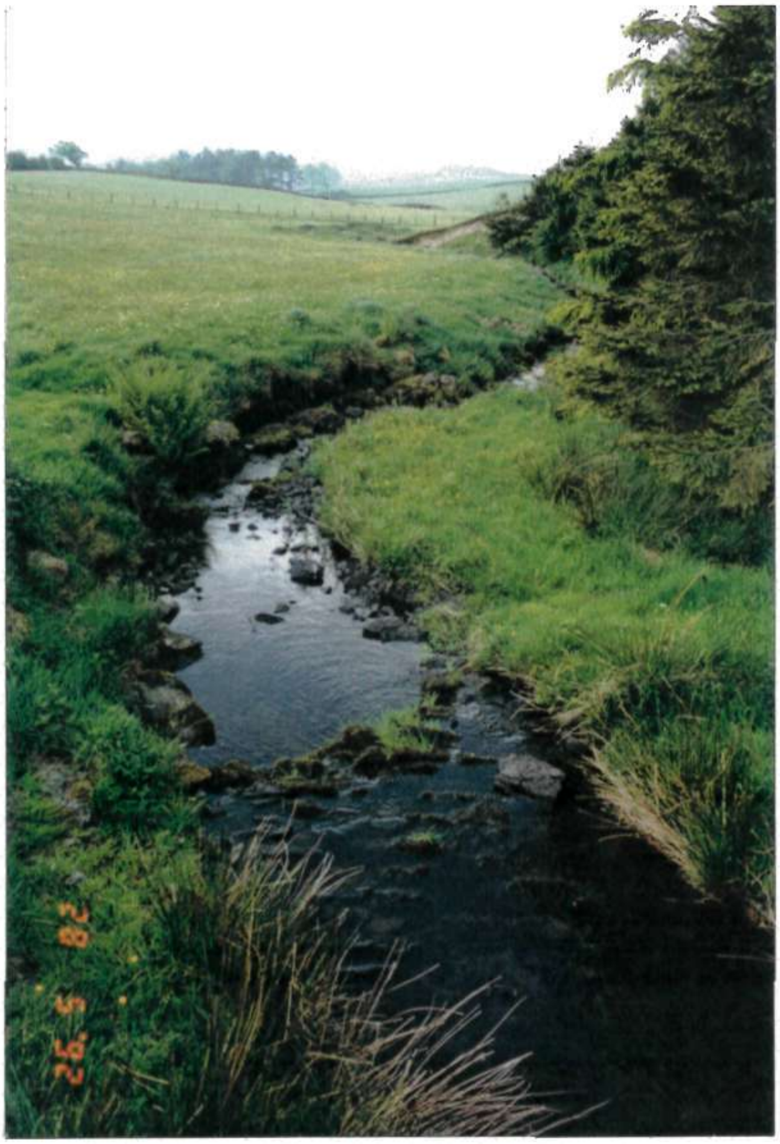
An Evaluation of the Survival of Atlantic Salmon (*Salmo salar* L.) Fry Stocked in Eight Streams in the North West of England



NRA/NW/FTR/95/8 **July 1995**

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July 1995

Summary

Eight streams from the North West of England were stocked with Atlantic salmon (*Salmo salar* L.) fed fry at densities ranging from 1 to 4/m^2 over a period of up to three years to evaluate survival to the end of the first and second growing periods and hence assess the value of stocking as a management practice.

Survival to the end of the first growing period (mean duration of 108 days) was found to vary between 7.8 and 41.3% with a mean of 22% and CV of 0.44. Survival from the end of the first growing period to the end of the second growing period (mean duration of 384 days) ranged from 19.9 to 34.1% with a mean of 26.3% and CV of 0.21. Survival was found to be positively related to 0+ trout density ($P < 0.05$) and negatively related to altitude ($P < 0.05$).

A comparison of the raw survival data (non standardised with respect to duration of experiments) with that from other studies in relation to stocking densities revealed a negative relationship between fry survival and stocking density ($P < 0.05$). Densities in excess of 5/m^2 tended to result in lower levels of survival.

Post stocking fry dispersal patterns were examined for the 1991 data. On average 86.7% of the number of fry surviving remained within the stocked zone by the end of the first growing period. With the exception of one stream there was little in the way of dispersal beyond the stocked zone. The dispersal pattern approximated to the normal distribution ($P < 0.05$).

It was estimated that stocking can result in a net gain of fish to a river system compared with natural productivity, however the numerical significance of this gain and its cost effectiveness need to be determined on a river specific basis.

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1. Introduction

The stocking of fish has been carried out as a means of (1) mitigation, (2) enhancement, (3) restoration or (4) the creation of a new fishery (Cowx 1994). In the case of anadromous fish the aim is to establish a significant adult return rate to the parent river or fishery, the level of significance being dependent on the objectives of the programme.

The stocking of juvenile Atlantic salmon (*Salmo salar* L.) has been a major preoccupation of fisheries managers in the U.K. for several decades. Unfortunately, in many instances there has been little or no evaluation of the consequences of such action (Harris 1978). Before contemplating any stocking programme it is necessary to establish that such a programme is the most appropriate course of action to take, for example habitat rehabilitation or improving access for migratory fish may be more sustainable alternatives. It is also necessary to appreciate that there are a variety of factors, some of which can be manipulated, that will determine the success of a stocking programme e.g. origin of stock, rearing strategy, method of release, age at release, stocking density, rate of adaptation to the natural environment, habitat, predation, competition, (McCrimmon 1954; Mills 1964, 1969; Harris 1978; Kennedy and Strange 1980; Kennedy 1988; Crozier and Kennedy 1993; Milner 1993; Potter and Russell 1994; Russell 1994; Whalen and LaBar 1994). Once a stocking program has been justified and the fish have been stocked it is essential to evaluate its success. It is only by such evaluation that we can begin to identify the best practicable and cost effective means of achieving the particular objectives of any salmon management strategy that incorporates a stocking programme.

The aim of this study was two fold, firstly to assess the survival of stocked hatchery reared Atlantic salmon fed fry to the end of their first and second growing periods, and secondly to use this information to project the potential adult return rates to a river and thus determine the efficacy of such actions in the North West region of England.

2. Methods

2.1 Study area

Eight streams (tributaries of the rivers Eden, Lune, and Ribble) were selected from a wide geographic range within North West England (Figure 1). Streams were selected on the basis of having suitable juvenile salmonid habitat, an absence of naturally produced juvenile salmon, and no known water quality problems.

The streams were stocked at densities ranging from 1 to $4/m^2$ over a period of up to three years. Six streams were stocked in 1991 and six in 1992. Four of the streams selected in 1991 were also used in 1992. Two streams were selected in 1993 both of which had been stocked in 1992 and one also having been stocked in 1991. The details are presented in Table 1.

Figure 1. Location of Experimental Sites

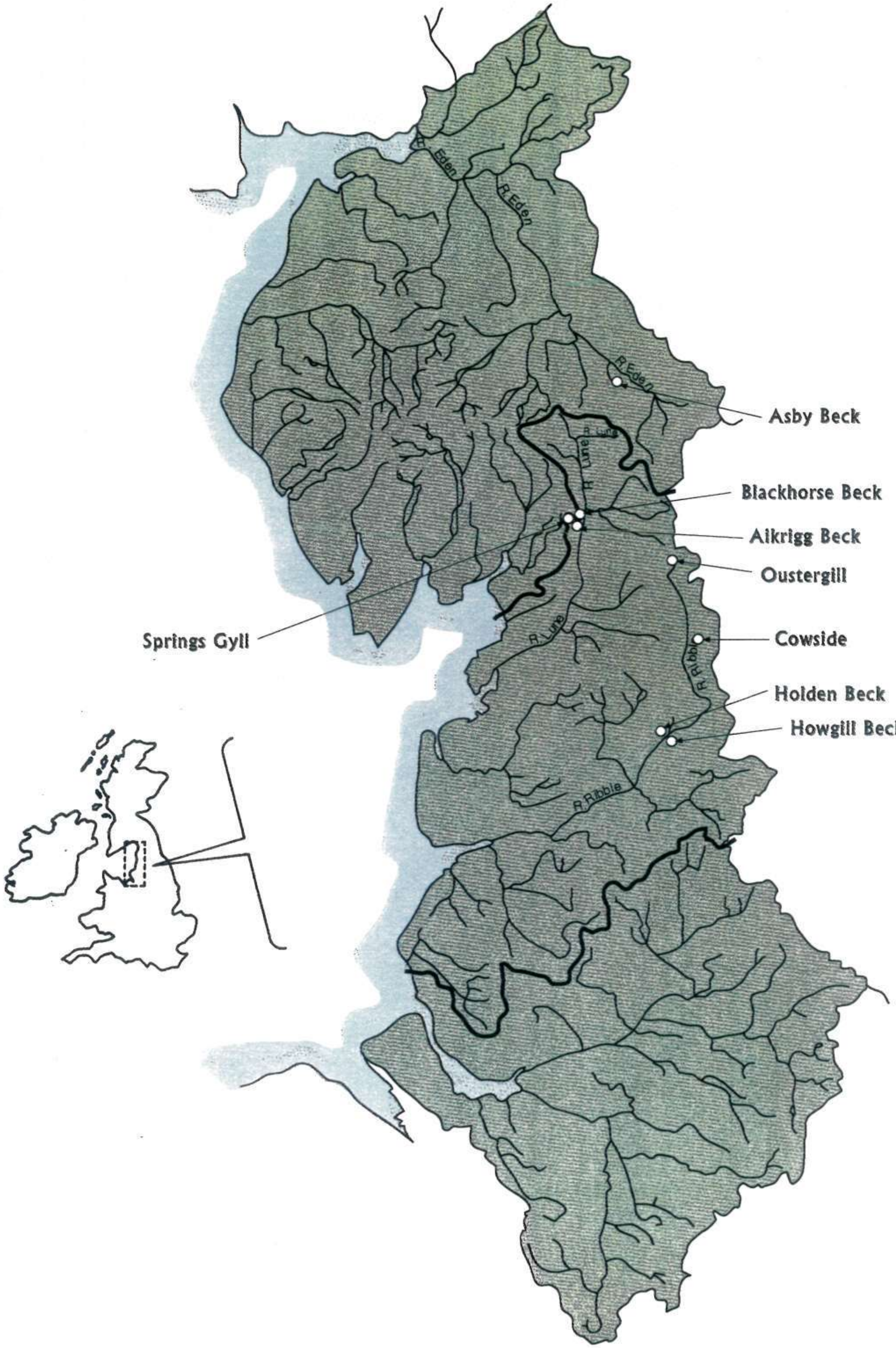


Table 1 Site details

River	Site	Stocking Density (m^{-2})	Grid reference	Altitude (m)	Mean width (m)	Date stocked	Date of first assessment	Date of second assessment
Eden	Asby Beck	1	NY684150	170	5.3	08/05/91	17/09/91	
Ribble	Howgill Beck	1	SD825462	140	2.3	22/04/91 24/06/92	13/09/91 09/10/92	09/10/92
Ribble	Oustergill	1	SD795836	410	1.5	22/04/91 30/06/92	05/09/91 29/09/92	29/09/92
Ribble	Holden Beck	2	SD757501	170	3.3	24/06/92	14/10/92	
Ribble	Cowside Beck	3	SD846668	330	2.2	22/04/91 30/06/92	06/09/91 07/10/92	07/10/92
Lune	Aikrigg Beck	3	SD605885	170	2.5	05/06/91 03/06/92 03/06/93	02/09/91 04/09/92 01/09/93	04/09/92
Lune	Springs Gyll	3	SD601892	180	1.7	05/06/91	04/09/91	
Lune	Blackhorse Beck	4	SD618931	240	1.4	03/06/92 03/06/93	01/09/92 07/09/93	07/09/93

Brown trout (*Salmo trutta* L.) were present at all the sites investigated; other species included bullhead (*Cottus gobio* L.), stoneloach (*Barbatula barbatula* L.), three-spined stickleback (*Gasterosteus aculeatus* L.), minnow (*Phoxinus phoxinus* L.) and eel (*Anguilla anguilla* L.).

2.2 Experimental design

The fry were derived from river specific broodstock and were reared in hatchery facilities until stocked out. The fish were released at 1 m intervals along the length of the stocked zone at the required density for each stream. The fish were stocked between April and June and the streams assessed in September or October of the same year to estimate the survival of stocked fry to the end of the first growing season. Some streams were also evaluated in September or October of the following year to estimate survival to the end of the second growing period.

At each stream the stocked zone consisted of a 500 m section. Within this zone five sites, 50 m each, were selected for assessment representing 50% of the stocked zone. These sites were situated at alternate intervals of 50 m starting from the downstream limit of the stocked zone (0 m). As previous studies on the fate of stocked salmon have indicated that a certain degree of fry dispersal occurs post stocking (McCrimmon 1954; Egglishaw and Shackley 1980; Kennedy 1984) a section upstream and downstream of the stocked zone was sampled. In 1991 a 500 m section downstream of the stocking zone was sampled, in the following years this was reduced to 100 m. Within this zone alternate 50 m sections were sampled starting at 50 m below the stocked zone. The stocked zone, the downstream section, and the section upstream of the stocked zone constituted the target area and ranged from 650 to 1173 m between streams (Figure 2).

Each site was isolated using stop nets and fished two to five times using pulsed D.C. electric fishing apparatus with a single anode in an upstream direction. All salmonids were anaesthetised using phenoxyethanol and the fork length recorded to the nearest 0.5 cm below. An examination of the length frequency distribution allowed for the separation of salmonids into 0+ and >0+ age classes. A population estimate was obtained for each age class by the Carle and Strub (1978) method.

The total number of stocked fish surviving (S) in the stream was calculated by determining the mean population estimate for each section (50 m) and multiplying by the total number of sections within the target area.

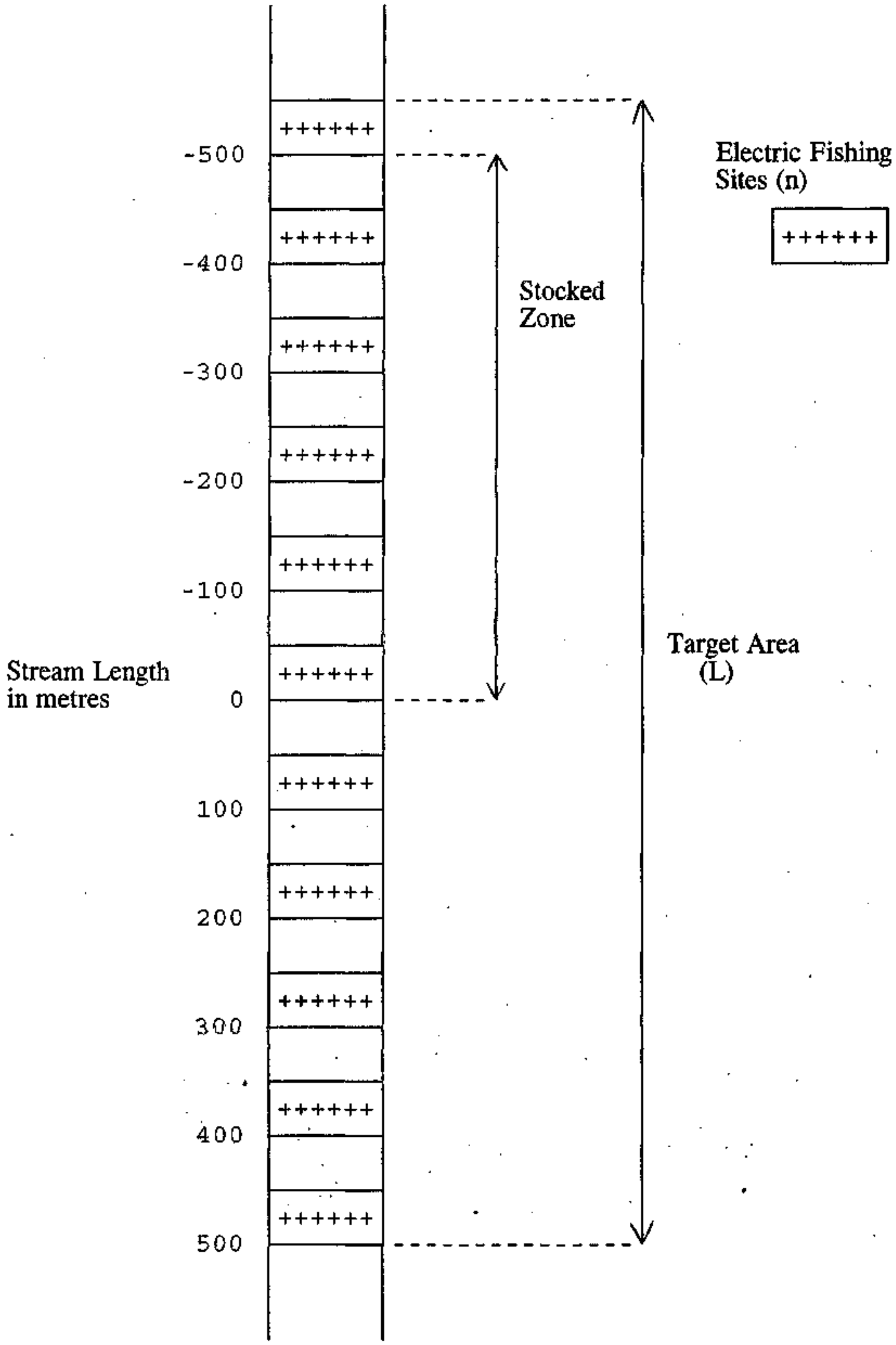
$$S = (L / l) * (\sum_{i=1}^{n} p_i / n)$$

Where

- L = length of target area
- l = standard length of electric fishing site
- p_i = population estimate
- n = number of sites fished

This was then expressed as a percentage of the total number of fry stocked.

Figure 2. Experimental Design



To account for differences in the length of time between stocking and assessment and in order to compare survival between sites and between years the number of fish surviving to the end of the assessment period was calculated as follows:

$$\text{Log}_e N_2 = \log_e N_1 - (Z * \Delta T)$$

Where

N_2 = number of fish surviving at the end of the assessment period
N_1 = number of fish at the beginning of the assessment period
Z = Instantaneous loss rate
ΔT = Time in days

ΔT represented the mean value between the date fish were stocked and the assessment date.

The data was analysed using the statistical package Minitab version 10 (Anon. 1994).. Replicate data were included in the analysis.

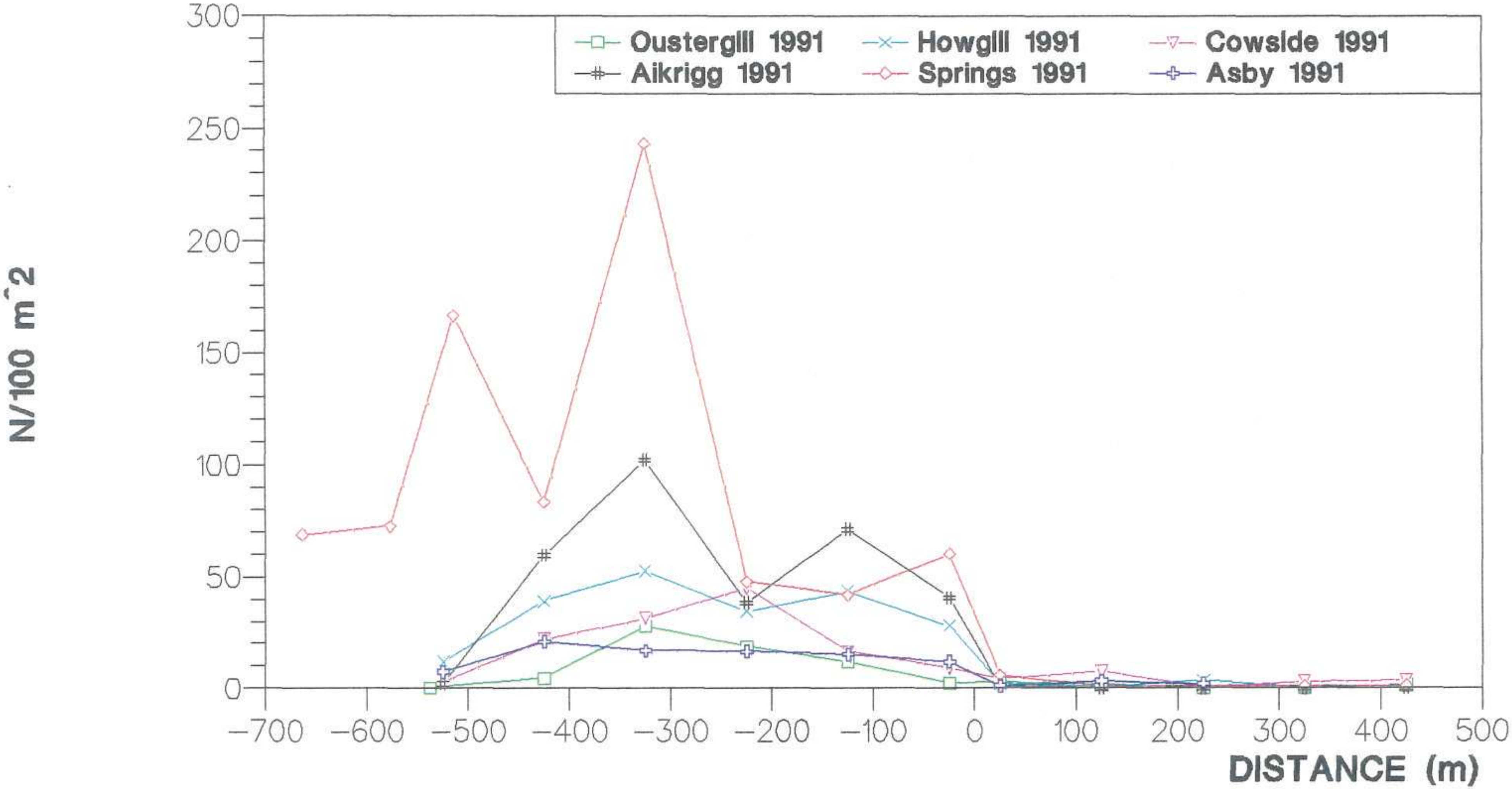
3. Results

3.1 Fry dispersal to the end of the first growing season

The dispersal of stocked fed fry within the target area at the end of the first growing season is shown in Figure 3. To make comparisons between streams the data for each site has been presented in terms of a proportion of the total population estimate for that stream. The majority of fish remained within the stocking zone (mean = 86.7%, std = 8.6) with very few migrating upstream or downstream of the zone. The exception was Springs Gyll where a significant upstream movement of fry was recorded (Figure 3).

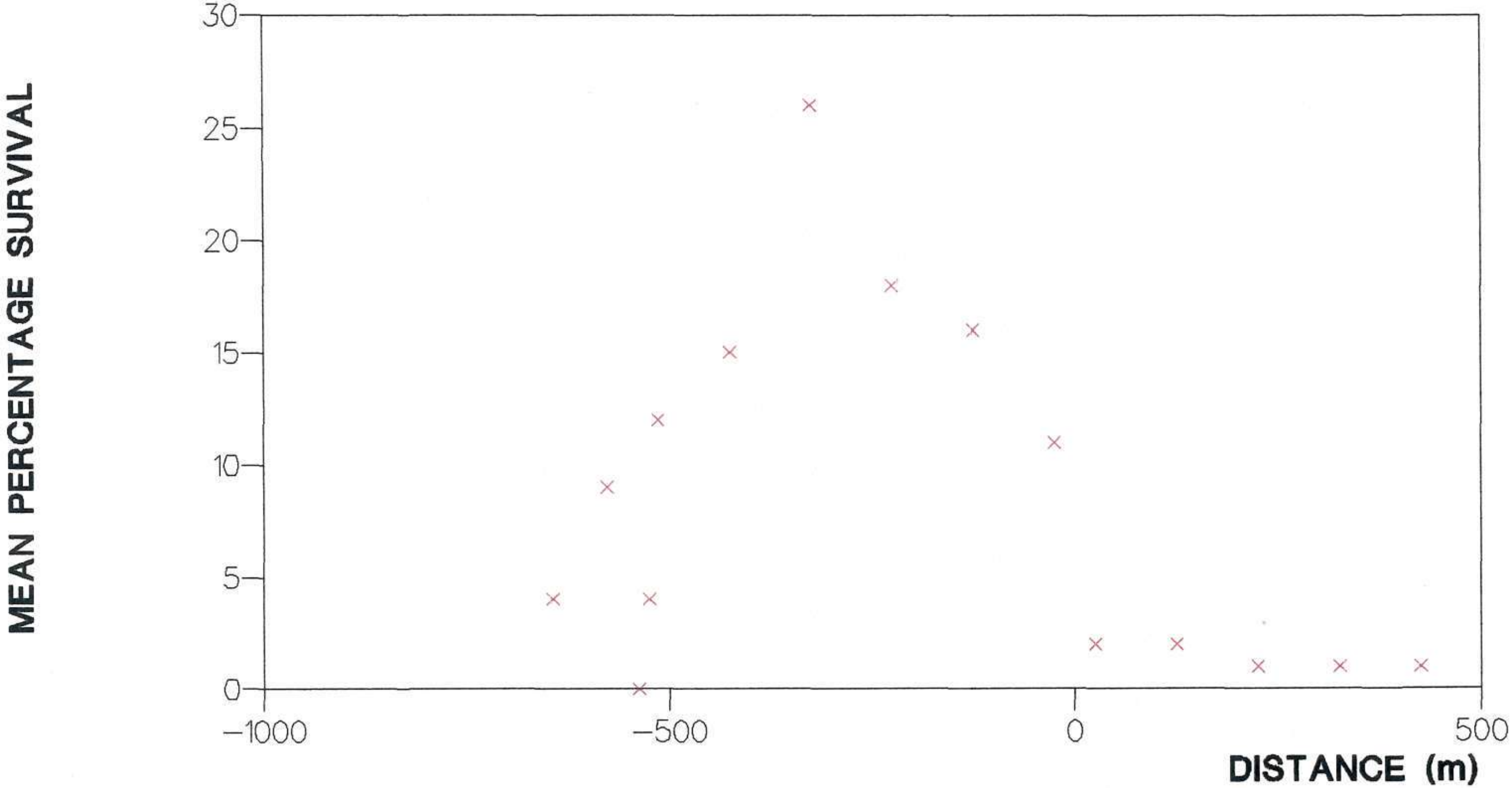
To obtain the average distribution pattern (Figure 4), the mean percentage found at that particular location was determined. This had the effect of biasing the results towards those locations where relatively few replicates were obtained. This was more significant when examining the upstream distribution, as except for Springs Gyll there was little if any significant movement. The dispersal pattern of fry could be adequately described by a normal distribution ($P < 0.05$, Anderson-Darling normality test) with a mean and standard deviation of -294.9 and 210.3 respectively. Such a pattern suggests that by the end of the first growing season 75% of fry remained within the stocked area, 16% migrated upstream and 9% downstream. The distribution is affected by the result from Springs Gyll as at the other sites little upstream sampling was required.

Figure 3. Distribution and abundance of salmon fry from stocking to the end of first growing season



Stocked zone is 0 to -500 m

Figure 4. Average fry distribution pattern for the 1991 data from stocking to the end of the first growing period



3.2 Survival of fry (standardised data) to the end of the first growing season

The results (standardised for a mean duration of 108 days) are presented in Table 2. 12.9 to 41.3% of fed fry survived to the end of the first growing season of 1991 with an average percentage survival of 21.7% (std = 10.8).

The results from 1991 indicated that there was limited downstream dispersal of fry from the stocked zone thus in subsequent years sampling downstream of the stocked zone was confined to the first 100 m. This was not considered to compromise the accuracy of the estimate. In 1992 the percentage survival of fed fry ranged from 1.2 to 29.2% with a mean of 16.4% (std = 11.5).

Two sites were stocked and assessed in 1993. Fry survival at Aikrigg Beck was 26.2% and at Black Horse Beck 32.9%.

The results for Aikrigg Beck over the period 1991 to 1993, and in comparison with the other streams, suggest that the 1992 finding may be an anomaly. There was no evidence to show that 1992 was a poor year for fry survival. However, there was evidence to indicate that a pollution incident had taken place in Aikrigg Beck in 1992 since the stream bed showed signs of deposition consistent with the breakdown of organic matter.

Excluding Aikrigg Beck (1992), the survival to the end of the first growing season over the period 1991-1993 ranged from 7.8 to 41.3% with a mean of 22.0% (std = 9.8). The survival of fry did not appear to be affected by stocking density over the range investigated. Mann-Whitney test suggested no significant difference in survival rate for fish stocked at 1 and 3/m^2 ($P > 0.05$).

3.3 Survival of fry (standardised data) to the end of the second growing season

Five sites were studied in consecutive years which permitted the assessment of the survival of fry from stocking to the end of their second growing period (a mean duration of 503 days). Percentage survival varied from 1.8% to 9.9% with a mean of 5.2% and standard deviation of 3.2 (Table 3a).

Percentage survival from the end of the first growing period to the end of the second (a mean duration of 384 days) varied from 19.9 to 34.1% with a mean of 26.3% (std = 5.5) (Table 3b).

3.4 The relationship between stocking density and fry survival (non standardised data) at the end of the first growing season

Figure 5 depicts the actual percentage survival obtained to the end of the first growing season together with that from similar studies in relation to stocking density. Few data points were available for stocking densities greater than 5/m^2.

The data complied with the basic assumptions of regression analysis (Zar 1984, Fry 1993). The standardised residuals revealed a pattern indicative of heteroscedasticity, thus a $\log_{10}$ transformation was applied (Zar 1984). The initial analysis revealed data points with

Table 2a Percentage survival of fed fry (derived from stocking densities of 1 to 4/m^2) at the end of the first growing period (standardised for a period of 108 days)

	Oustergill 1/m^2	Howgill Beck 1/m^2	Asby Beck 1/m^2	Holden Beck 2/m^2	Springs Gyll 3/m^2	Aikrigg Beck 3/m^2	Cowside Beck 3/m^2	Black Horse Beck 4/m^2
1991	15.8	41.3	23.0	-	24.3	12.9	12.9	-
1992	7.8	29.2	-	22.5	-	1.2	10.2	27.4
1993	-	-	-	-	-	26.2	-	32.9

Table 2b Daily instantaneous loss rate for fed fry to the end of the first growing period

	Oustergill 1/m^2	Howgill Beck 1/m^2	Asby Beck 1/m^2	Holden Beck 2/m^2	Springs Gyll 3/m^2	Aikrigg Beck 3/m^2	Cowside Beck 3/m^2	Black Horse Beck 4/m^2
1991	0.0171	0.0082	0.0136	-	0.0131	0.0189	0.0189	-
1992	0.0236	0.0114	-	0.0138	-	0.0410	0.0211	0.0120
1993	-	-	-	-	-	0.0124	-	0.0103

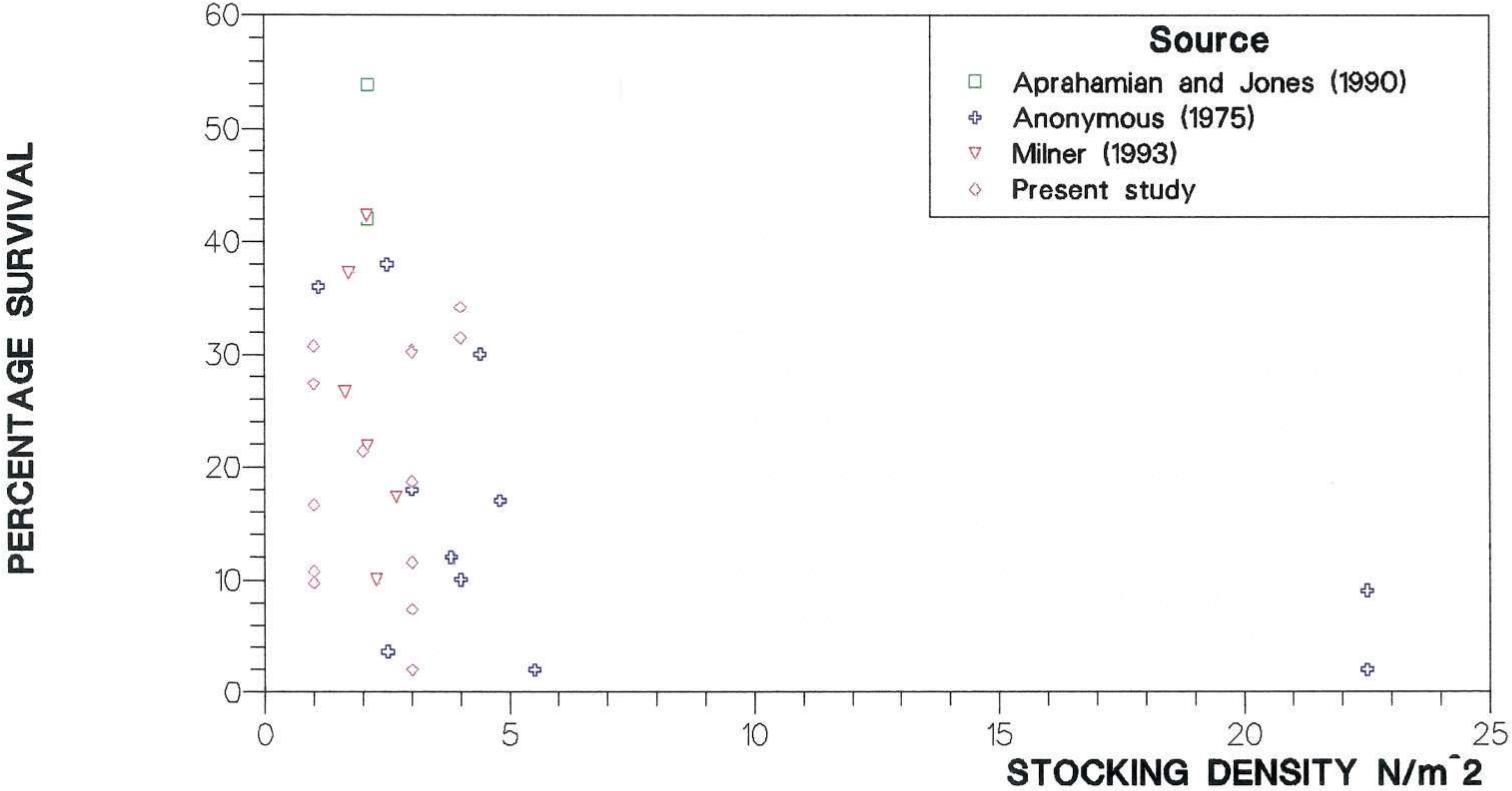
Table 3a Percentage survival and daily instantaneous loss rate (in parentheses) of fed fry (derived from stocking densities of 1 to 4/m^2) from stocking to the end of the second growing period (standardised for a period of 503 days)

	Oustergill 1/m^2	Howgill Beck 1/m^2	Asby Beck 1/m^2	Holden Beck 2/m^2	Springs Gyll 3/m^2	Aikrigg Beck 3/m^2	Cowside Beck 3/m^2	Black Horse Beck 4/m^2
1991-1992	2.7 (0.0072)	9.9 (0.0046)	-	-	-	5.1 (0.0059)	1.8 (0.0080)	-
1992-1993	-	-	-	-	-	-	-	6.6 (0.0054)

Table 3b Percentage survival and daily instantaneous loss rate (in parentheses) of fed fry from the end of the first growing season to the end of the second growing season (standardised for a period of 384 days)

	Oustergill 1/m^2	Howgill Beck 1/m^2	Asby Beck 1/m^2	Holden Beck 2/m^2	Springs Gyll 3/m^2	Aikrigg Beck 3/m^2	Cowside Beck 3/m^2	Black Horse Beck 4/m^2
1991-1992	23.2 (0.0038)	29.3 (0.0032)	-	-	-	34.1 (0.0028)	19.9 (0.0042)	-
1992-1993	-	-	-	-	-	-	-	25.1 (0.0036)

Figure 5. The relationship between fed fry survival and stocking density



standardised residuals < -2. Outliers with standardised residuals < -2 were considered for rejection after confirming that they were not extreme values of an unusually variable data set and that measurement or recording errors were not made (Fry 1993). On these criteria Aikrigg Beck 1992 was removed from the data set. A regression of the $\log_{10}$ transformed data showed that 18.8% (R^2) of the variation in fry survival could be explained by stocking density ($P <$ 0.05) according to the equation:

$$\text{Log}_{10} \text{ fed fry survival} = 1.46 - 0.521 \log_{10} \text{ stocking density}$$

A similar relationship was obtained using data derived from the literature for unfed fry (Figure 6). In this instance it was clear that unfed fry stocking densities in excess of 5/m^2 tended to result in lower survival rates. 48.7% of the variation in survival of unfed fry could be explained by stocking density ($P < 0.05$):

$$\text{Log}_{10} \text{ unfed fry survival} = 1.54 - 1.05 \log_{10} \text{ stocking density}$$

The regression lines obtained for both fed fry and unfed fry were examined by analysis of covariance (Fry 1993). There was no significant difference between the intercept or gradient of the two lines ($P > 0.05$). Both slopes were significantly different from zero ($P < 0.05$). Thus the two data sets can be treated as one. The combined data for unfed and fed fry was similarly significantly inversely related to stocking density (Figure 7):

$$\text{Log}_{10} \text{ fed and unfed fry survival} = 1.52 - 0.822 \log_{10} \text{ stocking density}$$

$R^2 = 37.0\%$ $\quad P < 0.05$

3.5 The relationship between fed fry survival (standardised data) and trout densities

A significant relationship existed between fed fry percentage survival and 0+ trout density of the form:

$$\text{Log}_{10} \text{ fed fry survival} = 0.934 + 0.336 \log_{10} \text{ 0+ trout density}$$

$R^2 = 49.5\%$ $\quad P < 0.05$

The results imply that 0+ trout densities ranging from 2 to 67/100 m^2 did not have a significant deleterious effect on the survival of stocked salmon fry by the end of the first growing season. The positive relationship between percentage survival and 0+ trout density probably reflects the quality of the habitat.

Figure 6. The relationship between unfed fry survival and stocking density

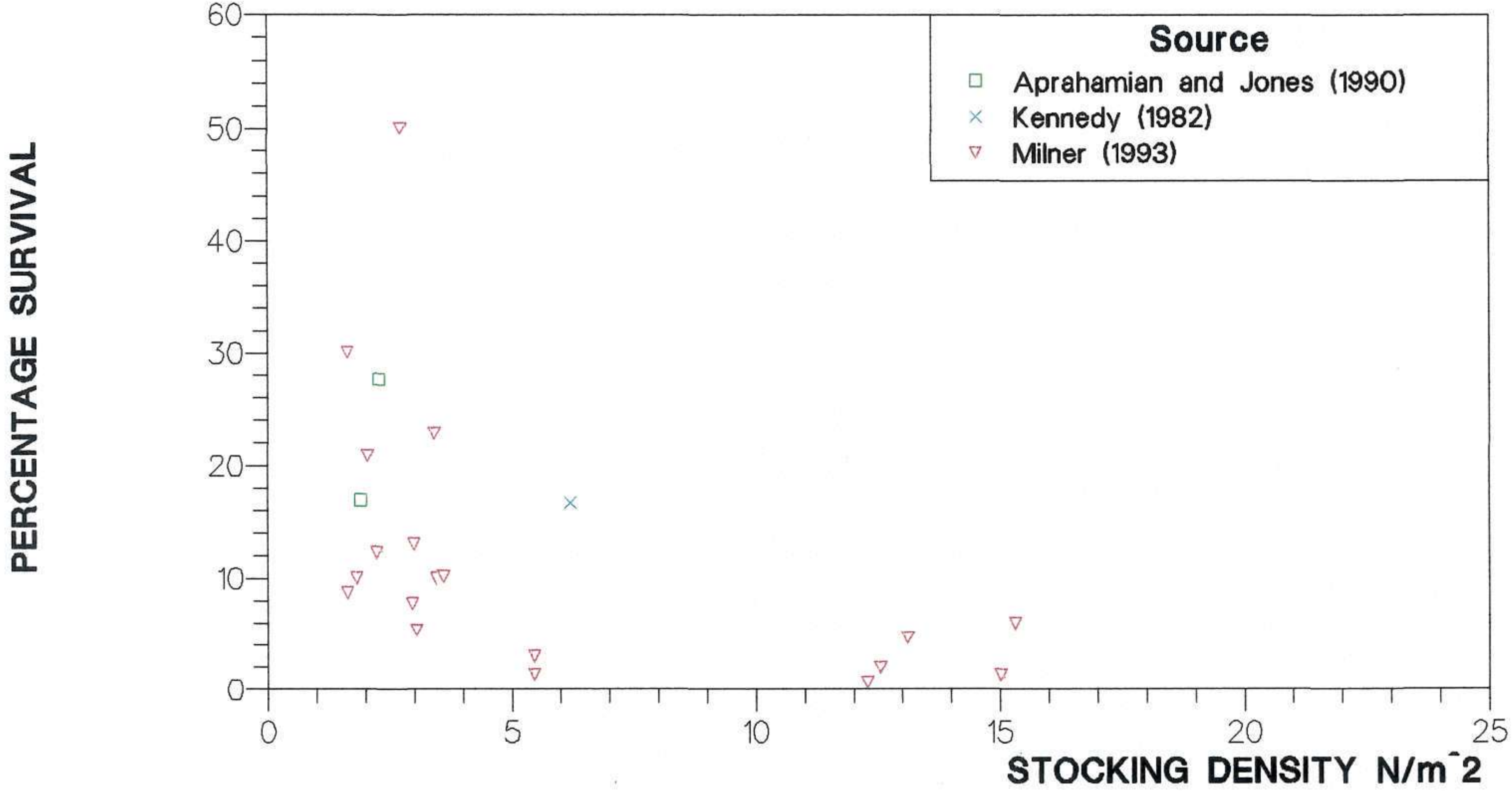
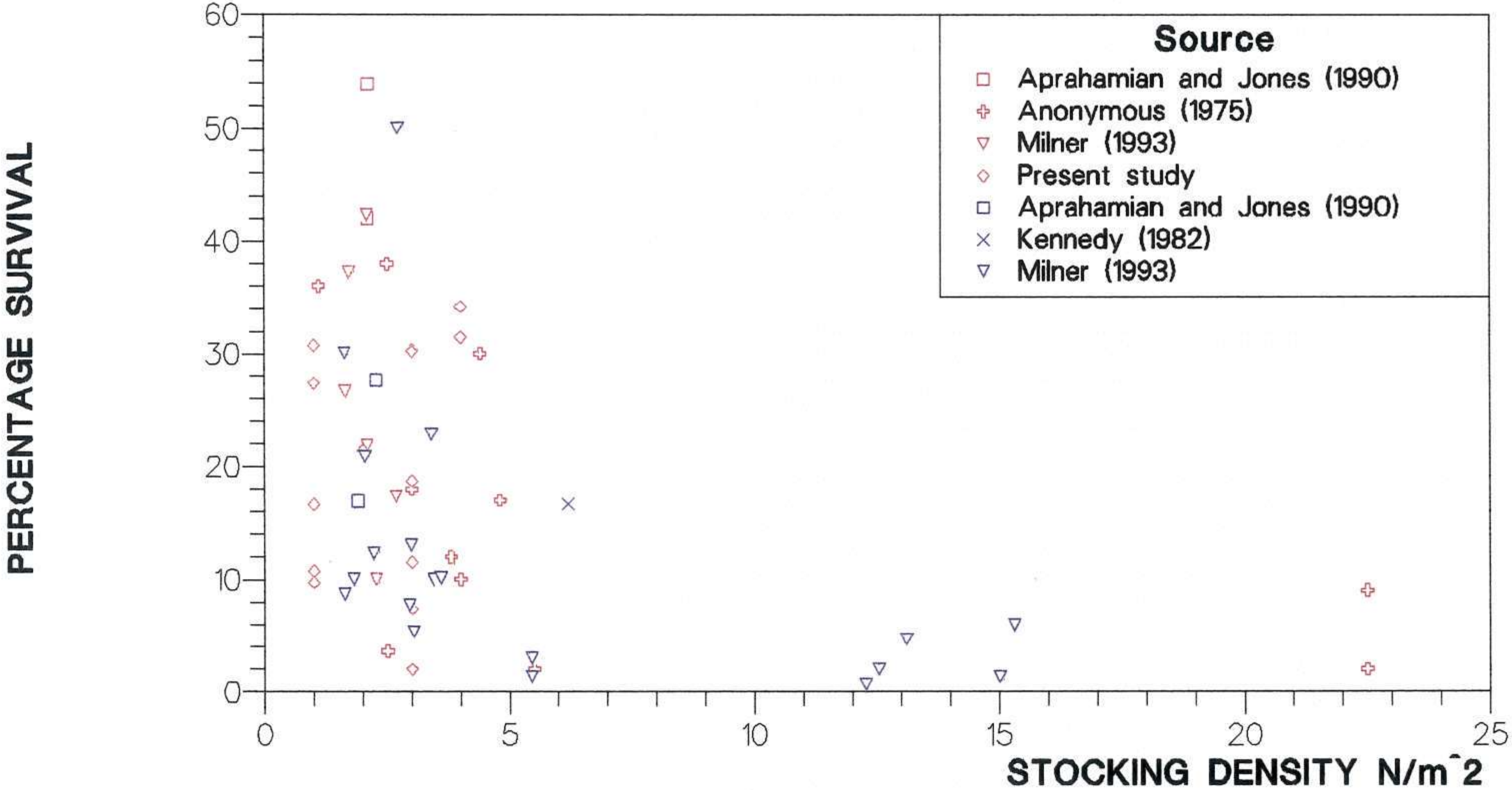


Figure 7. The relationship between fry survival and stocking density



Red = fed fry Blue = unfed fry

There was no significant relationship between fed fry survival to the end of the first growing season and >0+ trout densities which ranged from 3 to 32/100 m^2 ($P > 0.05$).

3.6 Fed fry survival (standardised data) and altitude

A significant negative relationship was found to exist between fry survival to the end of the first growing season and altitude. The relationship was:

$$\text{Log}_{10} \text{ fed fry survival} = 3.44 - 0.913 \log_{10} \text{altitude}$$

$R^2 = 47.6\%$ $P < 0.05$

The standardised residuals suggested an arc shaped pattern indicating that a polynomial model may be more appropriate. However when a second-degree polynomial model was used the resulting R^2 value (43.8%) was found to be slightly lower than that obtained with simple linear regression.

4. Discussion

The results from the present study showed that fry survival ranged from 7.8 to 41.3% with a mean of 22.0% and coefficient of variation (CV) of 0.44, and were comparable with those of other studies (Table 4).

Fry survival from the end of the first growing season to the end of the second growing season ranged from 19.9 to 34.1% with mean of 26.3% and CV of 0.21. By comparison Shackley *et al.* (1992) found that 14.5% of unfed fry survived from August to August the following year while Egglishaw and Shackley (1980) found that annual survival rates varied from 22 to 88%.

Survival from stocking to the end of the second growing period ranged from 1.8 to 9.9% with a mean of 5.2% and a CV of 0.62. This compares with 7.5% found by Shackley *et al.* (1992) for unfed fry in the Lui Water system of the Scottish Dee. Aprahamian and Jones (1990) observed higher levels of survival ranging from 12.2 to 30.9% in tributaries of the R. Usk, Wales.

At the range of stocking densities investigated there was insufficient evidence to determine the point at which density dependent mortality becomes a limiting factor. However, when the non standardised results were combined with those for fed and unfed fry obtained from the literature it was evident that survival to the end of the first growing season decreased significantly at stocking densities > 5/m^2. This relationship is noteworthy in view of the inherent variability of the data sets used; the difference between the time elapsed from the stocking date to the end of the first growing season, and the fact that these studies were carried out over a wide geographic range within the British Isles. To assess whether this relationship is representative and not an artifact of the data set it would be necessary to obtain standardised survival data and then repeat the analysis. The results also indicated that there is unlikely to be any significant benefit, in terms of survival, by stocking with fed fry in

Table 4 Atlantic salmon fry survival rates to the end of the first growing season

	Stocking density (m^{-2})	Percentage survival	Reference
Fed fry	0.1 - 1.8	6.7 - 22.7	Elson (1957)
	0.8	10.7 - 14.6	McCrimmon (1954)
	1.0 - 4.0	7.8 - 41.3	Present study
	1.1 -22.5	2.0 - 38.0	Anon. (1975)
	1.6 - 2.7	10.0 - 42.3	Milner (1993)
	2.1	42.0 - 53.9	Aprahamian and Jones (1990)
Unfed fry	0.1 - 0.9	7.0 - 55.0	Whalen and LaBar (1994)
	1.0 - 1.5	27.0 (ave.)	Orciari *et al.* (1994)
	1.6 (ave.)	24.0 - 29.0	Crozier and Moffet (1995)
	1.6 -15.3	0.7 - 50.0	Milner (1993)
	1.7 -15.5	1.3 - 30.3	Mills (1964, 1969)
	1.9	27.0	Crisp (1995)
	1.9 - 2.3	16.9 - 27.7	Aprahamian and Jones (1990)
	2.0 - 6.2	14.9 - 26.2	Egglishaw (1984)
	2.6 - 3.3	51.8	Shackley, Donaghy and Hay (1992)
	3.6 -29.3	9.4 - 31.0	Egglishaw and Shackley (1980)
	5.0 -10.0	2.2 - 11.3	McCarthy (1980)
	6.2	16.7	Kennedy (1982)

preference to unfed fry. Stocking experiments in North America using Atlantic salmon fry have achieved similar survival rates but at slightly lower stocking densities. Orciari *et al.* (1994) used stocking densities of 1.13 to 1.45/m^2 and obtained 18 to 35% survival to the end of the first growing season. To maximise smolt production they recommended a stocking density of 1 to 1.25/m^2. Whalen and LaBar (1994) used stocking densities of 0.12 to 0.96/m^2 and obtained survival rates between 7 to 55%. They observed that in most cases no significant increase in 0+ density was obtained by stocking at rates $\geq$ 0.5/m^2. In the British Isles the indications are that the optimum stocking density lies in the range of 1 to 4/m^2.

There was little in the way of migration upstream of the stocked zone in all but one of the streams investigated. Displacement downstream of the stocked zone extended over the whole of the target area, however in terms of the proportion of the total population few fish were found downstream of the first 100 m. Egglishaw and Shackley (1980) found the upstream limit of dispersal to be 100 to 200 m above the stocked zone and the downstream limit to be 400 to 600 m below the stocked zone. Kennedy (1982) recorded downstream displacement to occur 250 to 330 m below the stocking zone. In the present study most of the fish that survived remained within the stocked zone (73.1 to 98.6%, mean of 86.7%). This feature has also been observed in other studies e.g. Aprahamian and Jones (1990) estimated that 75.7 to 95.9% of the population derived from stocking of unfed fry remained within the stocked zone. For fed fry this was found to be 82.4 to 86.1%.

The results of this study revealed a significant negative relationship between fry survival to the end of the first growing period and altitude within a range of 140 to 410 m. In England and Wales the relationship between relative density of salmonids and altitude, ranging from 0 to 600 m, has been described by a 'bell-shaped' curve with a maximum density of 0+ salmonids being achieved at an altitude of approximately 200 m (S. Bernard per comm.). In the present study, however, the range in altitude of the sites studied forms part of the right hand side of the curvi-linear section of the bell shaped curve such that the relationship between 0+ salmon survival and altitude can be partially described by a linear model and also by a second-degree polynomial model. Fry survival is not likely to be a function of altitude *per se* but dependent on a number of characteristics some of which vary with altitude e.g. habitat, flow, productivity, and temperature. At certain altitudes these factors provide the optimum conditions for juvenile salmon productivity.

Using the information on the standardised survival rates derived from the present study it is possible to estimate the total number of returning adults (Figure 8). Thus with an initial quantity of 60,000 fed fry 208 returning adults would be expected at a cost of £37 each (£0.13 per fed fry, Harris 1995). If we assume an angler exploitation rate of 10% the cost per rod caught fish would be £370 and at 30% exploitation it would be £123.

From Figure 9 it can be seen that 100,000 eggs (reared to fed fry stage and then released) would be required to produce 208 returning adults. The same number of eggs in the natural environment would result in 81 returning adults. Thus the stocking exercise would result in a net gain to the river of 127 fish.

Figure 8 An estimate of the number adult returns expected from a stocking exercise using fed fry at a density of 1 to $4/m^2$.

60,000 Fed fry

↓ 22.0% survival to end of first growing season

13,200 0+ Parr

↓ 26.3% survival to end of second growing season

3,472 1+ Parr

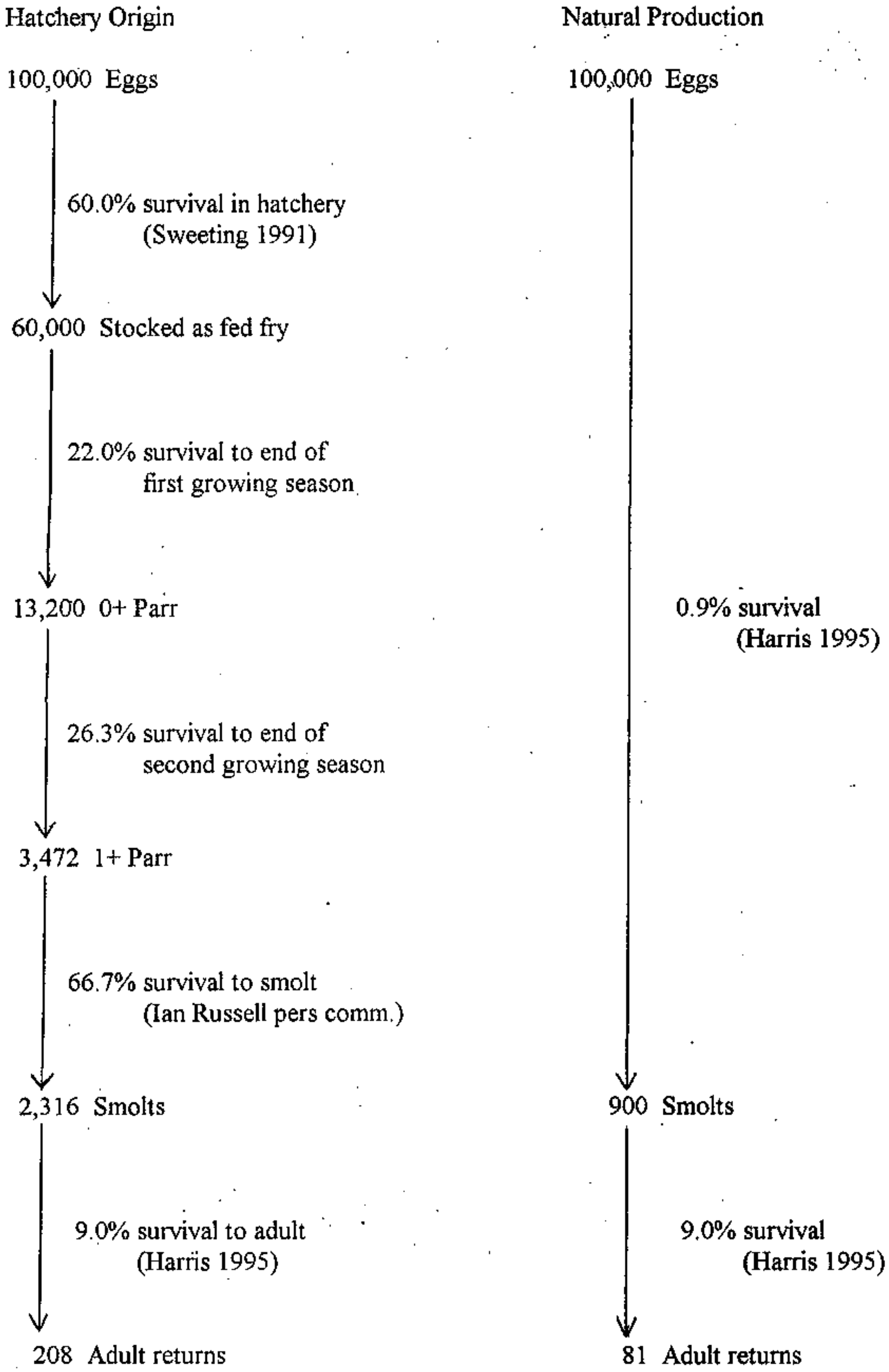
↓ 66.7% survival to smolt (Ian Russell pers comm.)

2,316 Smolts

↓ 9.0% survival to adult (Harris 1995)

208 Adult returns

Figure 9 A comparison of adult return rates resulting from natural productivity and the stocking of fed fry



5. Conclusion

The results of this study suggest that the stocking of fry can be beneficial to a river in terms of the actual number of adults produced, however, where a natural population already exists this gain must be viewed in context with the total run for that river. Stocking is therefore more likely to make a significant contribution to smaller river systems. The economic value of this practice must be a major consideration and the potential benefits should be clearly established before proceeding with a work programme.

6. Recommendations

(1) If the intention is to stock fry then the indications are that the most cost effective procedure would be to use unfed fry in preference to fed fry at a stocking density within a range of 1 to $4/m^2$ and at an altitude of between 140 to 330 m.

(2) Future studies on the fate of stocked fry should ensure that the target area includes a 100 m section both upstream and downstream of the stocked zone to ensure that the survival and dispersal of fry can be fully evaluated.

7. Acknowledgements

The authors are grateful for the contributions made by numerous NRA staff and students during the tenure of this study.

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