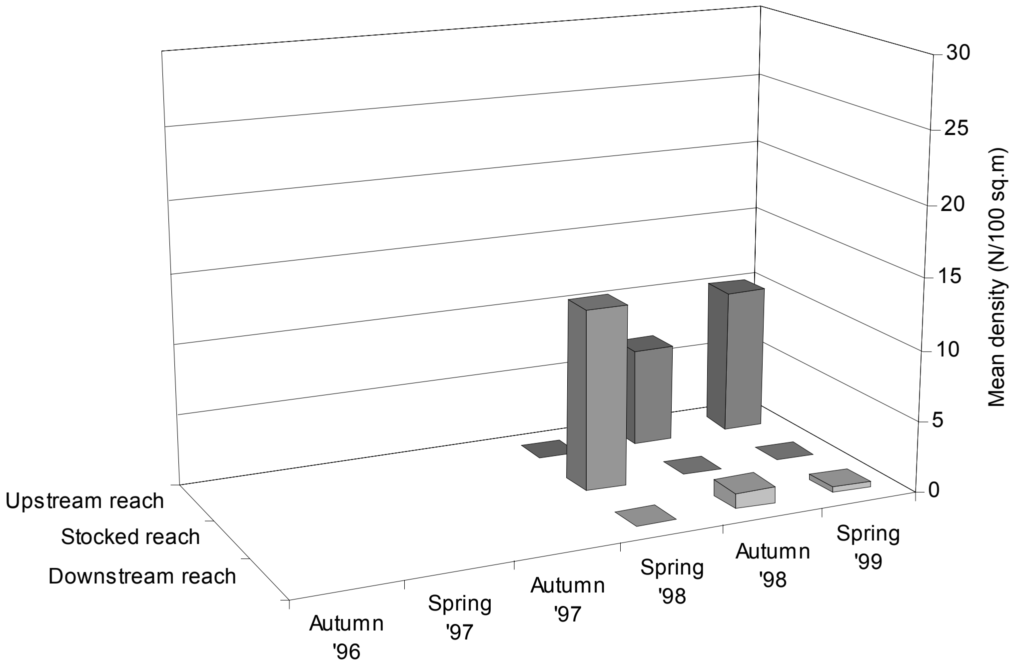

Figure D.4: **Persistence & dispersal of stocked fish in River Alderbourne; Chub stocked as Spring 2+**

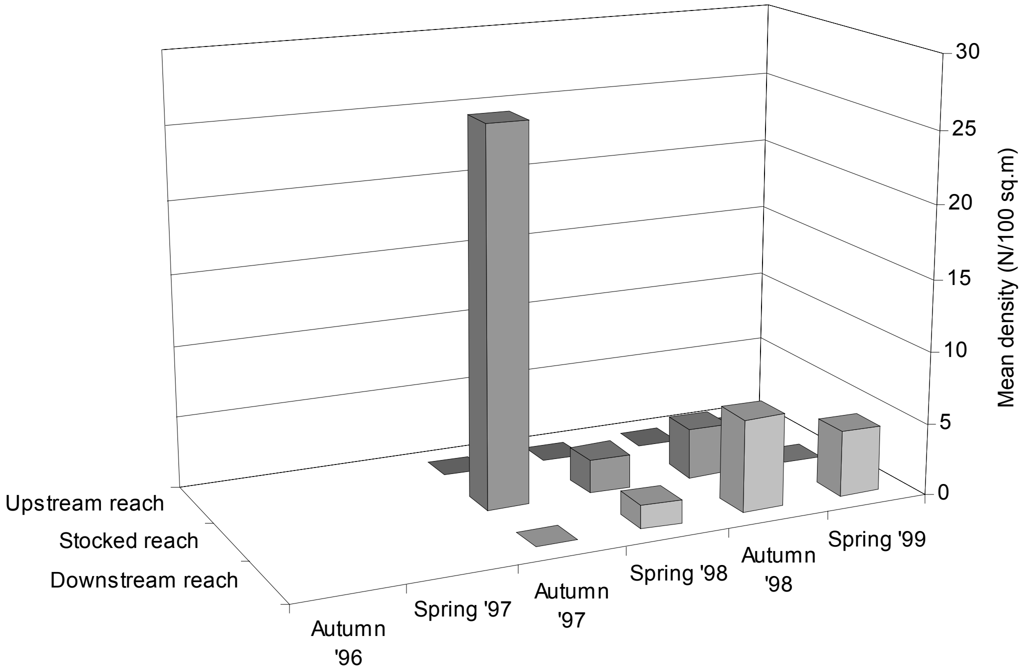

Figure D.5: Persistence & dispersal of stocked fish in River Alderbourne; Dace stocked as Autumn 1+

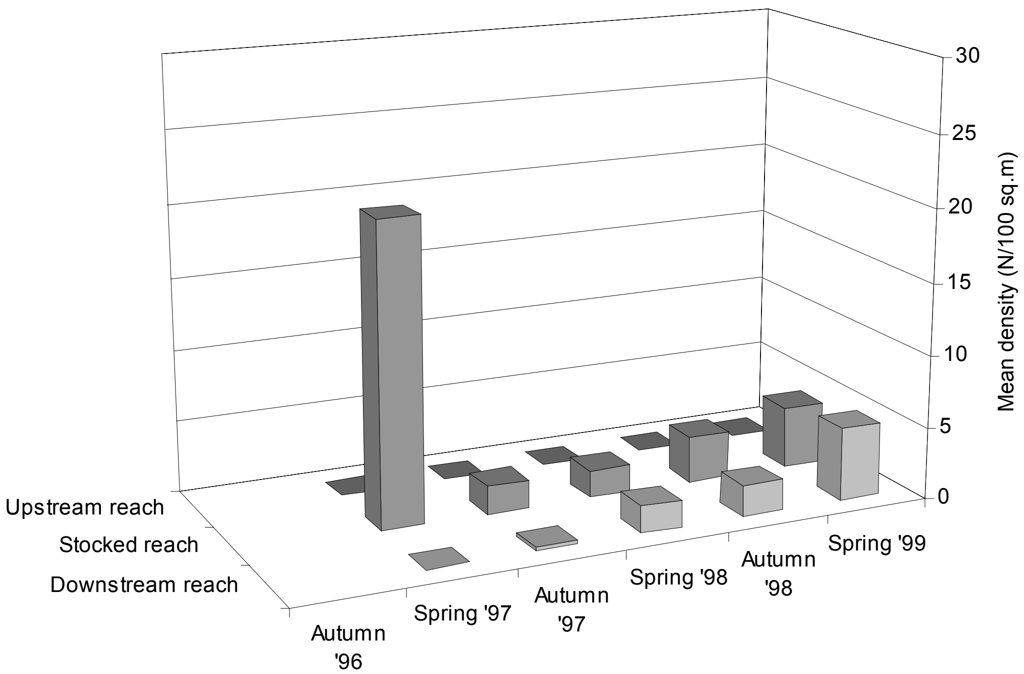

Figure D.6: Persistence & dispersal of stocked fish in River Alderbourne; Dace stocked as Spring 1+

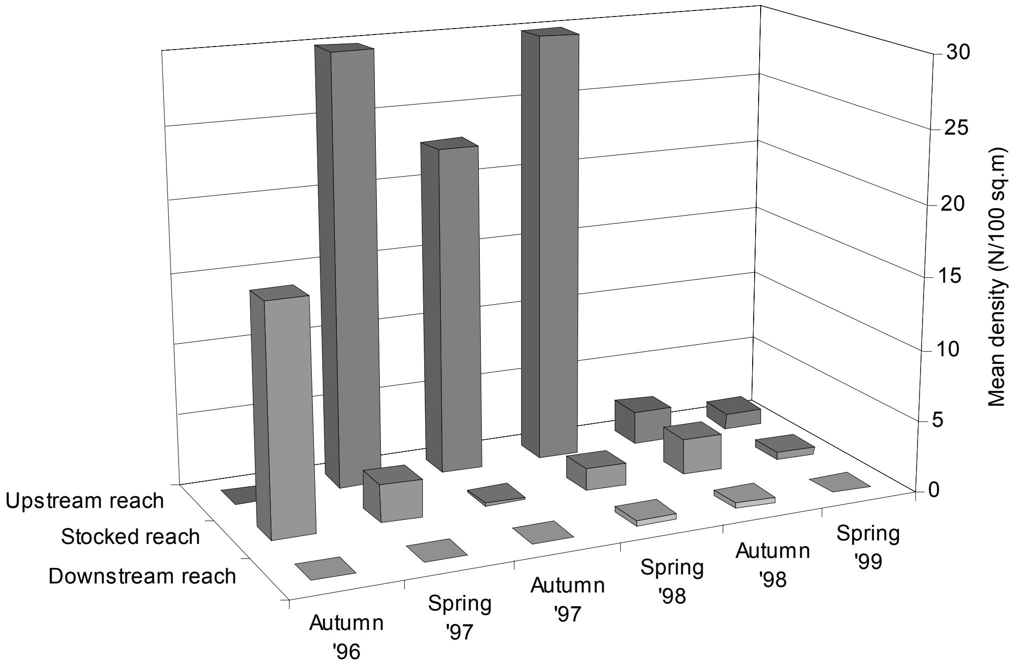

Figure D.7: Persistence & dispersal of stocked fish in River Alderbourne; Dace stocked as Autumn 2+

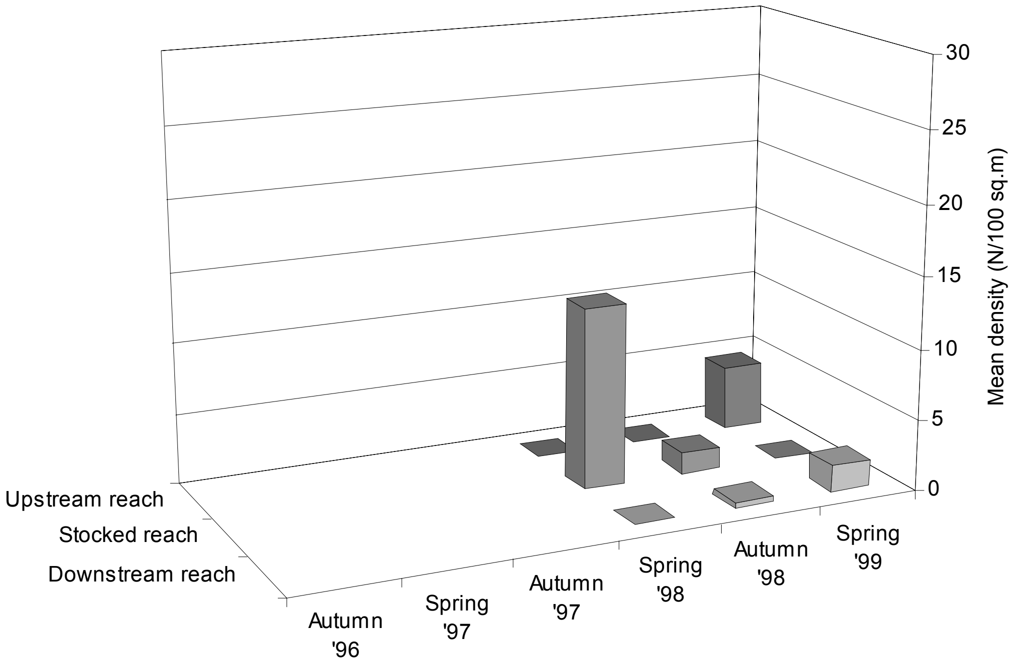

Figure D.8: Persistence & dispersal of stocked fish in River Alderbourne; Dace stocked as Spring 2+

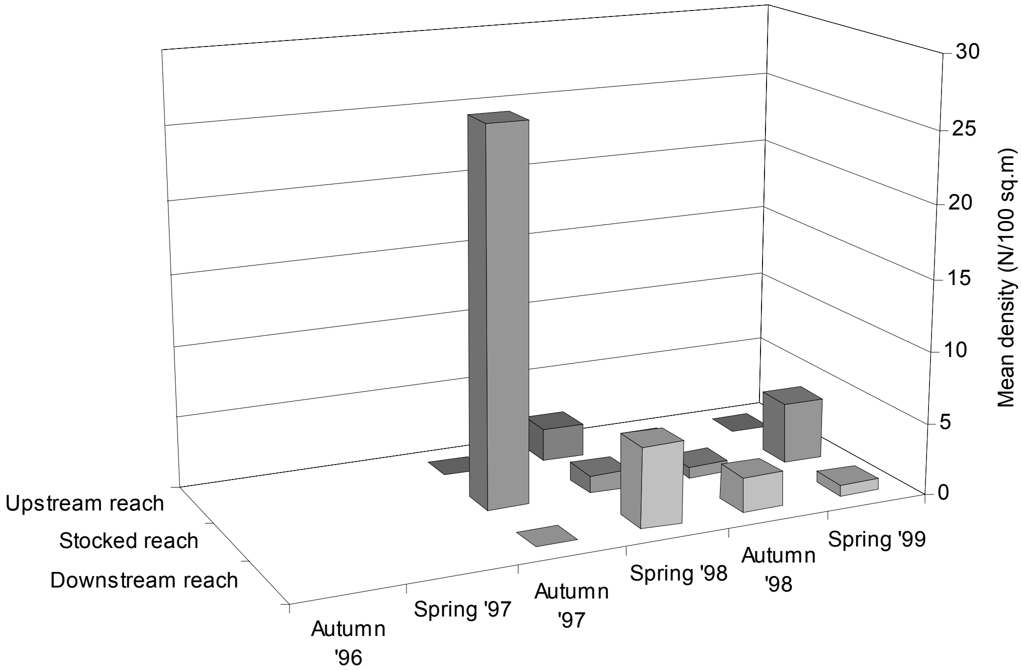

Figure D.9: **Persistence & dispersal of stocked fish in River Alderbourne; Roach stocked as Autumn 1+**

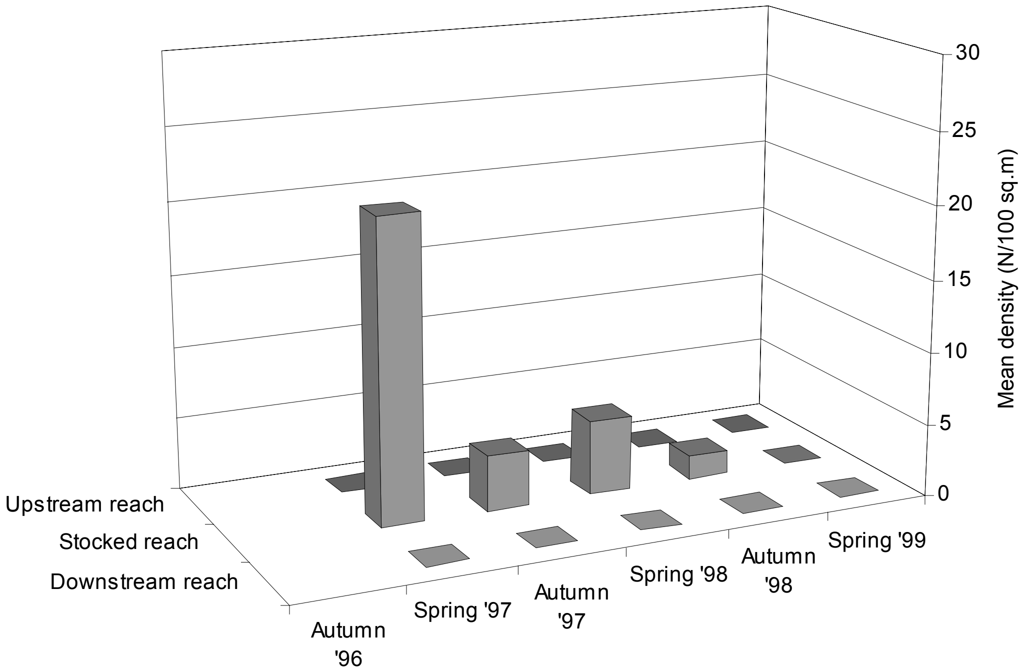

Figure D.10: **Persistence & dispersal of stocked fish in River Alderbourne; Roach stocked as Spring 1+**

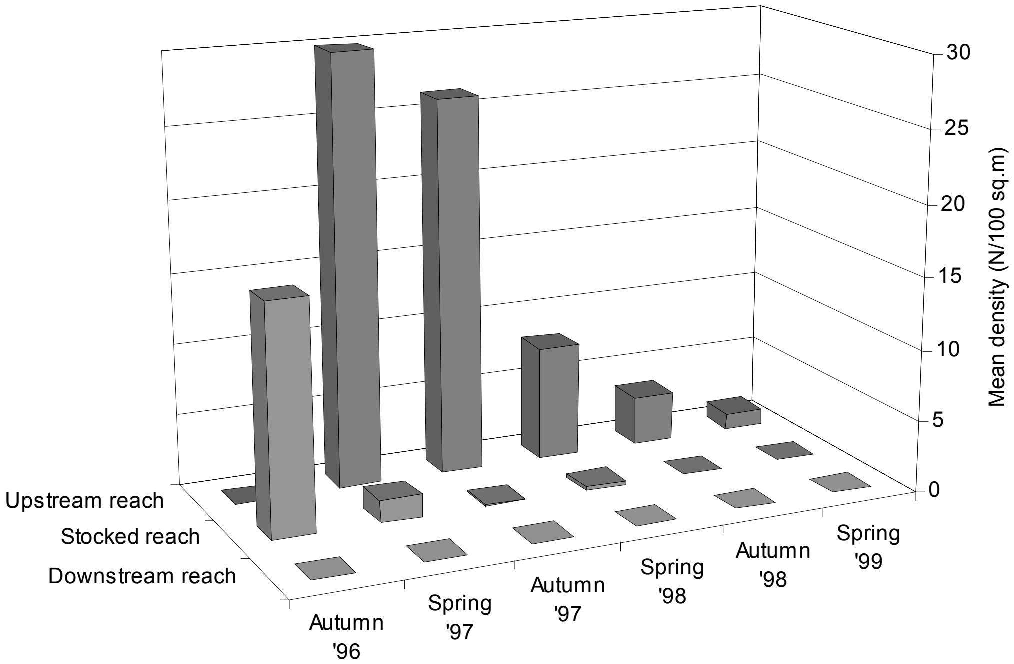

Figure D.11: Persistence & dispersal of stocked fish in River Alderbourne; Roach stocked as Autumn 2+

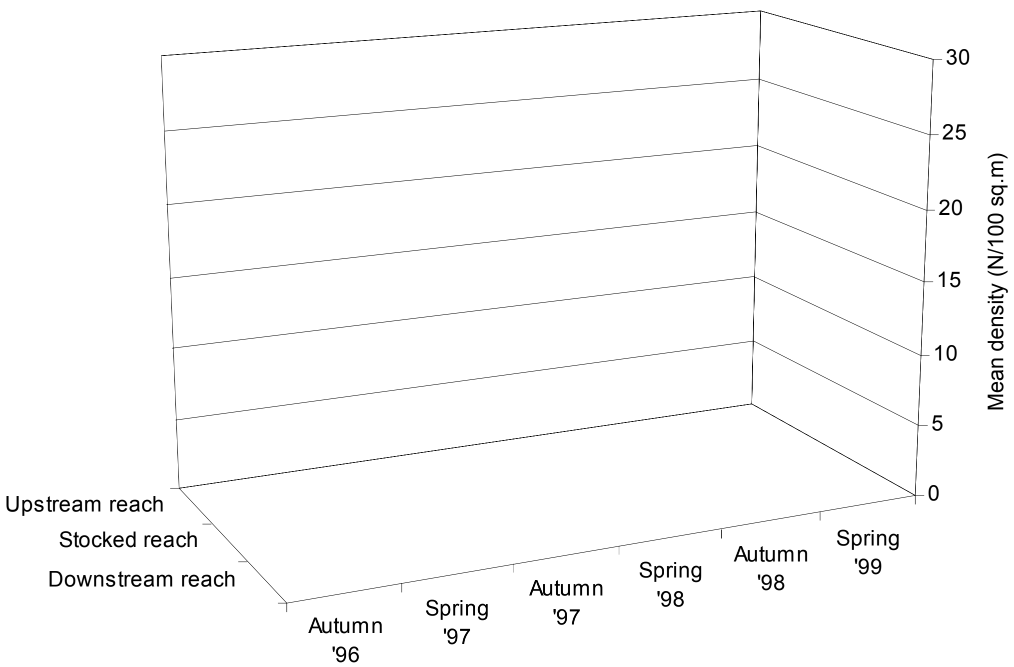

Figure D.12: Persistence & dispersal of stocked fish in River Alderbourne; Roach stocked as Spring 2+ (NB fish not available for stocking)

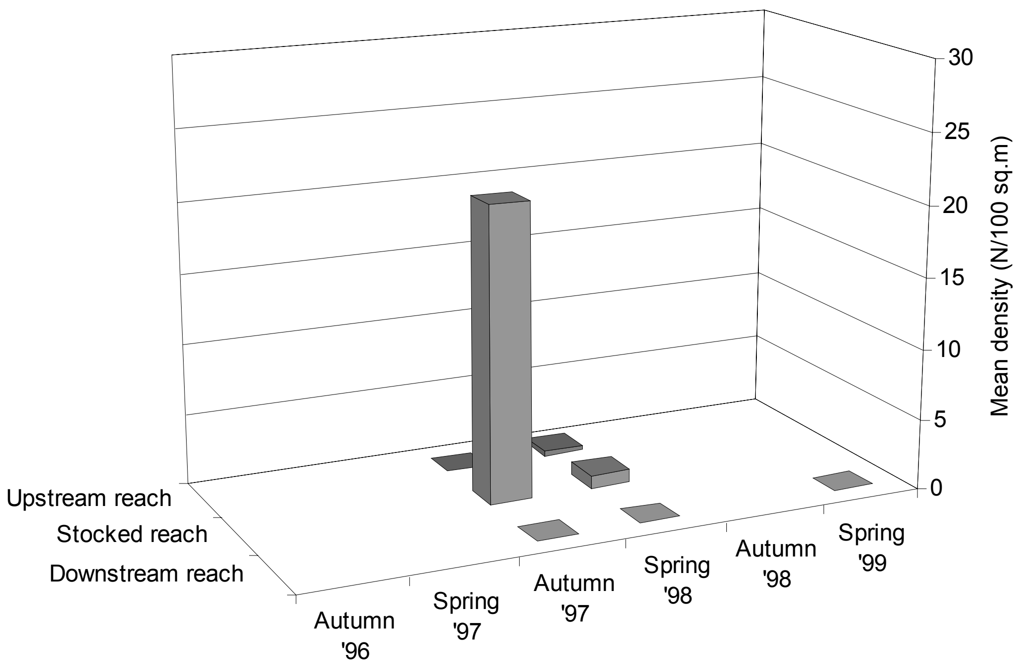

Figure D.13: Persistence & dispersal of stocked fish in River Cherwell; Chub stocked as Autumn 1+

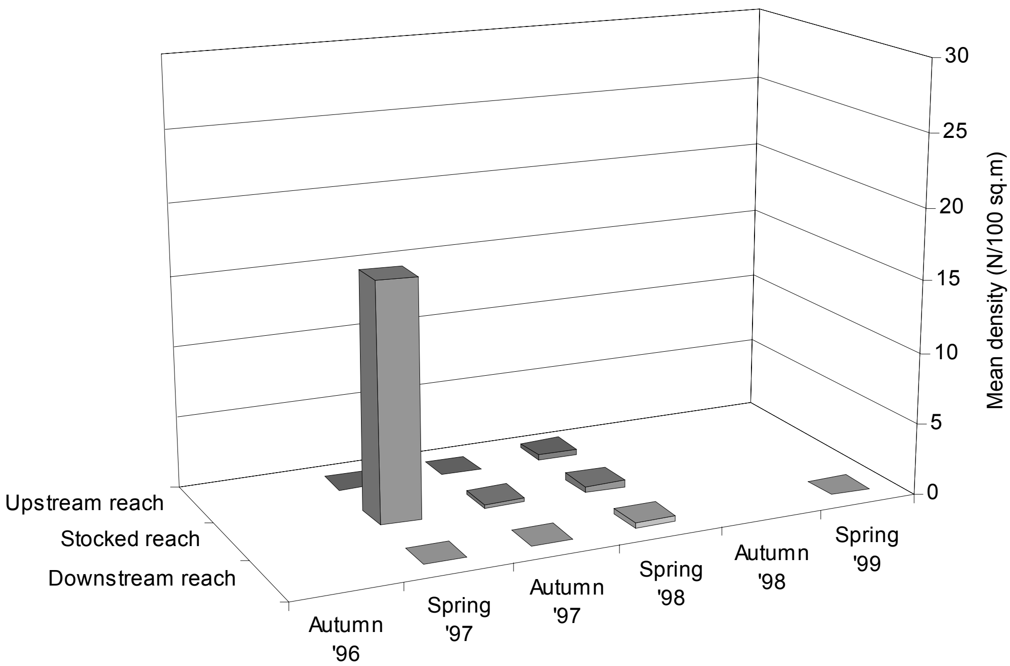

Figure D.14: Persistence & dispersal of stocked fish in River Cherwell; Chub stocked as Spring 1+

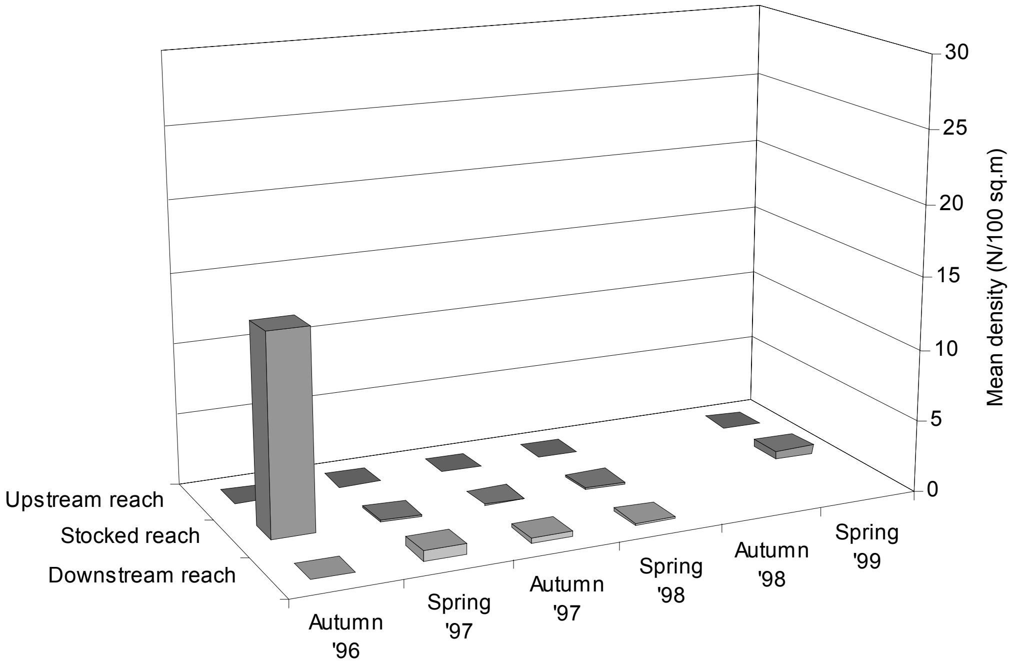

Figure D.15: Persistence & dispersal of stocked fish in River Cherwell; Chub stocked as Autumn 2+

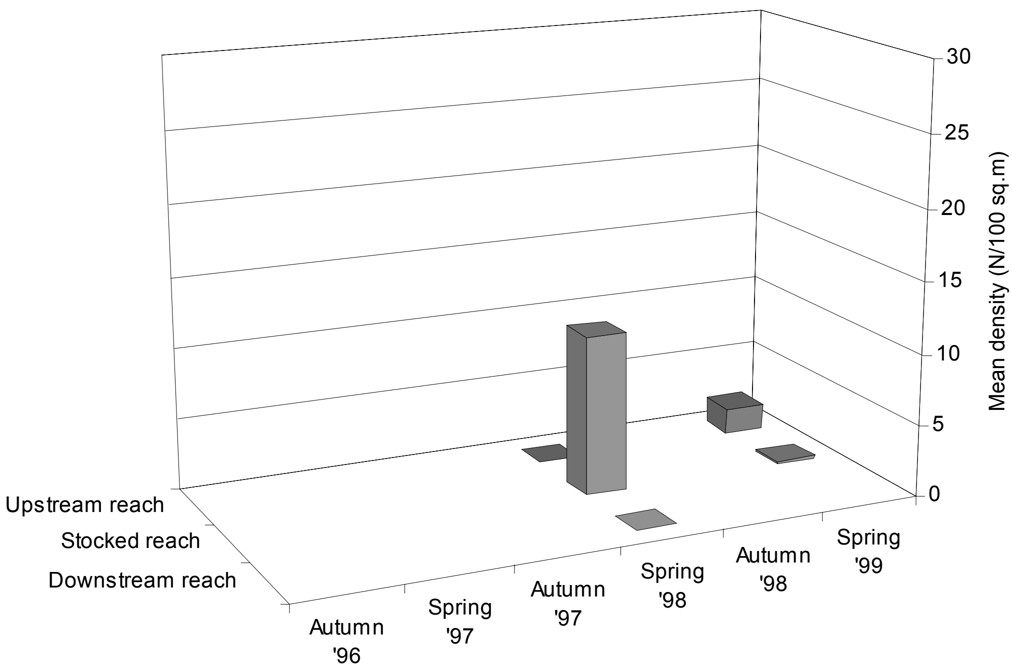

Figure D.16: Persistence & dispersal of stocked fish in River Cherwell; Chub stocked as Spring 2+

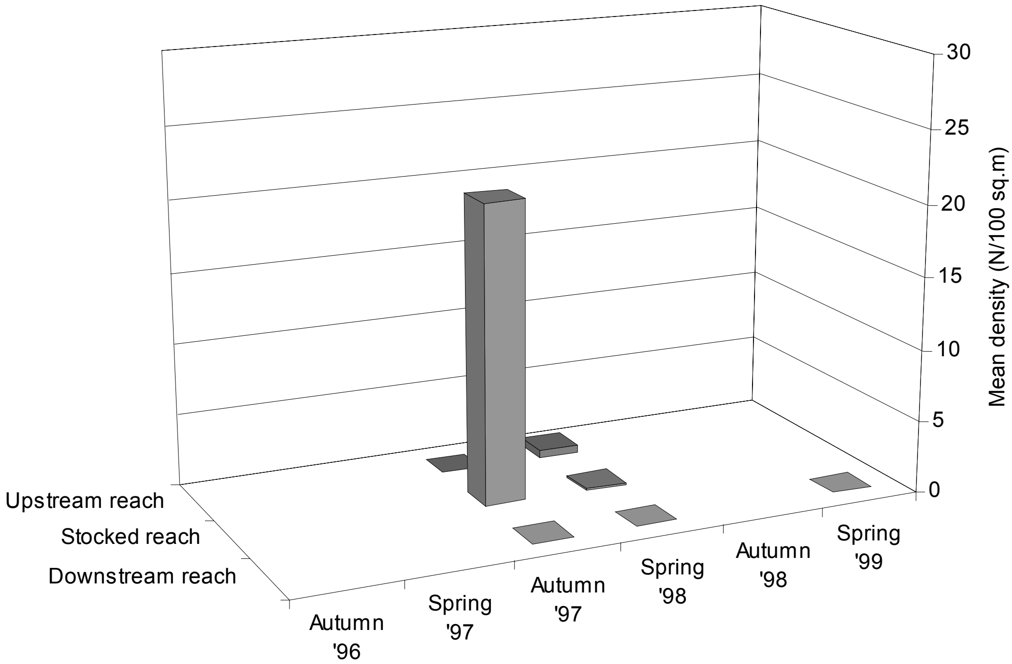

Figure D.17: Persistence & dispersal of stocked fish in River Cherwell; Dace stocked as Autumn 1+

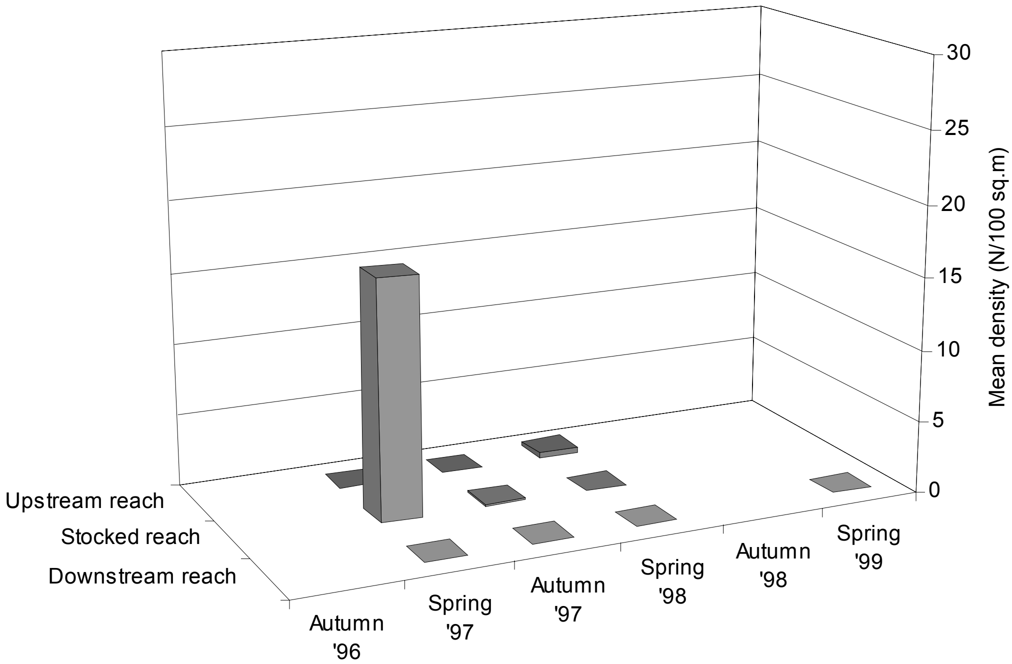

Figure D.18: Persistence & dispersal of stocked fish in River Cherwell; Dace stocked as Spring 1+

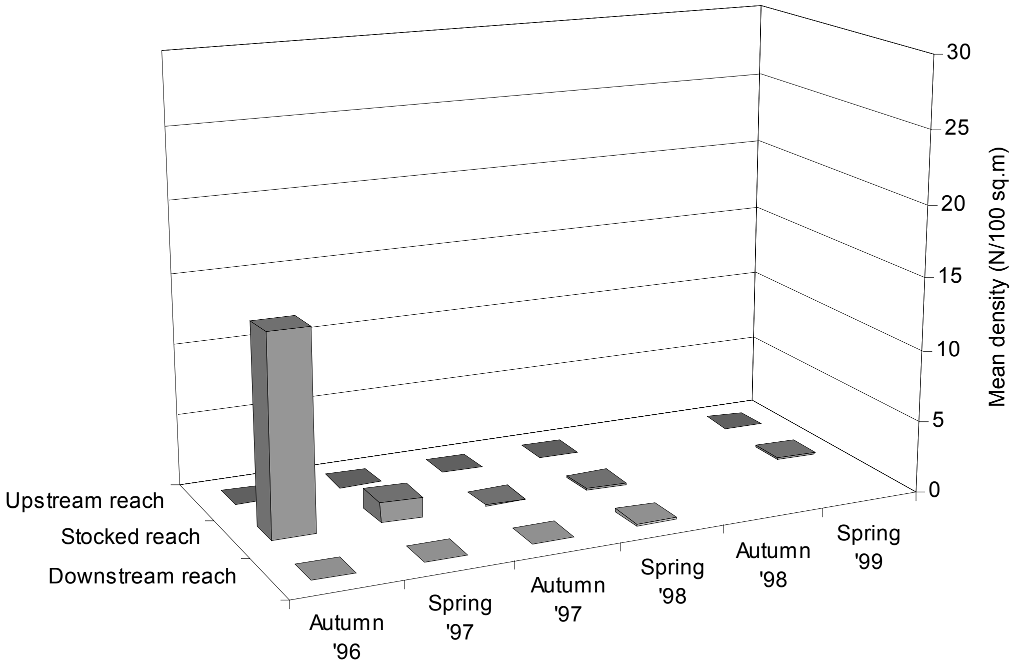

Figure D.19: Persistence & dispersal of stocked fish in River Cherwell; Dace stocked as Autumn 2+

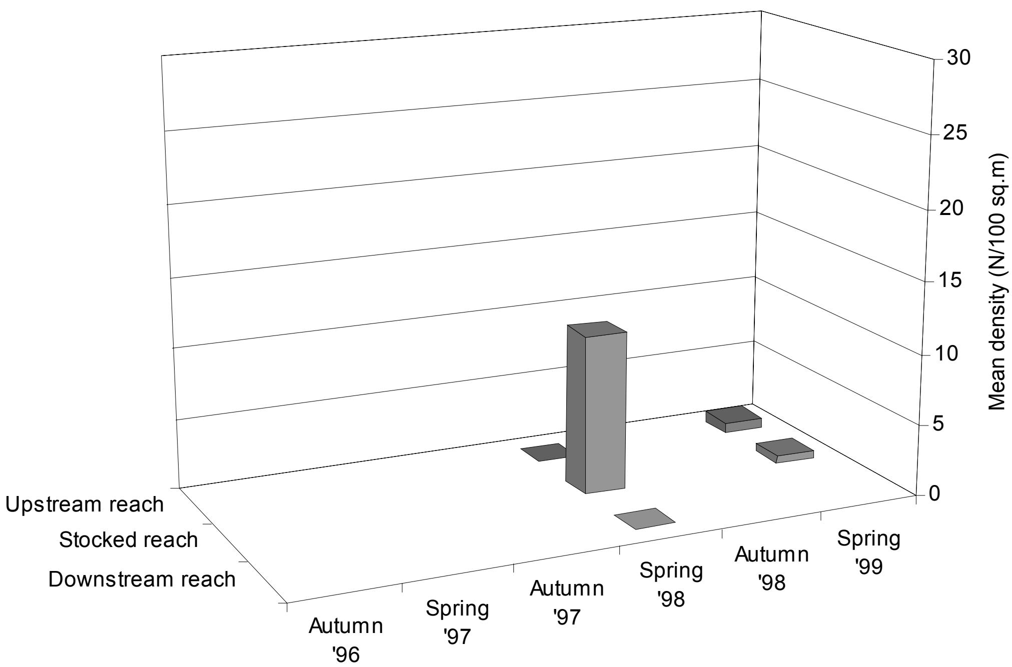

Figure D.20: Persistence & dispersal of stocked fish in River Cherwell; Dace stocked as Spring 2+

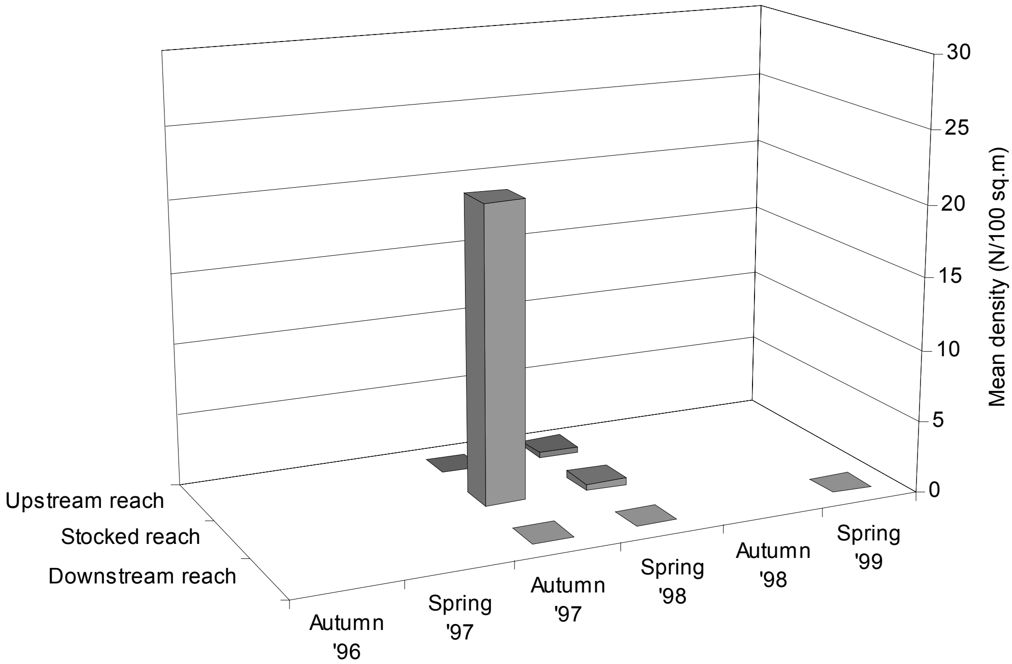

Figure D.21 Persistence & dispersal of stocked fish in River Cherwell; Roach stocked as Autumn 1+

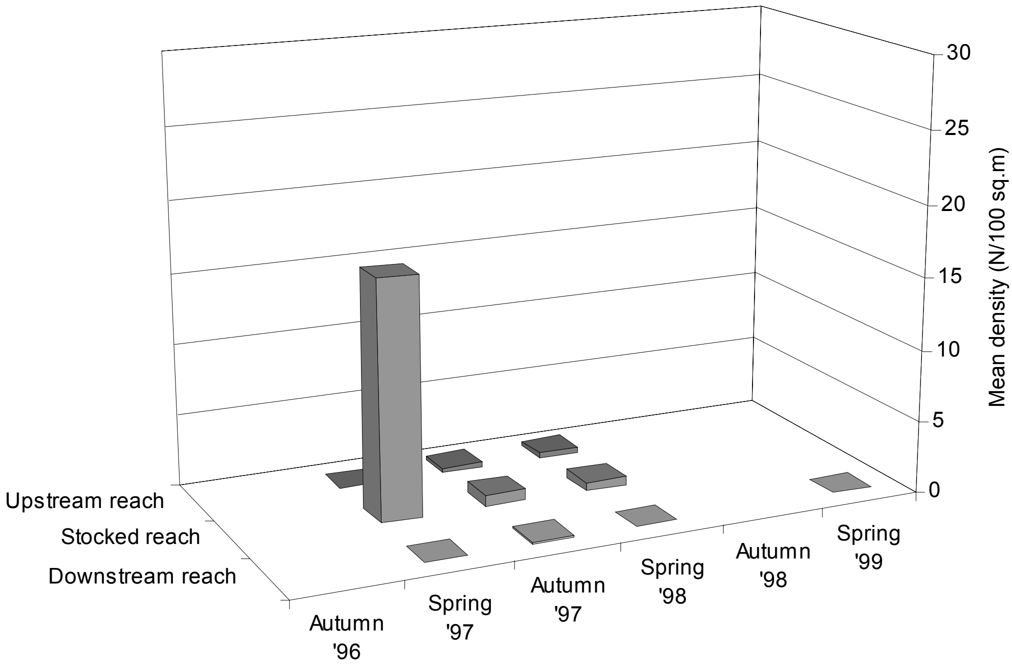

Figure D.22: Persistence & dispersal of stocked fish in River Cherwell; Roach stocked as Spring 1+

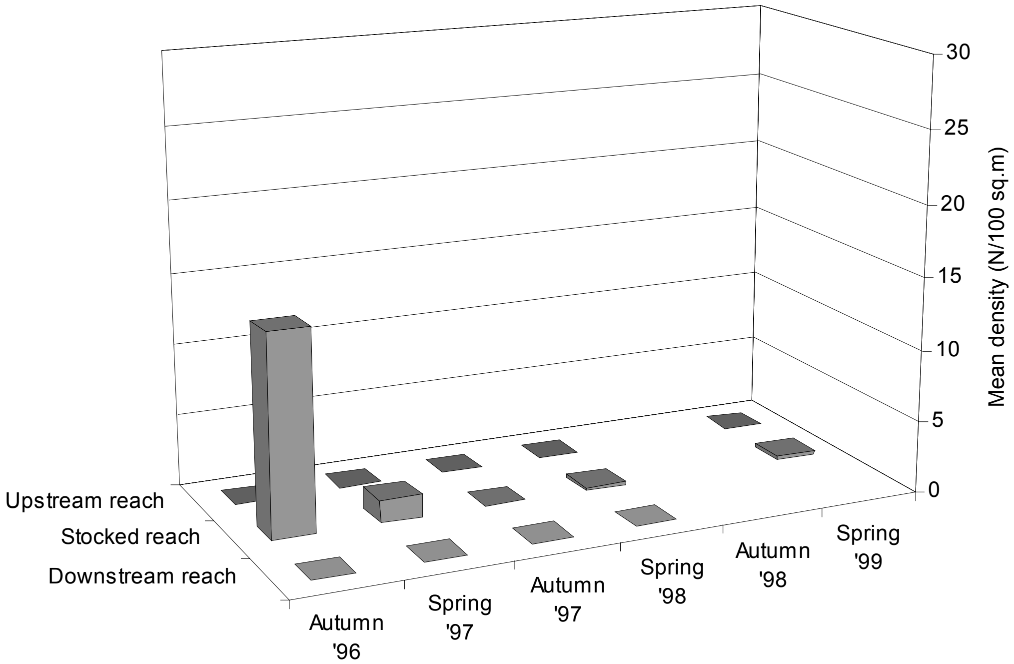

Figure D.23: Persistence & dispersal of stocked fish in River Cherwell; Roach stocked as Autumn 2+

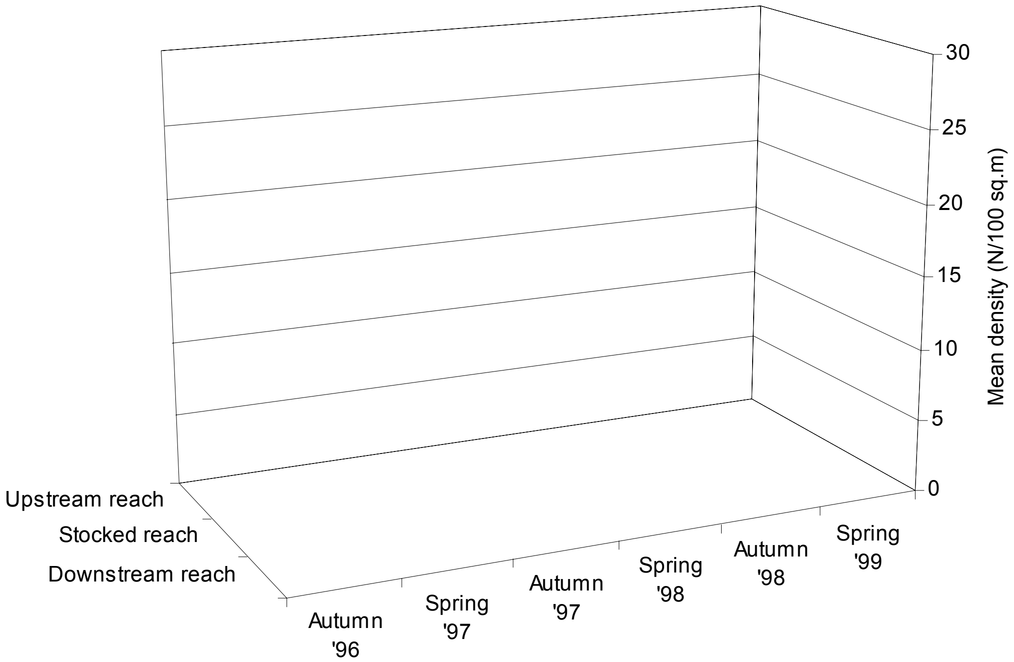

Figure D.24: Persistence & dispersal of stocked fish in River Cherwell; Roach stocked as Spring 2+(NB fish not available for stocking)

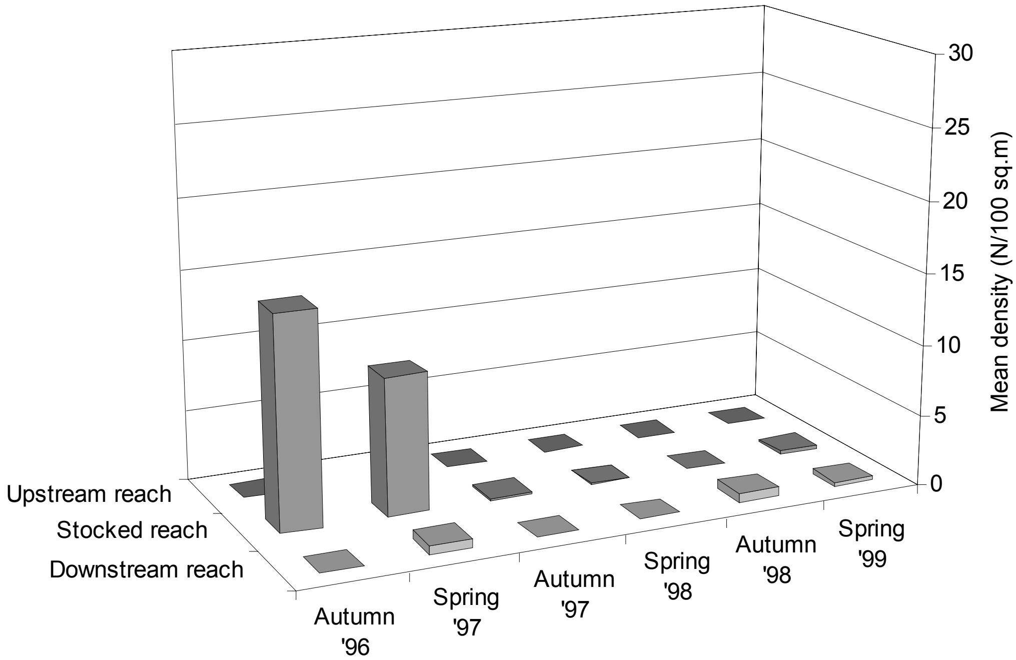

Figure D.25: Persistence & dispersal of stocked fish in River Hogsmill; Chub stocked as Autumn 1+

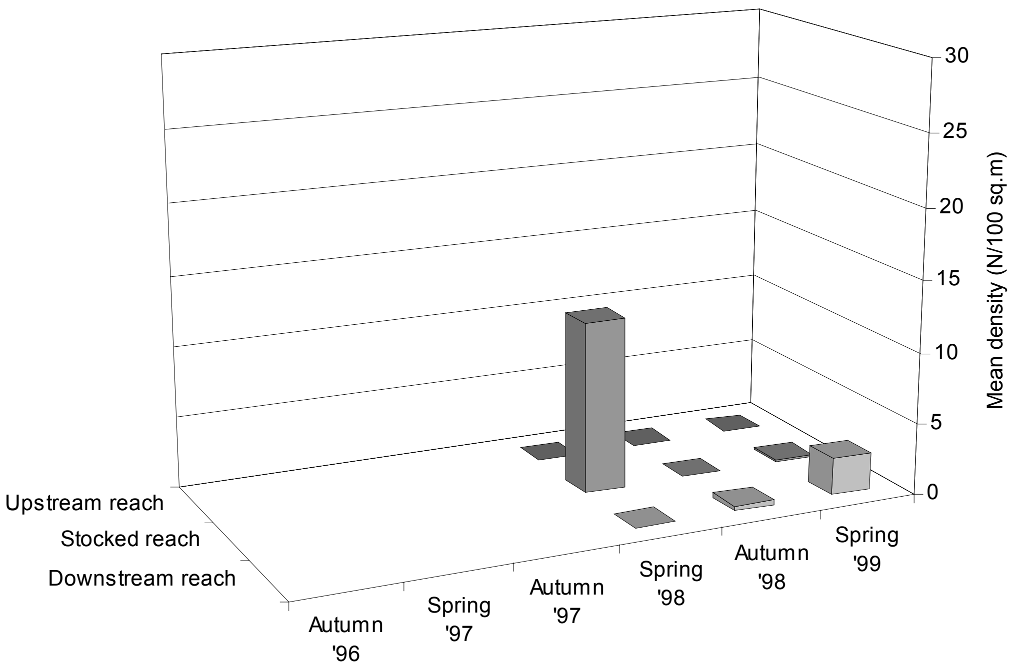

Figure D.26: Persistence & dispersal of stocked fish in River Hogsmill; Chub stocked as Spring 1+

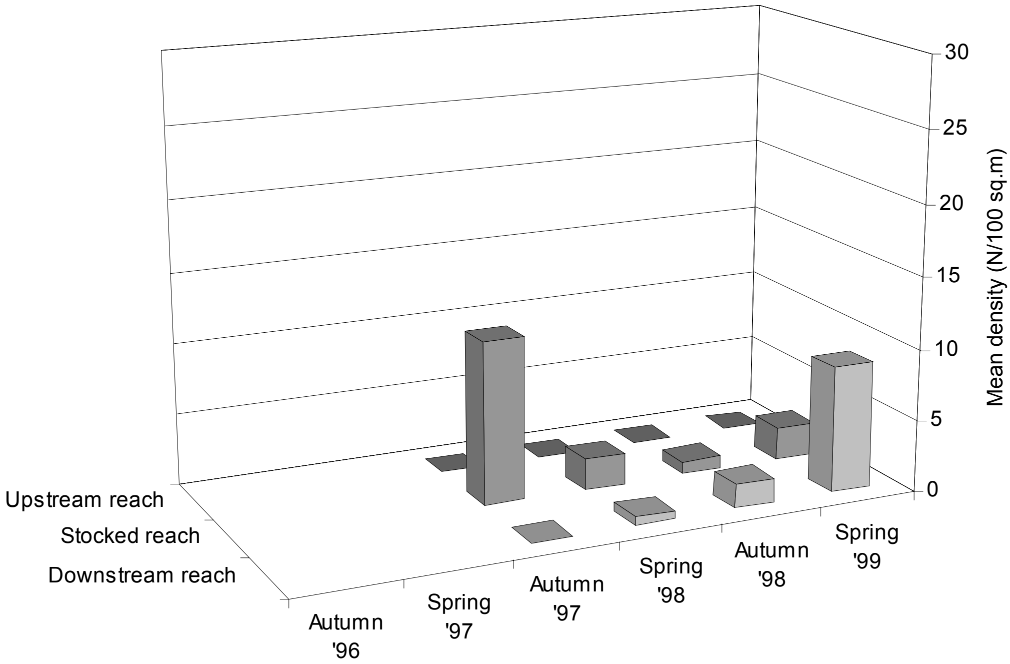

Figure D.27: Persistence & dispersal of stocked fish in River Hogsmill; Chub stocked as Autumn 2+

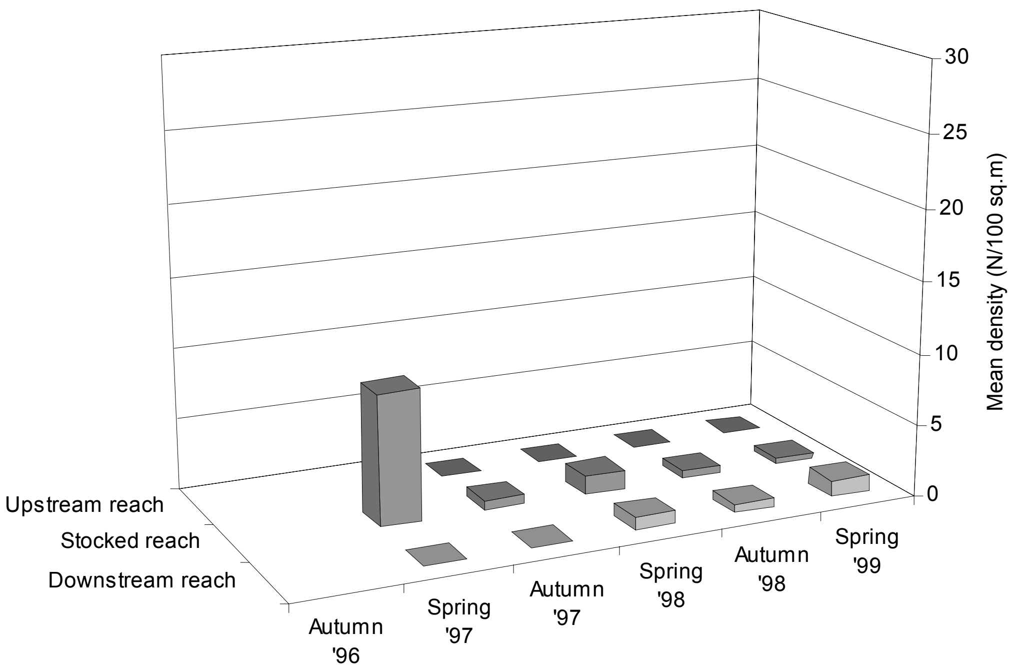

Figure D.28: Persistence & dispersal of stocked fish in River Hogsmill; Chub stocked as Spring 2+

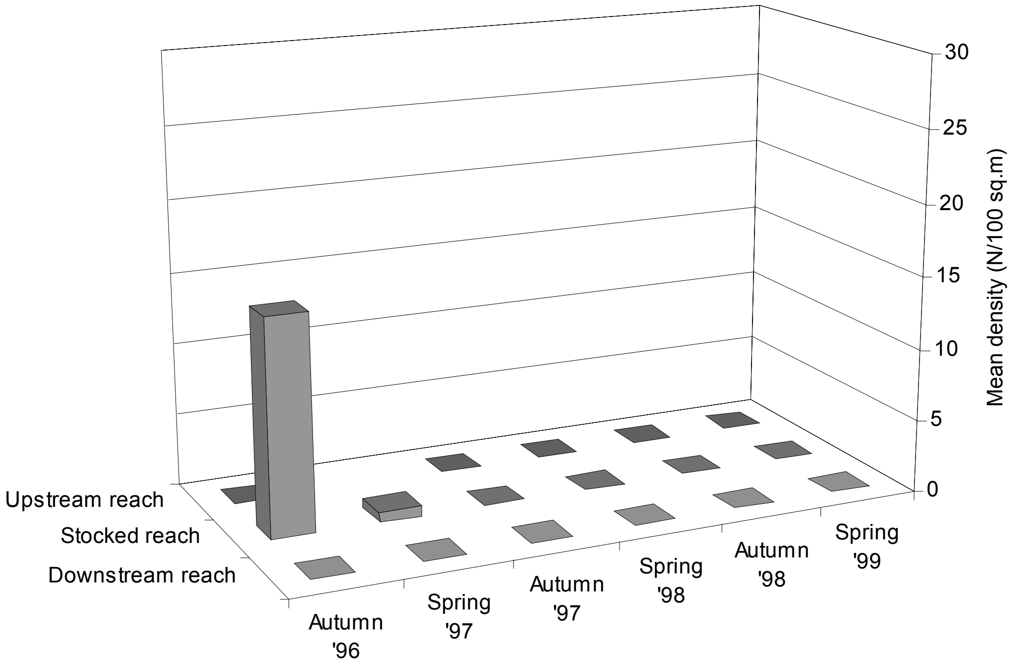

Figure D.29: Persistence & dispersal of stocked fish in River Hogsmill; Dace stocked as Autumn 1+

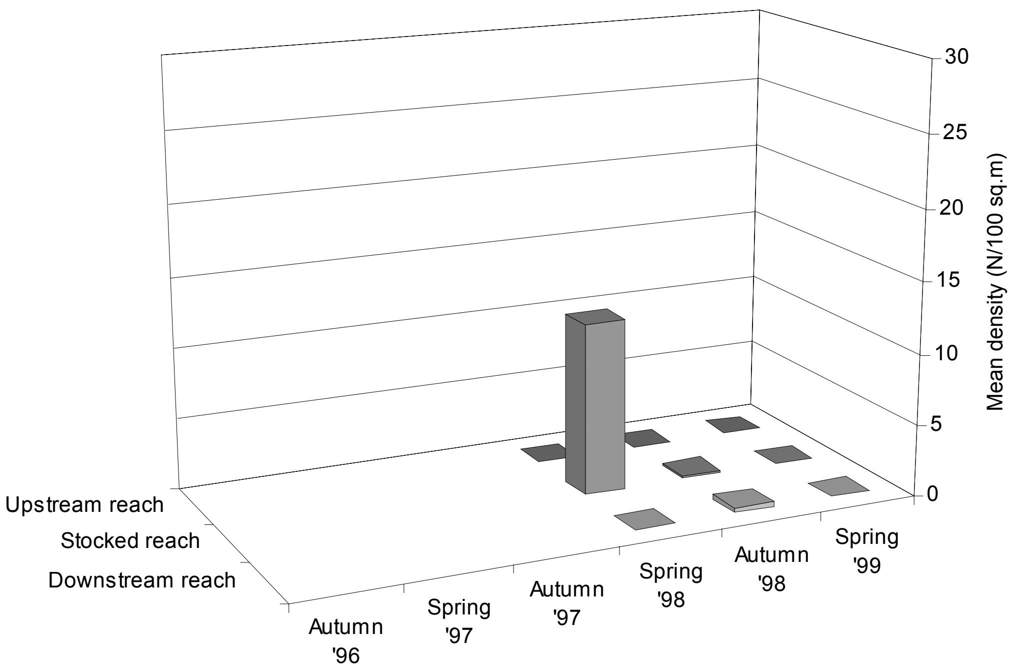

Figure D.30: Persistence & dispersal of stocked fish in River Hogsmill; Dace stocked as Spring 1+

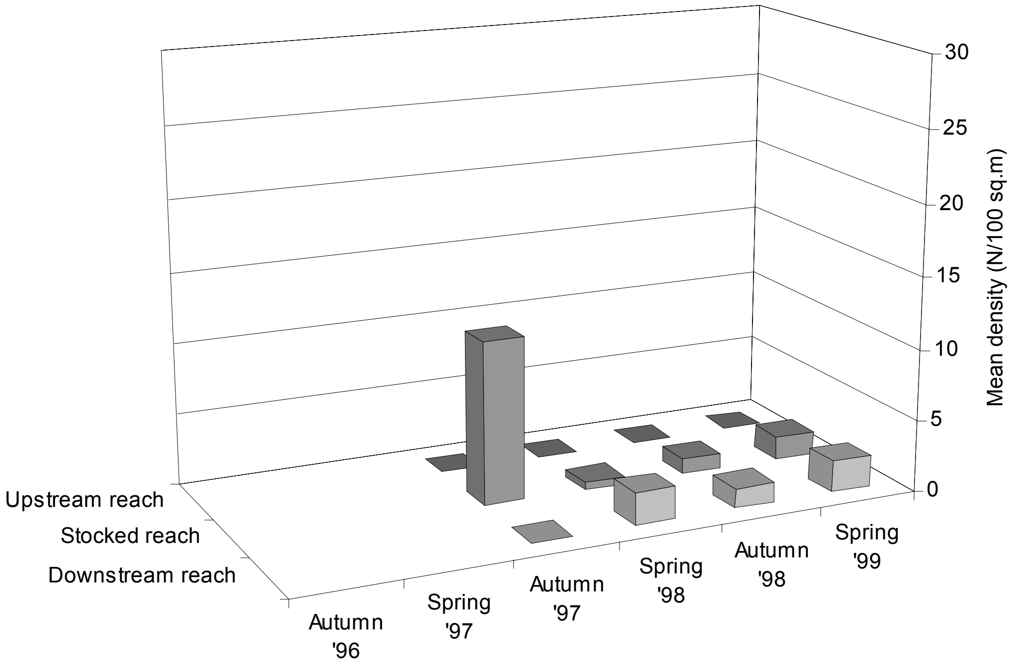

Figure D.31: Persistence & dispersal of stocked fish in River Hogsmill; Dace stocked as Autumn 2+

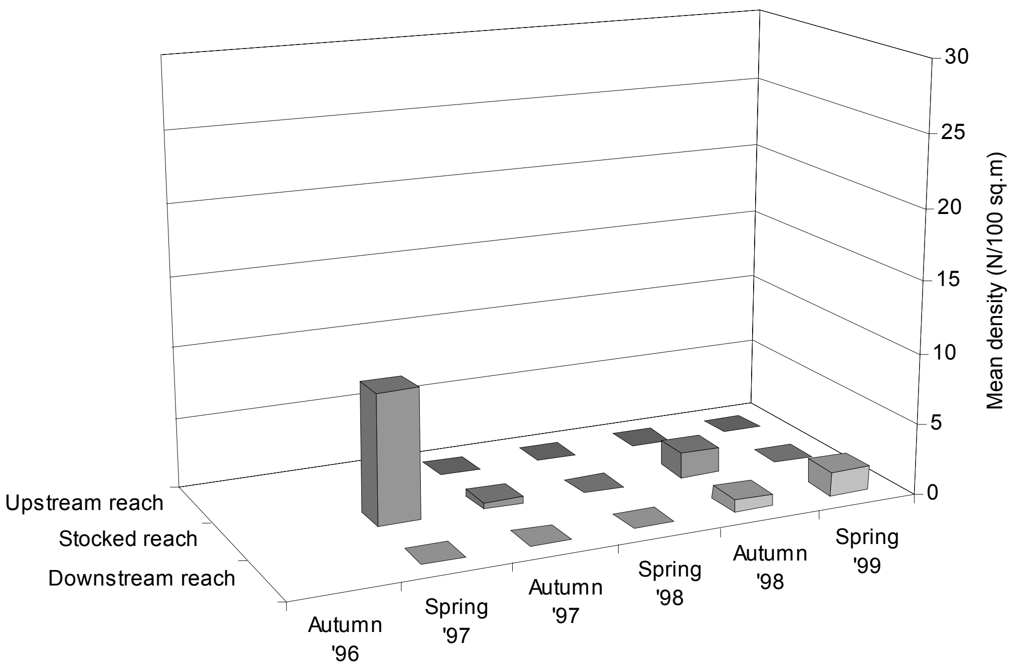

Figure D.32: Persistence & dispersal of stocked fish in River Hogsmill; Dace stocked as Spring 2+

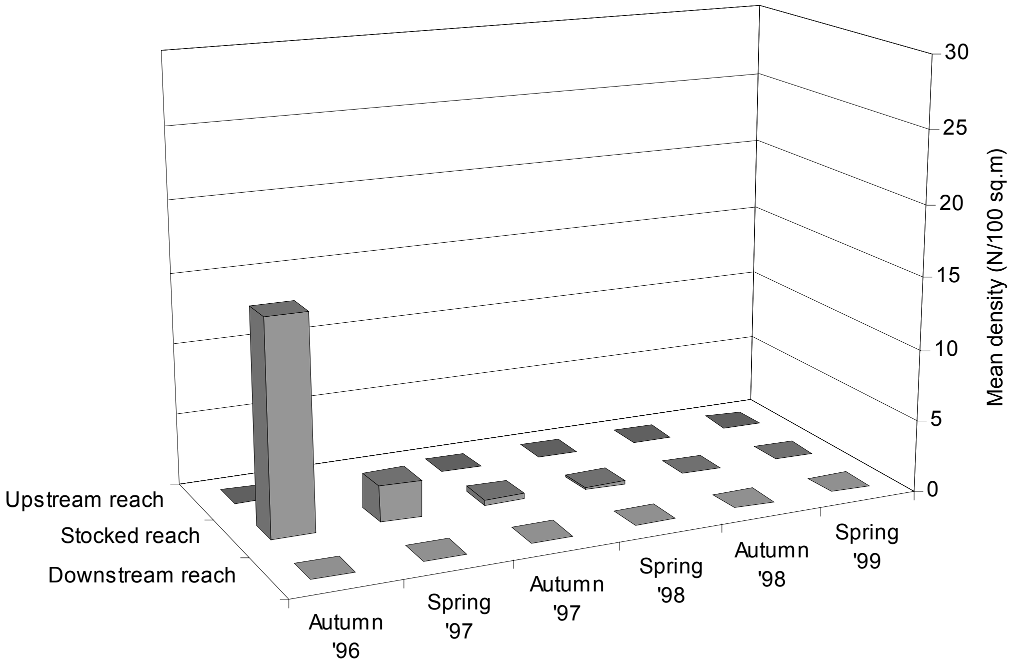

Figure D.33: Persistence & dispersal of stocked fish in River Hogsmill; Roach stocked as Autumn 1+

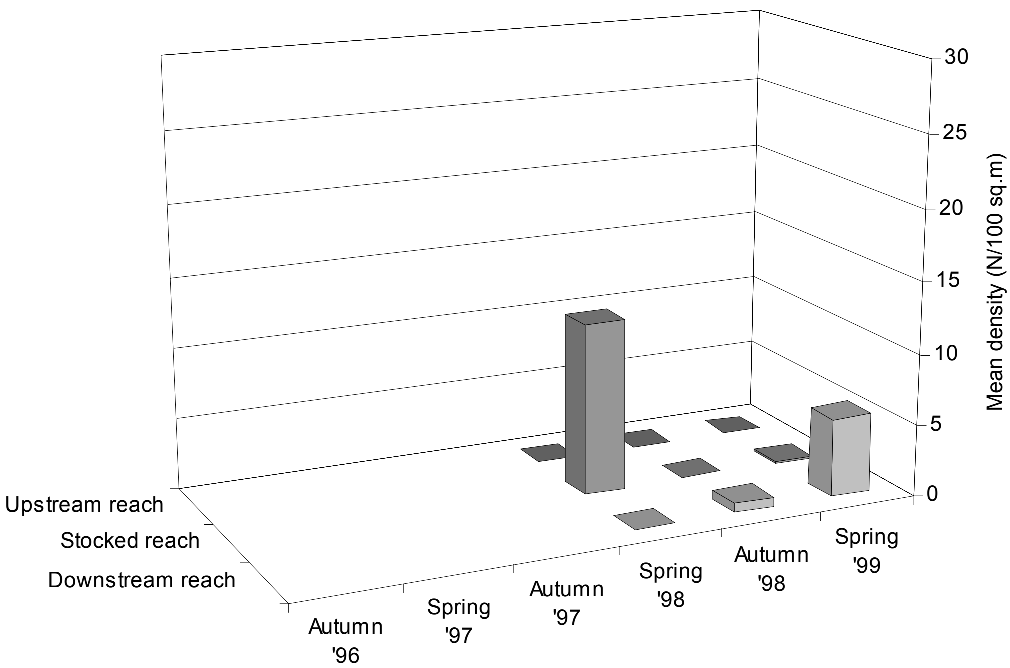

Figure D.34: Persistence & dispersal of stocked fish in River Hogsmill; Roach stocked as Spring 1+

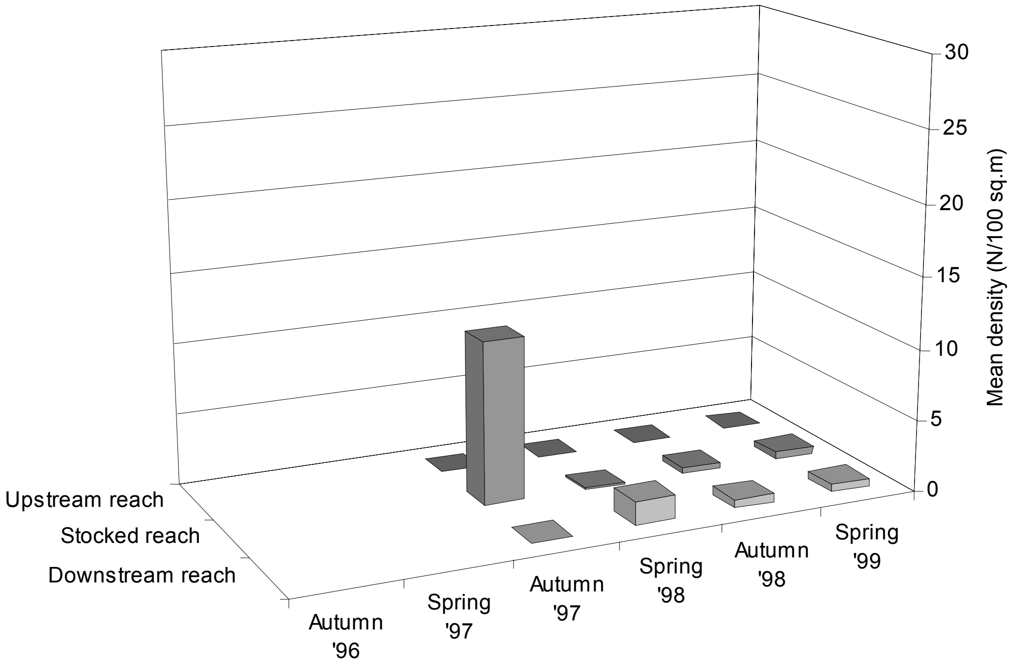

Figure D.35: Persistence & dispersal of stocked fish in River Hogsmill; Roach stocked as Autumn 2+

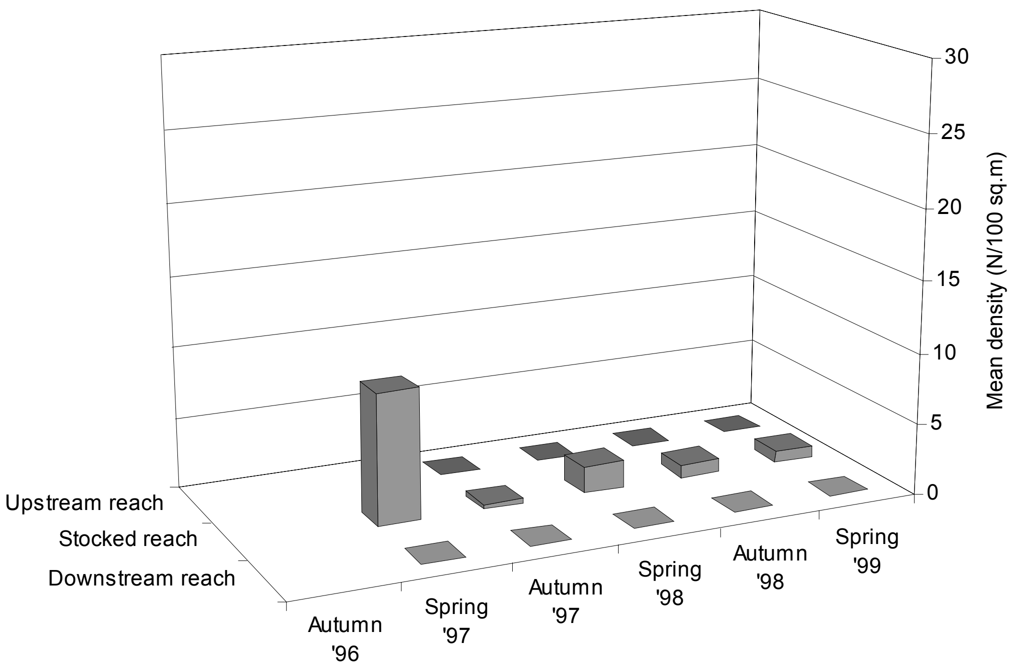

Figure D.36: Persistence & dispersal of stocked fish in River Hogsmill; Roach stocked as Spring 2+

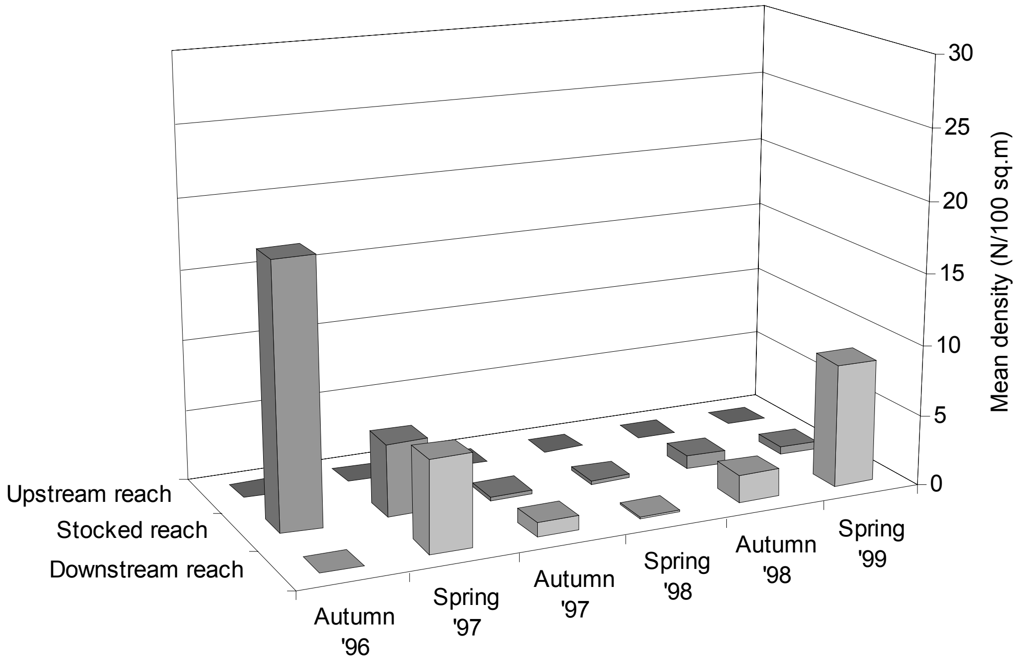

Figure D.37: Persistence & dispersal of stocked fish in River Lostock; Chub stocked as Autumn 1+

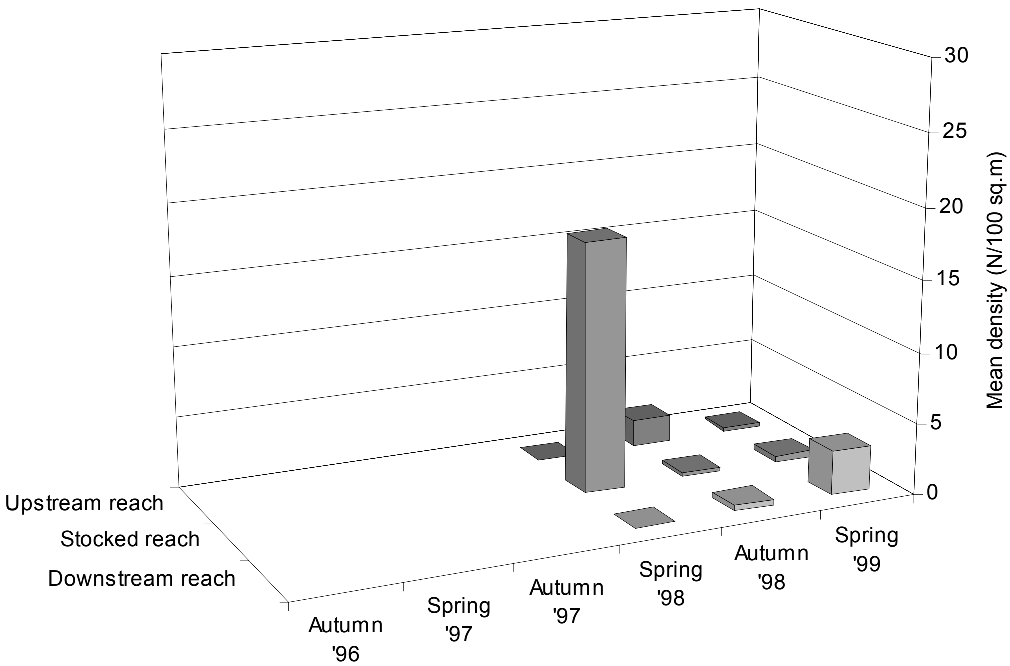

Figure D.38: Persistence & dispersal of stocked fish in River Lostock; Chub stocked as Spring 1+

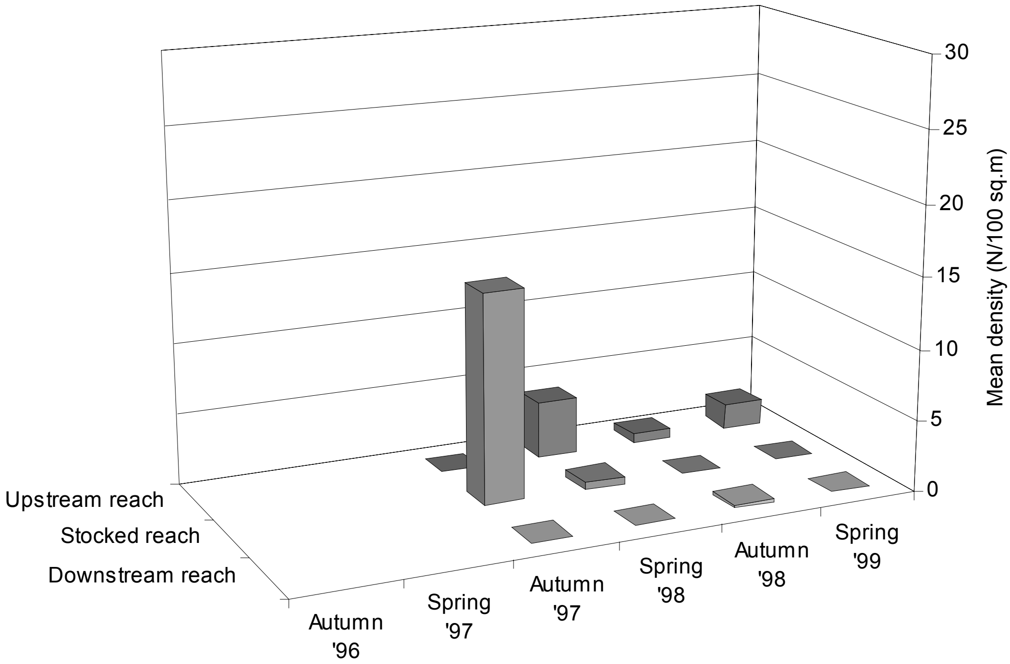

Figure D.39: **Persistence & dispersal of stocked fish in River Lostock; Chub stocked as Autumn 2+**

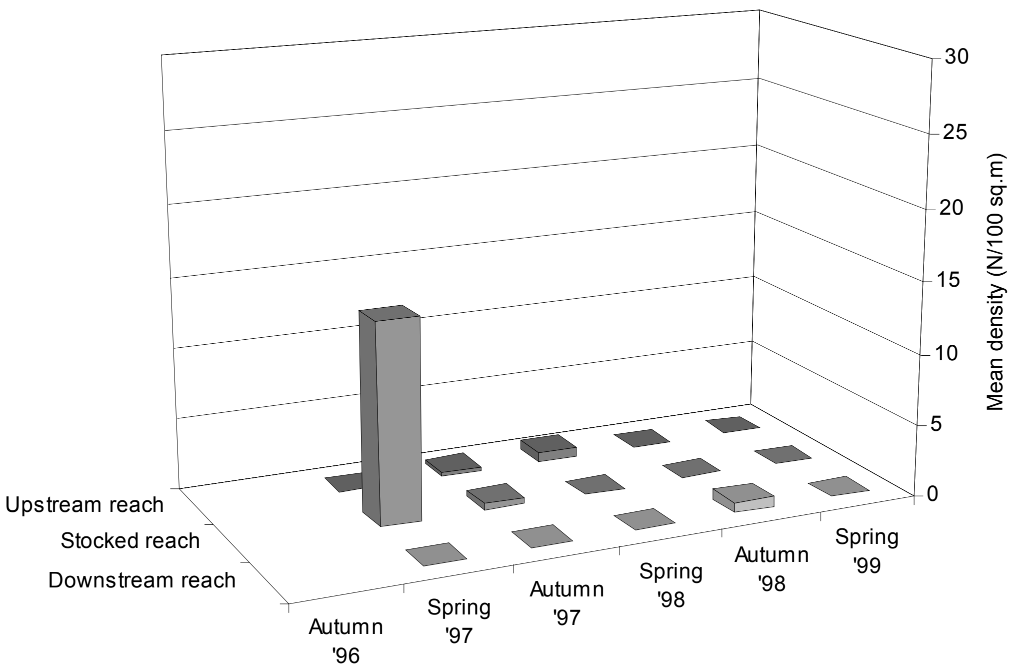

Figure D.40: **Persistence & dispersal of stocked fish in River Lostock; Chub stocked as Spring 2+**

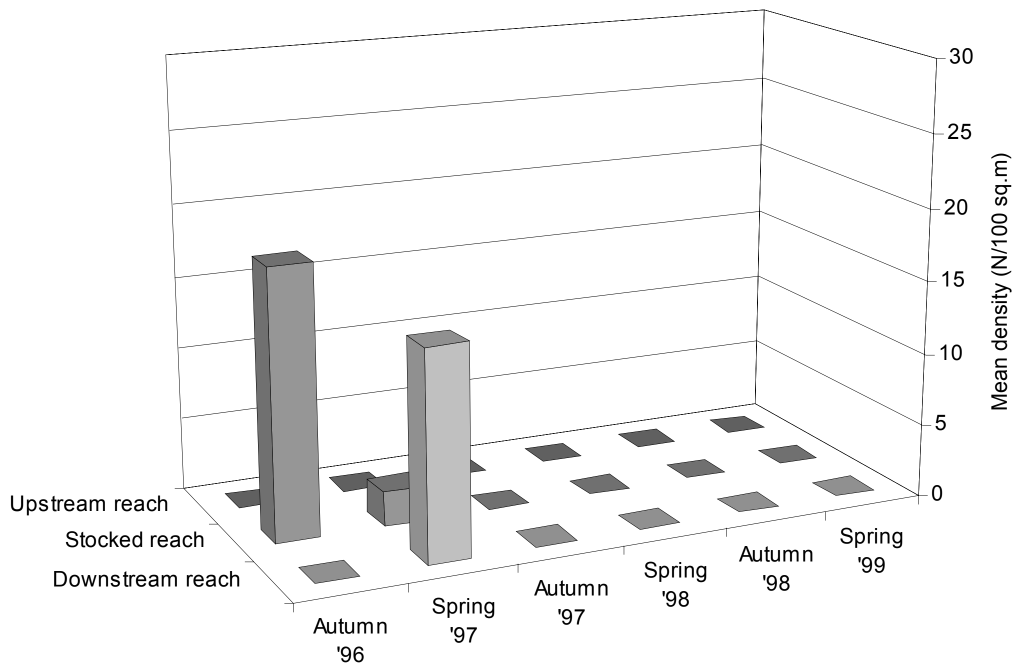

Figure D.41: Persistence & dispersal of stocked fish in River Lostock; Dace stocked as Autumn 1+

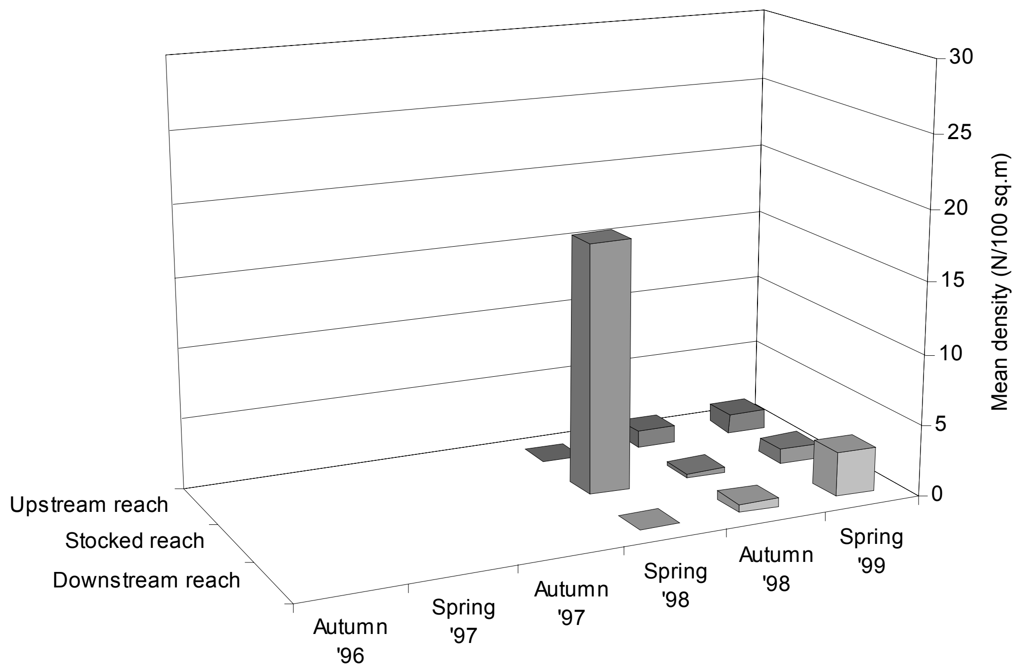

Figure D.42: Persistence & dispersal of stocked fish in River Lostock; Dace stocked as Spring 1+

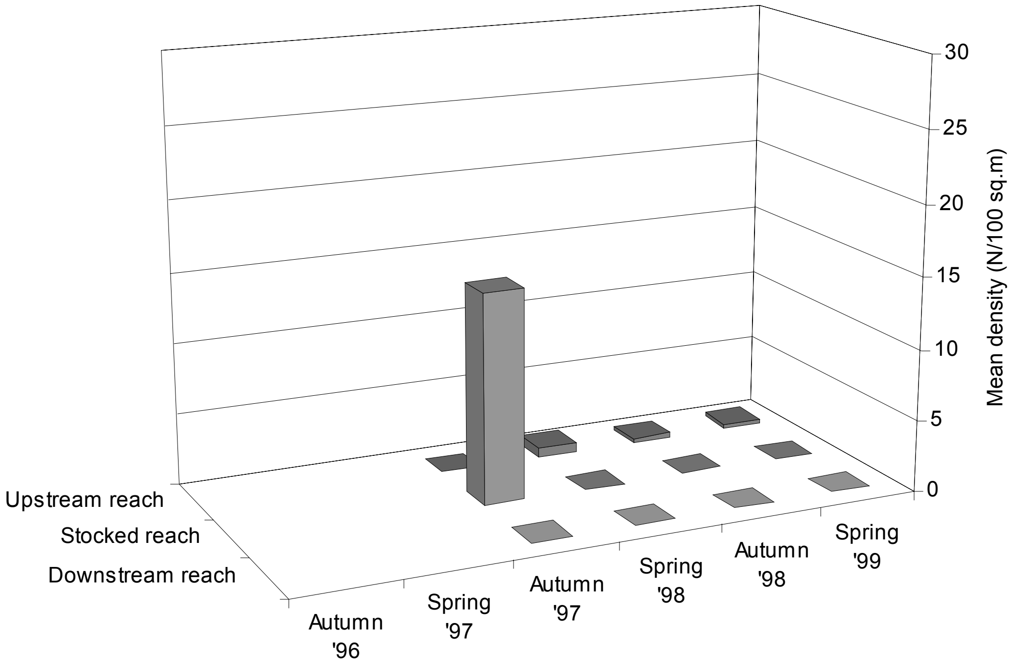

Figure D.43: Persistence & dispersal of stocked fish in River Lostock; Dace stocked as Autumn 2+

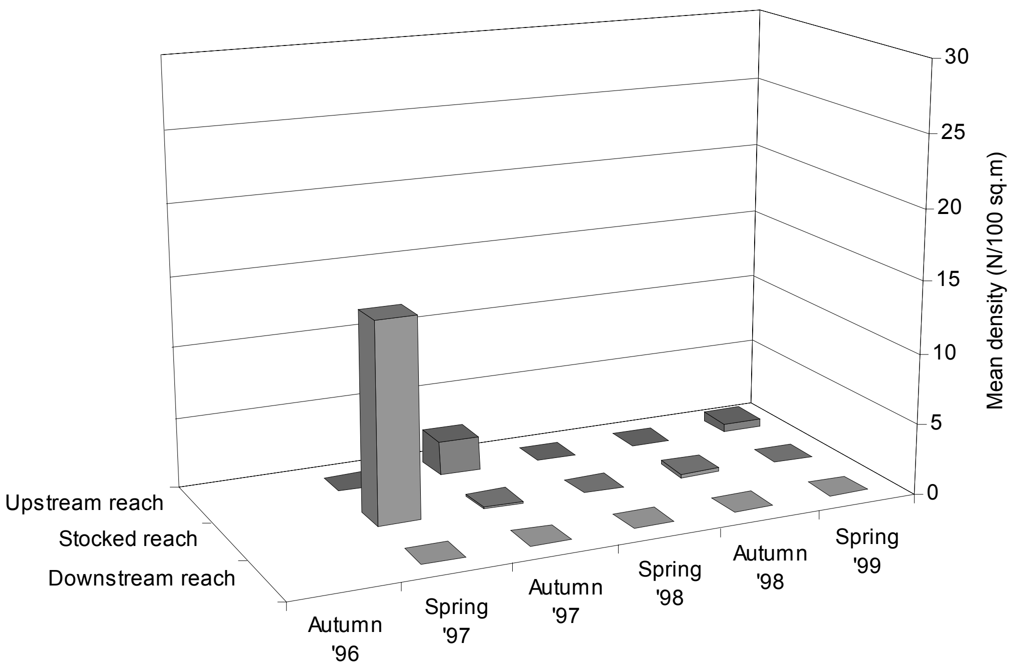

Figure D.44: Persistence & dispersal of stocked fish in River Lostock; Dace stocked as Spring 2+

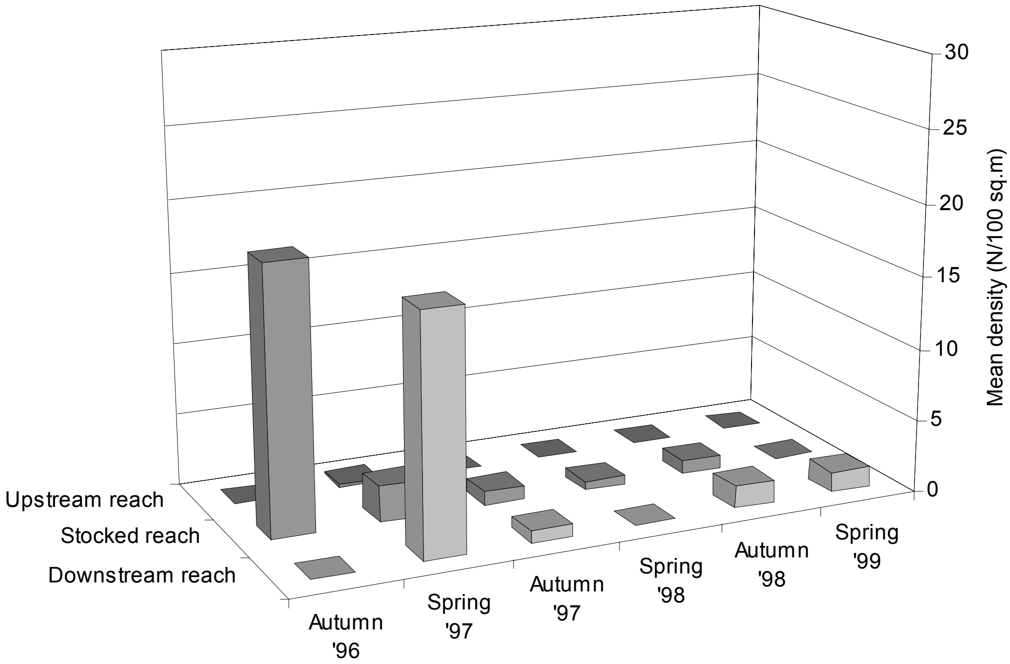

Figure D.45: **Persistence & dispersal of stocked fish in River Lostock; Roach stocked as Autumn 1+**

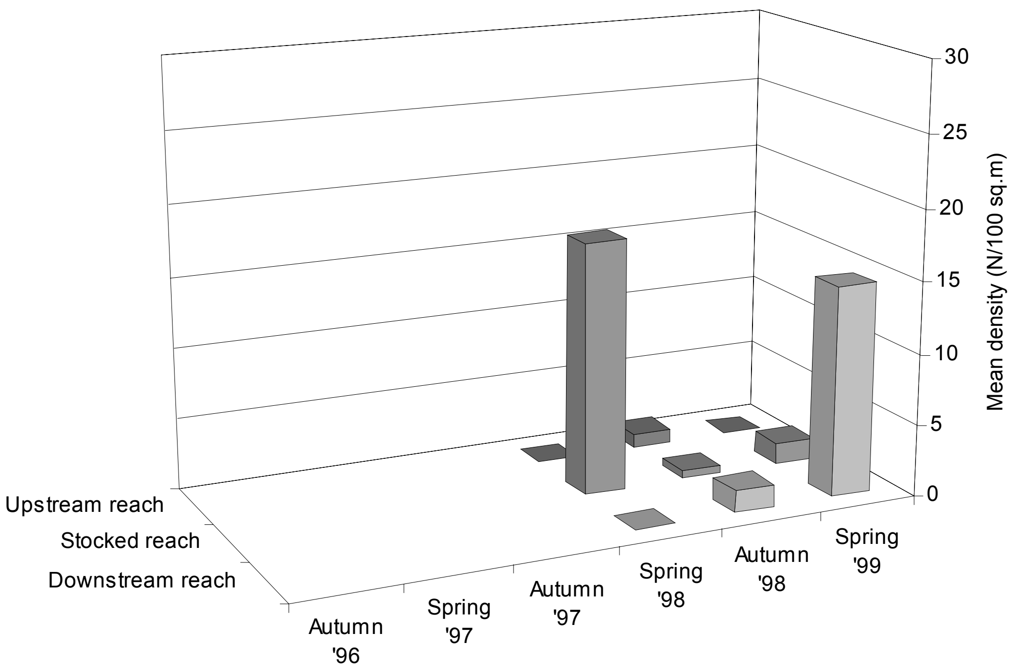

Figure D.46: **Persistence & dispersal of stocked fish in River Lostock; Roach stocked as Spring 1+**

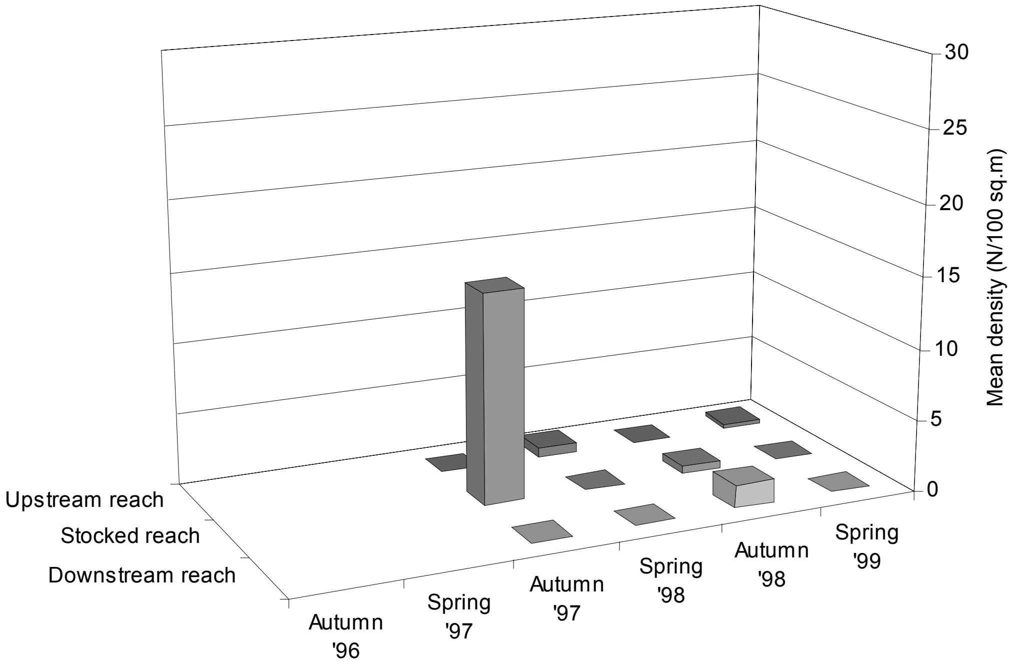

Figure D.47: Persistence & dispersal of stocked fish in River Lostock; Roach stocked as Autumn 2+

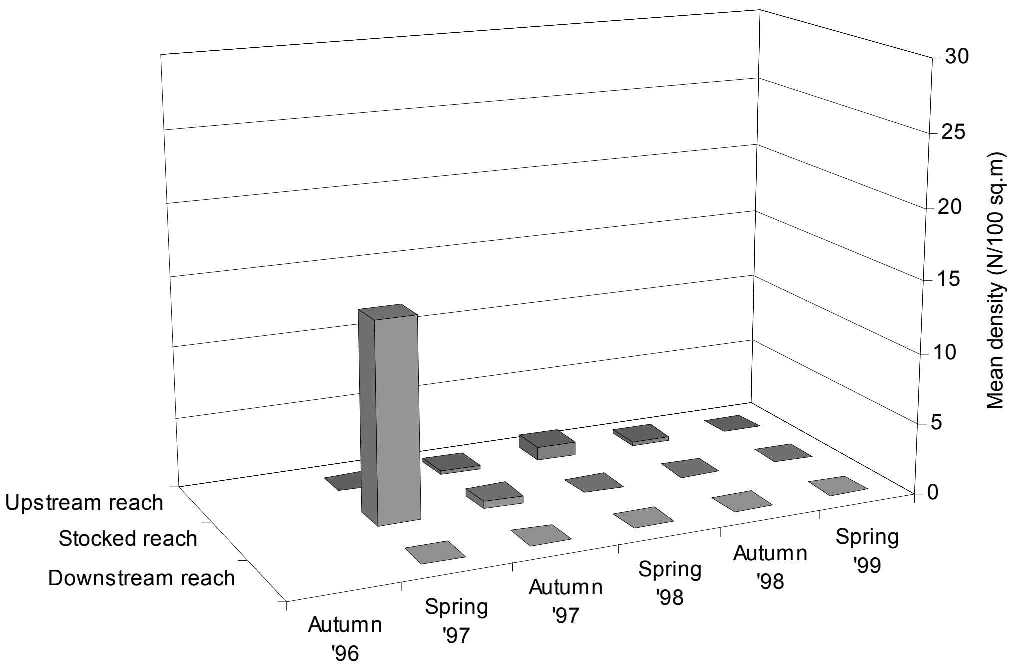

Figure D.48: Persistence & dispersal of stocked fish in River Lostock; Roach stocked as Spring 2+

APPENDIX E PRESENCE OF NON-STOCKED FISH IN STUDY SITES

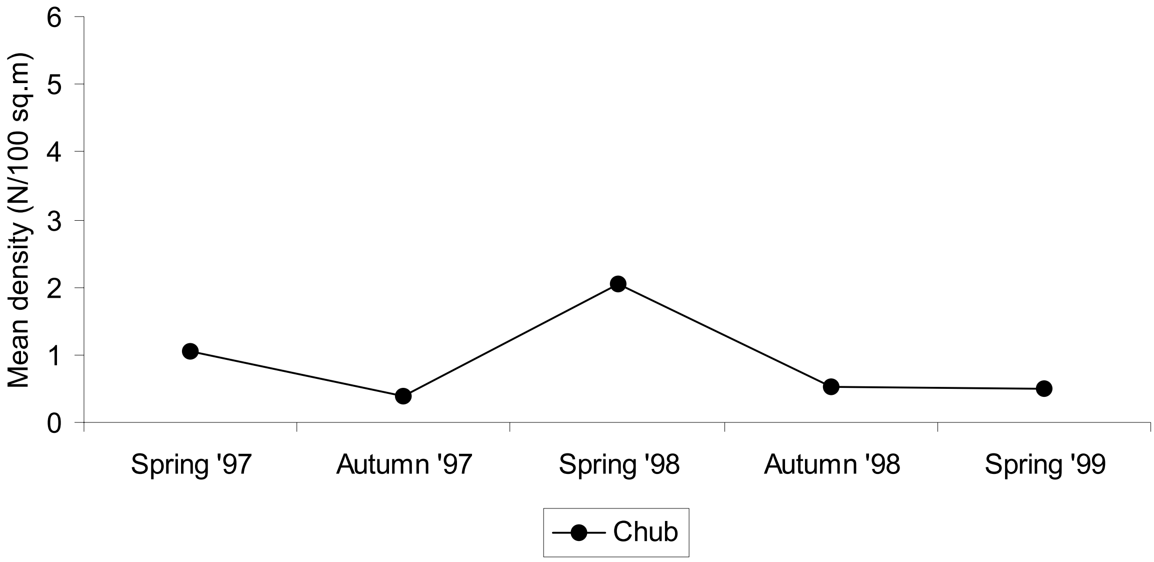

Figure E.1: Presence of non-stocked fish in River Alderbourne; upper reach

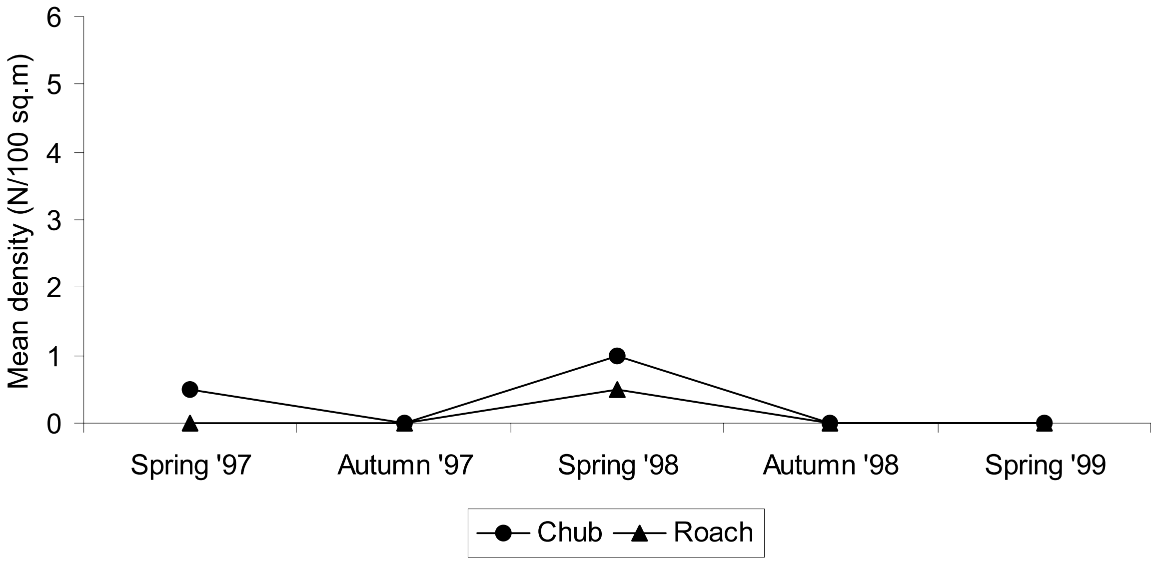

Figure E.2: Presence of non-stocked fish in River Alderbourne; lower reach

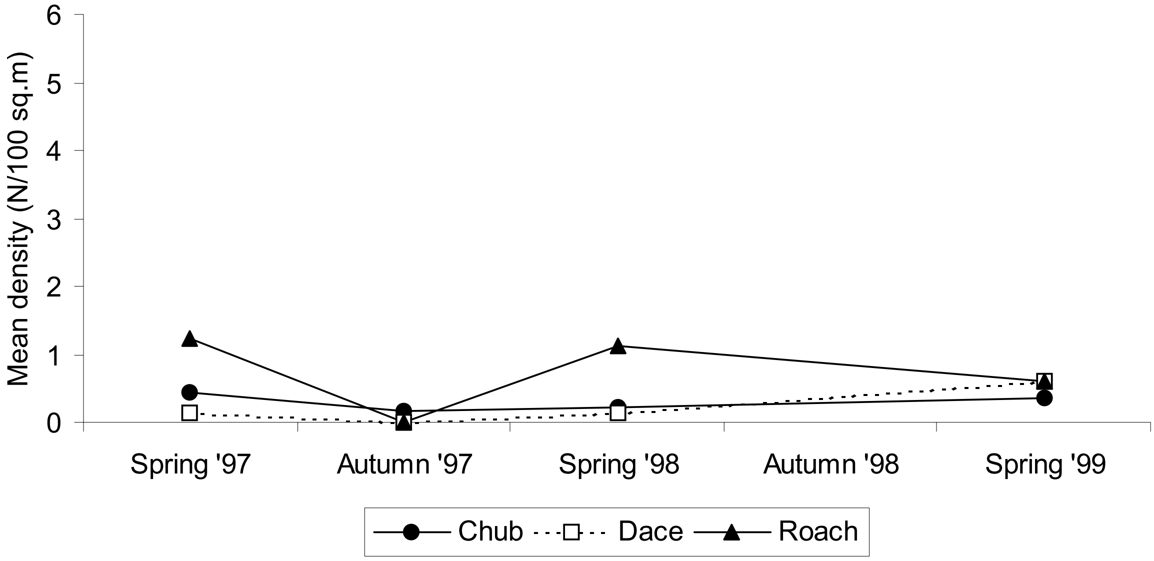

Figure E.3: Presence of non-stocked fish in River Cherwell; upper reach

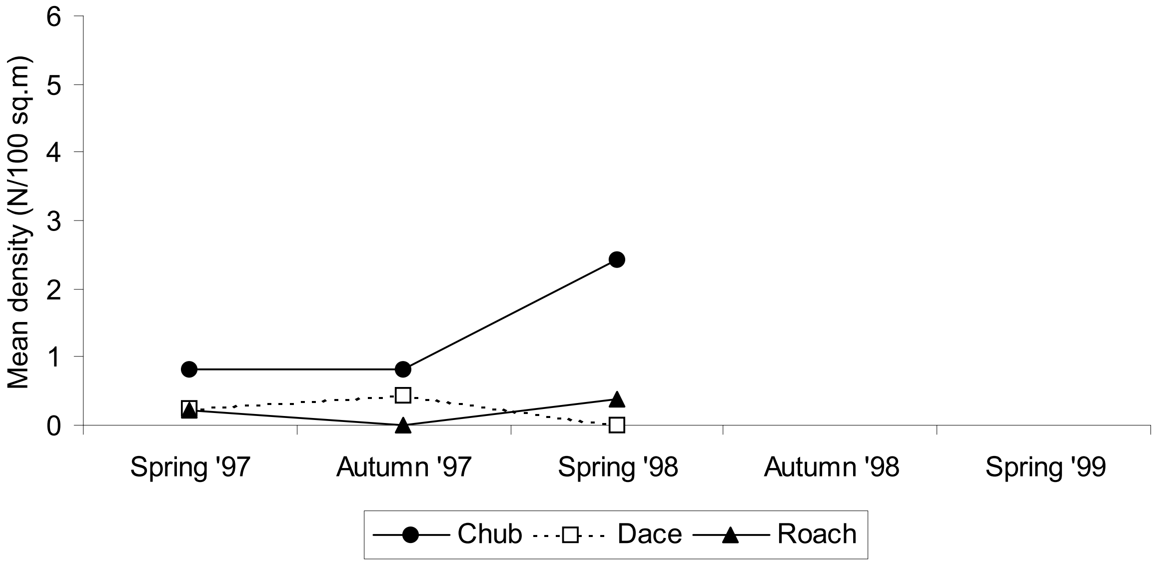

Figure E.4: Presence of non-stocked fish in River Cherwell; lower reach

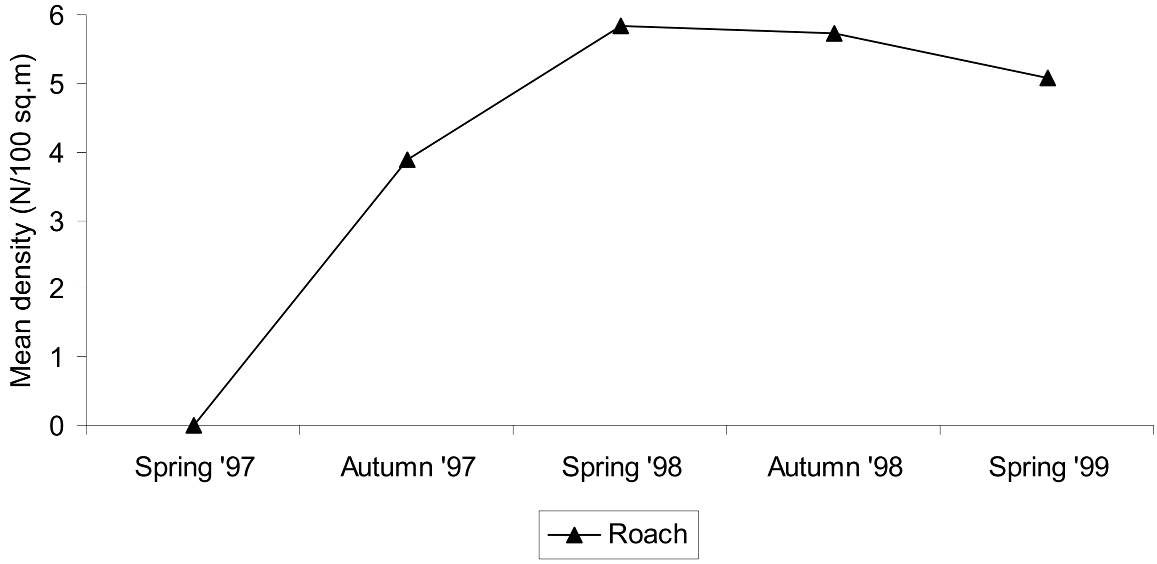

Figure E.5: Presence of non-stocked fish in River Hogsmill; upper reach

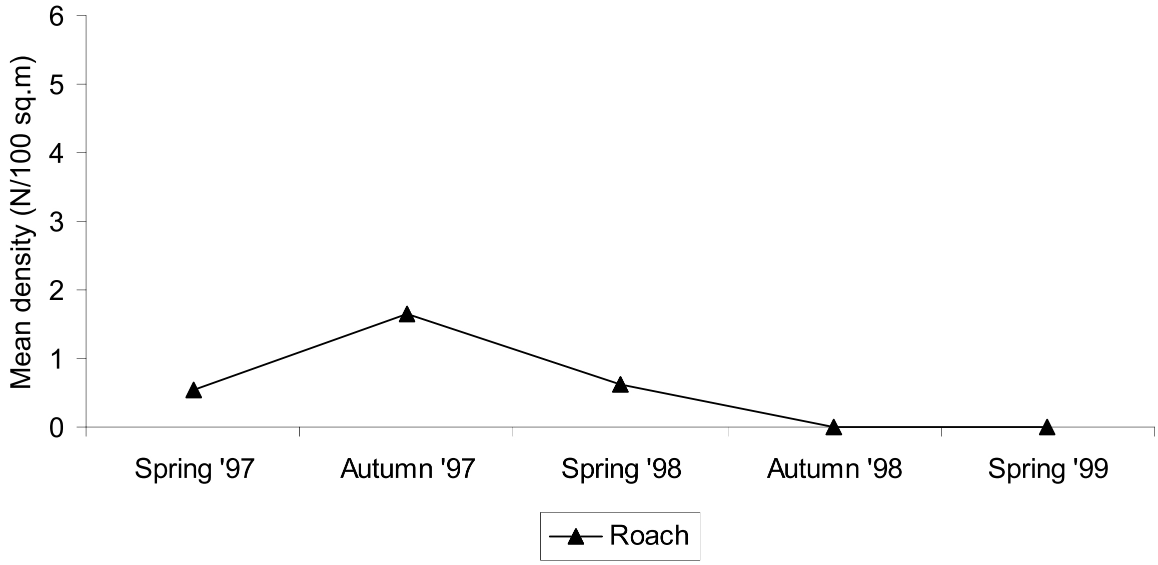

Figure E.6: Presence of non-stocked fish in River Hogsmill; lower reach

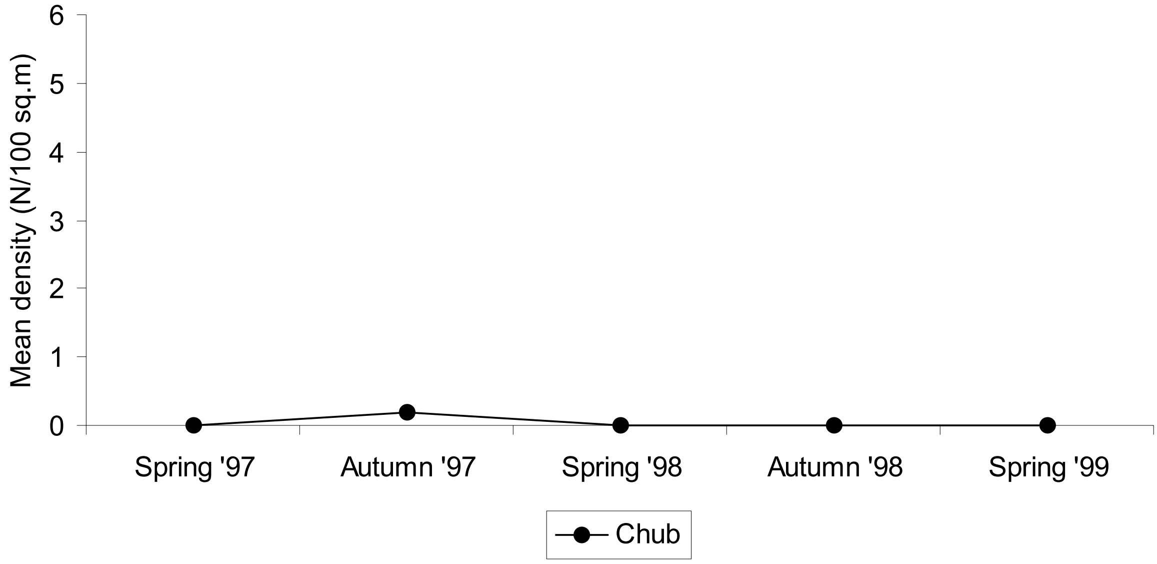

Figure E.7: Presence of non-stocked fish in River Lostock lower reach

APPENDIX F LENGTH FREQUENCY PLOTS FOR PIKE CAUGHT DURING SURVEYS

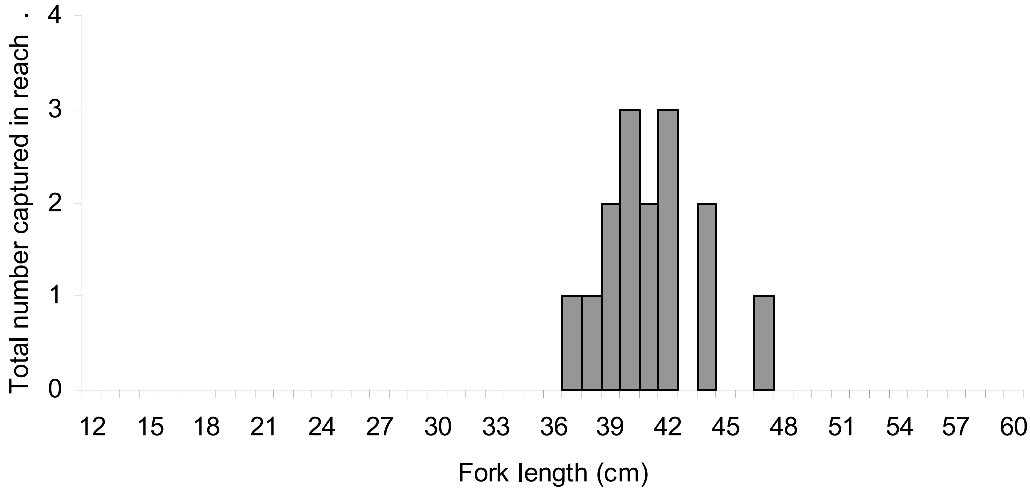

Figure F.1: Length frequency plot for pike captured in Cherwell upper stocked reach; Spring 1997

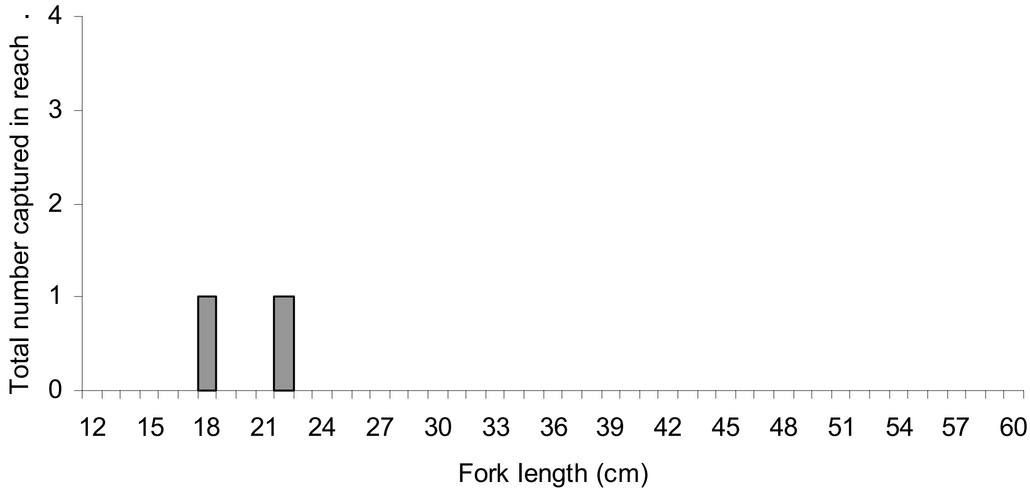

Figure F.2: Length frequency plot for pike captured in Cherwell upper stocked reach; Autumn 1997

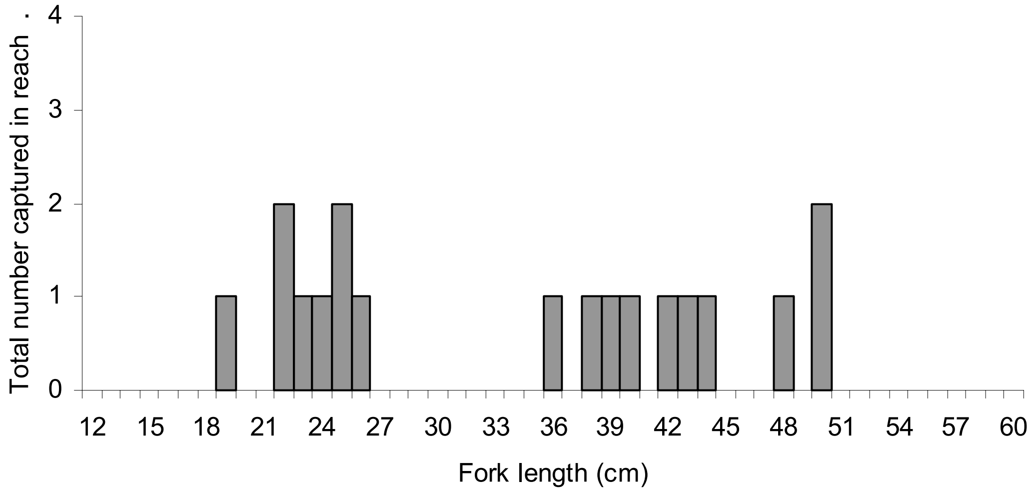

Figure F.3: Length frequency plot for pike captured in Cherwell upper stocked reach; Spring 1998

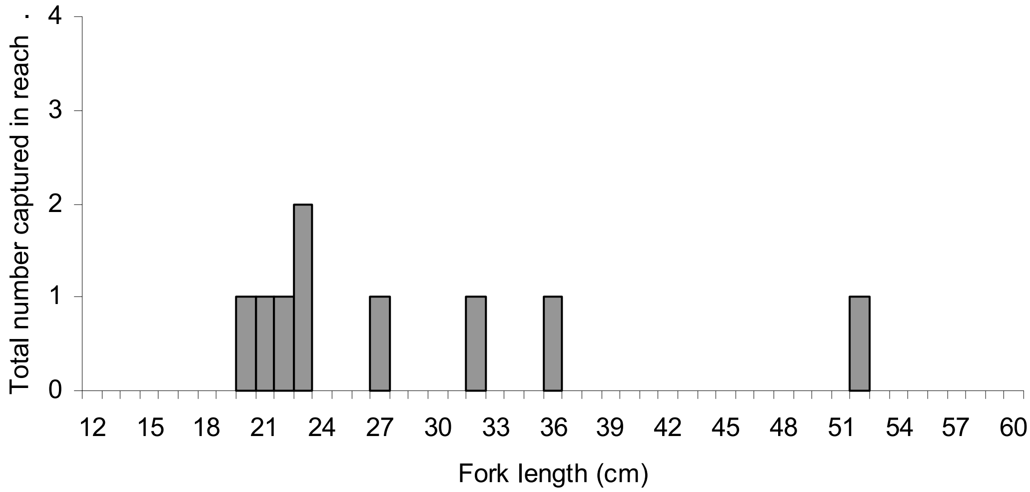

Figure F.4: Length frequency plot for pike captured in Cherwell upper stocked reach; Spring 1999

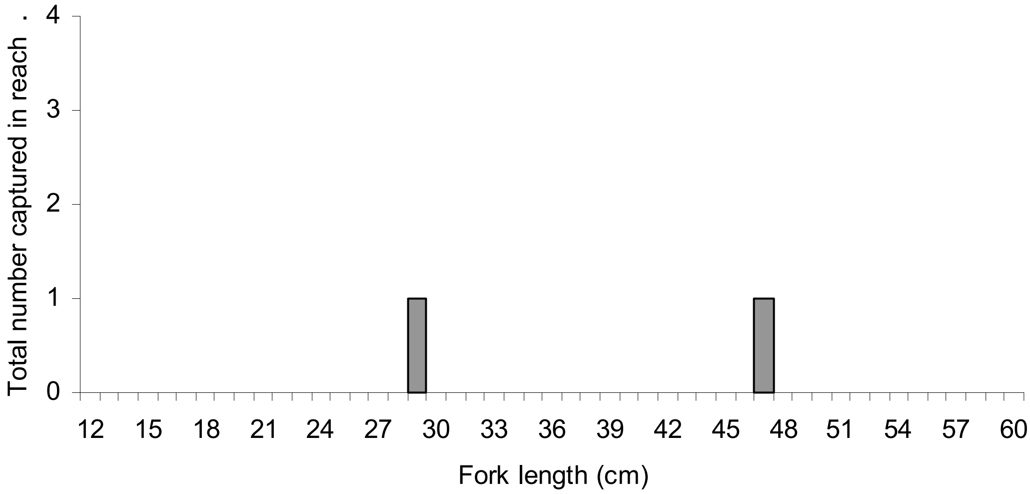

Figure F.5: **Length frequency plot for pike captured in Cherwell lower stocked reach; Spring 1997**

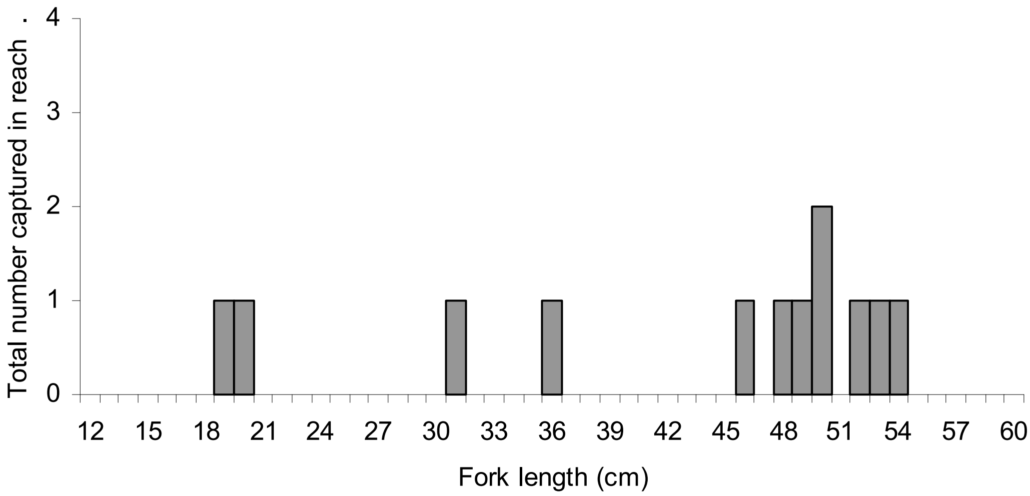

Figure F.6: **Length frequency plot for pike captured in Cherwell lower stocked reach; Autumn 1997**

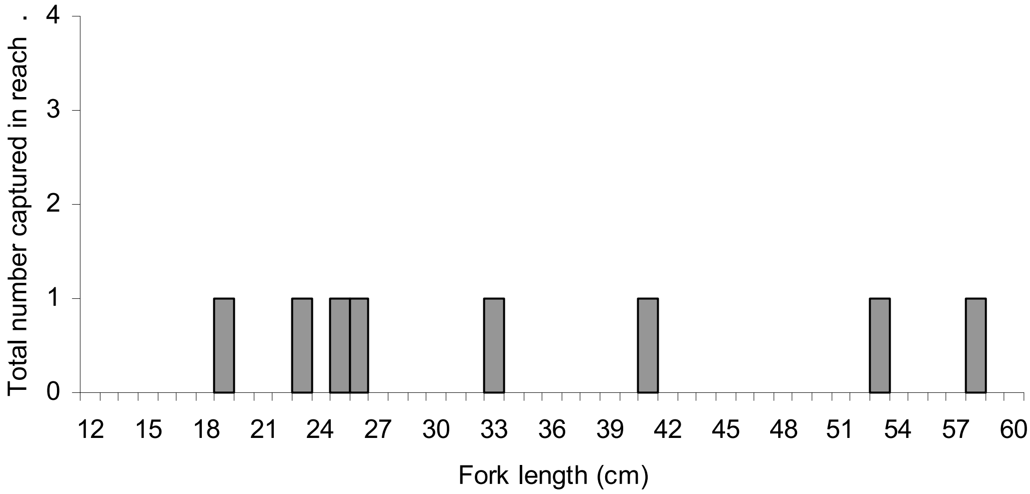

Figure F.7: **Length frequency plot for pike captured in Cherwell lower stocked reach; Spring 1998**

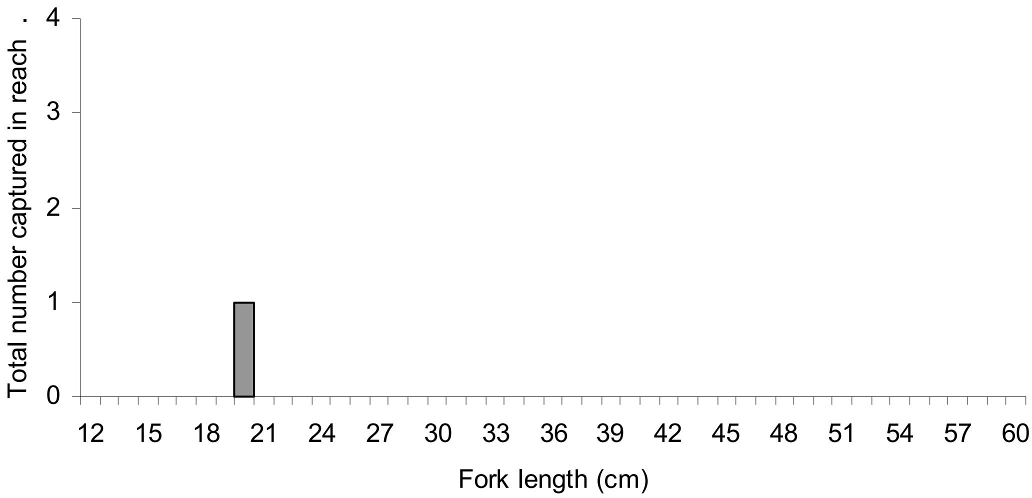

Figure F.8: **Length frequency plot for pike captured in Alderbourne lower stocked reach; Autumn 1998**

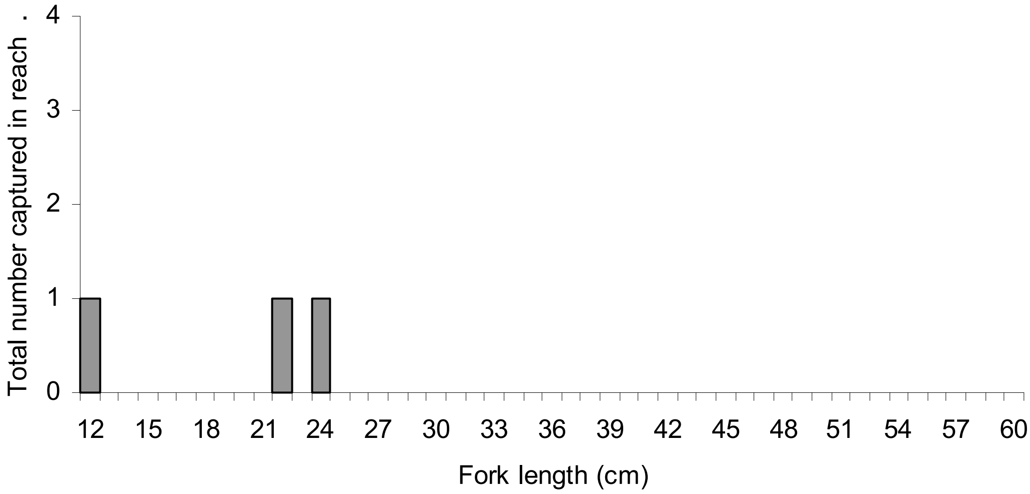

Figure F.9: Length frequency plot for pike captured in Alderbourne lower stocked reach; Spring 1999