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Page 32 - Table 3.1.1 should be replaced by the attached sheet

ICES Copenhagen 10 August 1994

Table 3.1.1 European rivers for which stock-recruitment data are available.

Country	River	Method	Type of index	Smolt output range	Physical characteristics
France	Bresle	US/DS trap	Spawner/Egg - smolt	690 - 2,550	Catchment: 748 km^2 Av. Flow: 6.5 m^3s^{-1}
	Nivelle	US trap + electrofishing	Spawner/Egg - parr	850 - 11,800	Catchment: 238 km^2 Av. Flow: 5.4 m^3s^{-1}
	Oir	US/DS trap	Spawner/Egg - parr	147 - 1,450	Catchment: 85 km^2
Ireland	Burrishoole	US/DS trap	Spawner - smolt Egg - smolt	3,794 - 16,136	lacustrine 450 ha fluvial 155,688 m^2
Norway	Imsa	US/DS trap	Spawner - smolt Egg - smolt	477 - 3,214	width 10 m
UK (E.& W.)	Dee	Partial US trap + electrofishing	Spawner - smolt Egg - smolt		width 60 m
	Wye	Electrofishing	Fry - presmolt		width >8 m
UK (N.Ireland)	Bush	US/DS trap + semi-quantitative electrofishing	Spawner - smolt Egg - smolt	10,006 - 33,365	Catchment 340 km^{-2}
UK (Scotland)	Girnock Burn	US/DS trap	Spawner - smolt Egg - smolt intermed. stages	1,132 - 3,679	width 10 m
	North Esk	Partial US/DS trap + US counter	Spawner - smolt Egg - smolt	93,000 - 275,000	width 45 m
	Shelligan Burn	Single site electrofishing	Fry - presmolt		width <3 m

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International Council for the
Exploration of the Sea

C.M.1994/M:6
Anadromous and Catadromous Fish Committee

REPORT OF THE WORKSHOP ON SALMON SPAWNING STOCK TARGETS IN THE NORTH-EAST ATLANTIC

Bushmills, N. Ireland, 7-9 December 1993

This document is a report of a Working Group of the International Council for the Exploration of the Sea and does not necessarily represent the views of the Council. Therefore, it should not be quoted without consultation with the General Secretary.

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1. INTRODUCTION

1.1 Background:

The North Atlantic Salmon Conservation Organisation (NASCO) annually asks ICES to provide advice on the status of salmon stocks throughout the North Atlantic as a basis for managing salmon fisheries and setting catch levels. For North American stocks, this advice is based upon established spawning stock targets. In the North East Atlantic, however, advice has been based only on time series of data on smolt runs, catches, adult returns, etc. from a limited number of stocks. The Working Group on North Atlantic Salmon has advised that the status of stocks in the North East Atlantic would best be appraised by considering adult escapement evaluated against spawning targets in a similar manner to that adopted for Canadian stocks (Anon, 1993). However, Canadian spawning targets are based upon different levels of freshwater productivity, which may not be appropriate for the North East Atlantic rivers. It was therefore recognised that there was a need to review the available data and examine methods for developing target egg deposition or adult spawner requirements in the NE Atlantic.

The objective of the Workshop was therefore to take the first steps in developing methodologies for setting spawning escapement targets in rivers throughout the North-East Atlantic as a basis for evaluating the status of salmon stocks.

1.2 Terms of reference:

a) evaluate methods that could be used to establish egg deposition requirements or other spawning escapement targets for Atlantic salmon stocks;

b) examine methods that could be used to determine the proportions of the various stock components required to meet the escapement targets;

c) determine the data that are available in the Northeast Atlantic which could be used to set spawning targets;

d) make recommendations on the appropriateness of the various methods in the Northeast Atlantic;

e) report to the Working Group on North Atlantic Salmon, the Anadromous and Catadromous Fish Committee, and ACFM. The report will also be made available to the Atlantic Salmon Trust.

1.3 Participants:

R Borgström	Norway
G Chaput	Canada
W Crozier (Rapporteur)	U.K. (N. Ireland)
D A Dunkley	U.K. (Scotland)
J Erkinaro	Finland
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L Karlsson	Sweden
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G Mawle	U.K. (England and Wales)
N Milner	U.K. (England and Wales)
E Niemela	Finland
M O'Connell	Canada
N O'Maoileidigh	Ireland
E C E Potter (Chairman)	U.K. (England and Wales)
E Prevost	France
A Romakkaniemi	Finland

2. SPAWNING STOCK TARGETS IN NORTH AMERICA

2.1 Establishment of egg deposition targets in Canada

The status of Atlantic salmon stocks in Canada has been reviewed annually by the Canadian Atlantic Fisheries Scientific Advisory Committee (CAFSAC). The review consists of the estimation of total returns of salmon to individual rivers: the estimation of the spawning escapement and a comparison of the virtual egg depositions to a target egg deposition established for the river. The number of individual rivers which have undergone annual review has increased from 3 in 1977 to 11 for the 1992 returns.

Since the first assessments were conducted in 1977, the Anadromous, Catadromous and Freshwater Fishes Subcommittee of CAFSAC considered that there was a minimum egg deposition requirement to maximise smolt production.

> "Management of Atlantic salmon is based on maximum stock-recruitment resultant of an identified minimum number of adult spawners ... For all three river systems, a similar method has been employed to estimate the minimum number of required spawners. The basic assumption is that for maximum smolt production, about 44 lb of female salmon are required per mile of stream 10-yd wide (Elson 1957) (20 kg/14,700m^2). With female large salmon carrying approximately 800 eggs per pound..., egg deposition is then at the general rate of 200 eggs 100 per yd^2 (240/100m^2)." (CAFSAC 1977).

In 1978, a special task force addressed the question of the total Atlantic salmon production potential of the rivers in Canada. The standard 240 eggs 100m^{-2} was used for most river systems except for those in Newfoundland and Labrador where the target egg depositions were adjusted for the estimated smolt productivity of the rivers on the following basis:

Quality Criterion	Smolts 100m^{-2}	Eggs Required 100m^{-2}
Good	>3	225
Fair	2-3	190
Poor	<2	150

In 1980, a modelling workshop, convened to address the question of stock and recruitment and target egg deposition for Atlantic salmon, concluded that a deposition rate of 200 eggs 100m^{-2} would adequately support the variability in rates of egg deposition advocated for certain river systems but that this value should be considered as a minimum rather than an optimum value.

The contribution of lacustrine habitat to the production of smolts was first considered in 1986 and it was not until 1990 that a model for calculating the additional eggs required for lacustrine areas was evaluated and accepted for rivers in Newfoundland.

The use of target egg depositions is now well established in Canada and targets have been tabled for 22 rivers in the maritime region and 9 rivers in Newfoundland.

The target egg deposition is the desired point for the stock level rather than a point of last resort. It was defined synonymously with the conservation level of the stock. The definition of conservation, borrowed from the United Nations Environment Program, World Conservation Strategy 1980, was as follows:

> "That aspect of renewable resource management which ensures that utilisation is sustainable and which safeguards ecological processes and genetic diversity for the maintenance of the resource concerned. Conservation ensures that the

> fullest sustainable advantage is derived from the resource base and that facilities are so located and conducted that the resource base is maintained." (CAFSAC 1991).

The translation of conservation into management principles is based on the potential productivity of rivers, and egg deposition targets of 240 eggs 100m^{-2} of fluvial habitat and 368 eggs ha^{-1} of lacustrine habitat (in Newfoundland) were adopted for that purpose. It is well recognised that the smolt productive capacity of different habitats is variable, and there remains a need to set targets for individual rivers. Until production estimates are refined on a river by river basis, however, the above targets can and are being used to assess the status of Atlantic salmon stocks in Canada.

2.2 Biological basis of the egg deposition target of 240 eggs 100m^{-2}

The standard 240 eggs 100m^{-2} is composed of two parts; the numerator which is the eggs, and the denominator which is a measure of habitat area. The numerator defines a level of production for Atlantic salmon while the denominator scales the production value for transportability to other river systems. The two components are intrinsically linked; using a different category of habitat invariably changes the value of the numerator (Kennedy and Crozier 1993). In Canada, both components have their origin in studies on the Pollett River and the Miramichi River.

The data from the Pollett River can be divided into two distinct experimental phases. The first experiment considered smolt production levels from stocking of fry, while the second experiment considered smolt production resulting from natural spawning.

In the first experiment, fry were stocked in a section of the Pollett River, which was devoid of salmon, at densities ranging from 20 to 220 fry 100yd^{-2}. Under conditions of predator control, Elson (1975) concluded that the maximum smolt production was 5 smolts 100yd^{-2} and this level could be achieved at fry stocking densities of 35-40 fry 100yd^{-2}. The optimum stocking level derived by Elson was a subjective interpretation of the data.

In the second experiment, adult salmon were allowed to enter the same section of the Pollett River and to spawn naturally. An index of fry abundance, smolt production values and corresponding egg depositions are available for eight year classes. Elson (1975) concluded that the egg to fry relationship was linear (Fig. 2.2.1) but that the egg to smolt relationship was curvilinear with relative smolt production decreasing with increasing egg depositions (Fig. 2.2.2). The data suggested that the maximum smolt production from this experiment was about 5 to 6 smolts 100yd^{-2}, similar to those from the stocking experiment. The optimal egg depositions required to produce this number of smolts was in the order of 200-250 eggs 100yd^{-2} (240-290 eggs 100m^{-2}).

In a re-examination of the Pollett River data, four stock-recruitment relationships (linear, linear without intercept term, log-linear and Ricker models) gave significant fits to the egg-to-smolt data. The only two models which provided some measure of maximum smolt production (the log-linear and Ricker models) confirmed Elson's conclusion that maximum production was in the order of 5 smolts 100yd^{-2}. However, the Ricker model suggested that the egg deposition rate required to achieve maximum smolt production was 580 eggs 100yd^{-2}, which was twice the value suggested by Elson.

A second data set was explored by Elson (1975) to confirm the egg deposition values which had been derived from the experiments on the Pollett River. Between 1953 and 1970, estimates of egg depositions for the Northwest Miramichi River were obtained from the returns of salmon enumerated at a counting fence, while indices of fry abundance were available from juvenile surveys. Elson suggested that egg depositions of 140 eggs 100yd^{-2} would be optimum for the production of fry which would in turn result in smolt production levels of 5 or 6 smolts 100yd^{-2}. However, re-examination of these data has revealed two problems with Elson's interpretation. First, the estimated level of smolt production above the fence, during the study, averaged only 1 smolt 100yd^{-2}, not the normal 5 to 6 as suggested by Elson. Second, during the time series in question, the watershed was sprayed with DDT insecticide causing reduced survivals of juvenile salmon (Elson, 1974). If the year classes which were directly impacted by the DDT spraying are excluded from the analysis, only the Ricker stock-recruit relationship can be reasonably adjusted to the egg to fry data and maximum recruitment of fry would be predicted to occur at depositions of 520 eggs 100yd^{-2}, three times the level suggested by Elson (1975).

Re-analysis of the Pollett River data does not confirm the original conclusions of Elson (1975) that smolt production would be maximised at an egg deposition level of 240 eggs 100m^{-2}. The analysis suggests that maximum smolt production, and for the Miramichi maximum fry production, was achieved at deposition levels just over 500 eggs 100 yd^{-2}, twice the originally proposed value.

However, other studies and approaches do provide estimates of optimum egg depositions which are close to 240 eggs 100m^{-2}, and specific studies on Canadian stocks indicate that the current target of 240 eggs lies somewhere between the level required for maximising smolt production and that for maximising adult recruitment.

Symons (1979) indicated that the egg to smolt relationship is compensatory and asymptotic and that maximum smolt production depended upon the average smolt age. For stocks producing mainly 2 year-old smolts, an average production of just over 5 smolts 100m^{-2} could be achieved at egg deposition levels of 200 eggs 100m^{-2}, whereas for 3 year-old-smolt stocks, an average of 2 smolts 100m^{-2} could be produced from egg deposition levels of 150-200 eggs 100m^{-2}.

A smolt production potential of 3 smolts 100m^{-2} is considered a more realistic average level for Canada and has been used as the standard production value for fluvial habitat in Newfoundland. Analysis of juvenile densities in the Miramichi and Restigouche rivers in Canada indicated that egg depositions of at least 240 eggs 100m^{-2} are required to achieve maximum densities of fry and parr. Adult-adult stock-recruit relationships from Canada indicated that for one stock, the maximum gain (see section 4) was achieved at egg deposition levels of 300 eggs 100m^{-2} while in the other stock, the maximum gain was achieved at levels of 100 eggs 100m^{-2}.

2.3 Habitat area used for egg deposition targets

Egg deposition targets must be related to an area of habitat. In the case of the early studies from the Pollett River and the Miramichi, the total bottom area of stream accessible to salmon was used. The criteria currently used to quantify salmon habitat in Canada have not been standardised and vary between management regions. For many rivers, the total bottom area is used, while in others, areas with gradients less than 0.12% are excluded.

The Workshop noted that the most readily available and therefore the most commonly used value is the total wetted area. It also felt that since salmon juveniles utilise a wide range of habitats (including estuaries), ignoring habitat on the basis of low gradient values, substrate type and other physical attributes may result in an underestimation of the total potential production of the river system. However in rivers where deep, downstream sections are little used for spawning or nursery areas, there inclusion may have a large effect on the nominal area. In applying targets over a number of different river systems, usable area may therefore be a more useful value.

It was recognised that there was a need to standardise the type of habitat and the method of quantifying that habitat for the rivers being considered. River specific targets which are defined using adult stock-recruit data can ignore the habitat component. However, the habitat area becomes important when we want to explore underlying relationships in the population dynamics of Atlantic salmon which can be used to manage stocks which lack long-term stock-recruit data (i.e. transportability to other river systems).

In Newfoundland, lacustrine areas are estimated on the basis of the total surface area obtained from topographic maps.

2.4 Generalised smolt production model for Canadian rivers.

2.4.1 Approach

The assessment of Atlantic salmon stocks in Canada is based on comparing estimates of actual egg deposition to a target level of 240 eggs $100m^{-2}$ of fluvial habitat (plus 368 eggs ha^{-1} of lacustrine habitat in Newfoundland). This target egg deposition represents the level which is expected to maximise smolt production and is applied equally to all rivers, regardless of the stock characteristics of the recruiting adults. Since adult characteristics vary between stocks, an egg deposition level which maximises returns of 1SW salmon for one river may not be appropriate for a river where the dominant component is 2SW fish. However, the relationship between egg deposition and smolt production may be more consistent between rivers. A general model is therefore proposed which relates egg depositions and smolt production and which is then applied to derive a target egg deposition for rivers with adult salmon of different stock characteristics.

2.4.2 Data and Methods

Egg to smolt data are available for eight rivers in Canada, for variable time series, which can be categorised into two groups: 6 rivers with predominantly or exclusively fluvial habitat, and 2 rivers with large areas of lacustrine habitat known to be used for rearing of parr. In all the rivers, the habitat which was considered available for production of smolts was the fluvial area.

The following model is fitted to the data set:

$$\text{Smolt density} = a_r\,[\text{Egg Density}]^{b_r}$$

where subscript 'r' refers to the 'river group'.

To understand the parameters of the model, it is useful to divide both sides by [Egg Density], such that:

$$[\text{Smolt Density}]/[\text{Egg Density}] = a_r\,[\text{Egg Density}]^{(b_r-1)} = a_r/([\text{Egg Density}]^{(1-b_r)})$$

By doing so, the left hand side equates to the egg-to-smolt survival rate.

We expect $0 <= b <= 1$.

If $b = 1$ (i.e. $1-b = 0$), then the survival rate is constant and determined by density independent effects. If $b = 0$, then survival rate is inversely proportional to egg density. Thus:

If $b = 1$: $[\text{Smolt Density}]/[\text{Egg Density}] = [\text{Survival Rate}] = a_r$

If $b = 0$: $[\text{Survival Rate}] = a_r/[\text{Egg Density}]$

More generally, $1-b$ represents the density dependent component of the egg-to-smolt survival rate on the egg density. Values of $1-b$ near 0 correspond to a weak density dependent effect and values near 1 correspond to a strong density dependent effect.

The fit of the data to the model was evaluated by first converting to the linear equivalent form by natural logarithm transformation. Differences between the egg-to-smolt survival rates in the fluvial group relative to the lacustrine group were tested by treating river category in a dummy variable split-slope model.

2.4.3 Results

The estimated egg densities in the eight rivers varied between 21 and 3,141 eggs $100m^{-2}$ of fluvial habitat area. Estimated smolt densities varied between 0.5 and 7.6 smolts $100m^{-2}$ of fluvial habitat area. The variation within river systems was as important as the variation between river systems. The egg-to-smolt survival rates decrease quickly with increasing egg depositions (Fig. 2.4.1). A preliminary fitting of the model indicated that the survival rates from the Miramichi River, after adjusting for egg density, were abnormally low, probably as a result of effects of industry. These data were excluded from further analysis. The adjusted model gives the following equations:

Fluvial group: $[\text{Smolt Density}] = 0.67*[\text{Egg Density}]^{0.28}$

Lacustrine group: $[\text{Smolt Density}] = 0.89*[\text{Egg Density}]^{0.28}$

The final model fit indicated that the slope parameter (log[b]) was not significantly different between the two river groups but there was a significant difference in the intercept term (log[a]) (Fig. 2.4.2.).The similarity in the **b** coefficient indicates that the density dependent component of the egg-to-smolt survival rate is the same for both river groups. This would support the hypothesis that the density dependent relationship between egg density and survival rate is determined at the time of egg deposition, hatching, or soon afterwards and is not related to the smolt rearing habitat.

The difference in the **a** coefficients for the two groups indicates that the overall density independent survival rate is different and this is dependent upon the quantity of smolt rearing habitat. For equivalent egg depositions, the rivers in the lacustrine group can produce 33% more smolts in terms of fluvial habitat than the rivers without lacustrine habitat. The increased production may result from the additional lacustrine areas available for production or the presence of fewer competing or predatory species.

Smolt production increases with increasing egg deposition in a compensatory manner. This analysis indicates that the density dependent mortality occurs very early in the life cycle. This has also been shown in studies of Atlantic salmon on the River Bush (Kennedy and Crozier 1993) and on brown trout (Elliott, 1993).

2.4.4 Conversion to Target Egg Depositions

Target egg depositions should be based on optimising or maximising the recruitment back to the river. The general egg-to-smolt recruitment curve derived in this analysis assumes that all eggs are equivalent, although this is clearly an oversimplification. Targets derived on the basis of maximising fry, parr or smolts also assume that smolts are equivalent regardless of their river origin. This is also incorrect given the variability in adult characteristics of salmon stocks and must therefore be adjusted for.

Using the characteristics of the adult stock and assuming that there is no density-dependent mortality of smolts at sea, we can convert the smolt value to recruited eggs and solve for objective reference levels on the stock-recruitment curve. The following example illustrates the process:

Western Arm Brook

Life stage	1SW
Sex Ratio	74%
Fecundity	1540 kg^{-1}
Mean Weight	2.05 kg
Sea Survival	8%

Egg depositions ($100m^{-2}$) required for:

Maximum gain (Recruited eggs - spawner eggs)	200 eggs $100m^{-2}$
For replacement	1185 eggs $100m^{-2}$

It is clear from Fig. 2.4.3 that the egg depositions for optimising smolt production or in this case, recruiting eggs is sensitive to sea survival. As sea survival increases, the number of eggs required to achieve maximum gain also increases. Of all the parameters, sea survival is likely to vary the most. For Western Arm Brook, the sea survival back to the counting fence as 1SW salmon has varied between 2.2% and 12.1%.

This approach would allow a general egg-to-smolt stock-recruitment curve to be tailored to different river systems with stocks of different adult characteristics and different sea survival. This would be a move away from using a fixed egg deposition value to be applied to all rivers, such as the value of 240 eggs $100m^{-2}$ which is currently used in Canada.

2.5 Methods used to determine target stock composition

2.5.1 Atlantic Canada

Having established the target egg deposition, several methods are used to decide upon the required composition of the spawning stock, including splitting the target on the basis of present size composition of the stock, to using the historical composition, or requiring that all eggs come from large salmon. In Atlantic Canada, spawner requirements are calculated on the basis of all eggs being deposited by large salmon (>= 63 cm fork length) for the following reasons:

1. large salmon are predominantly female (generally > 70% female) whereas small salmon are predominantly male (generally < 25% female). Consequently, as many as eight small salmon may be required to produce the same number of eggs as one large salmon;

2. in several river system large salmon returns can be predicted one year in advance but small salmon cannot. From a management standpoint, relying on large salmon for egg deposition makes good sense.

The small salmon spawner requirement is calculated on the basis of ensuring that there is sufficient male salmon escapement to meet the female component of the spawner target. In this case, egg depositions by small salmon are treated as top-up or buffer against poor density independent survival.

2.5.2 Newfoundland

Target spawning requirements in terms of adults in Newfoundland are calculated for small salmon (<63 cm in length) only. Most small salmon are virgin grilse (1SW), with some repeat spawning grilse. Egg depositions from large salmon (>63 cm) are considered as a buffer to estimates of spawning requirements. These fish constitute up to 10% of total runs in most rivers and are predominantly repeat spawning grilse.

3. STOCK AND RECRUITMENT STUDIES IN EUROPE

3.1 Introduction

The Workshop reviewed river systems with available data on stock-recruitment relationships with a view to establishing whether suitable information existed to suggest a basis for setting spawning targets for European stocks. Data were available from the River Bush (N. Ireland), R. Burrishoole (Ireland), Girnock Burn and Shelligan (Scotland), Wye (Wales), Nivelle, Oir and Bresle (France). Data were also available from the River Imsa (Norway), North Esk (Scotland) and R. Dee (Wales) (Table 3.1.1). In addition, the availability of data likely to yield stock-recruitment information in the future was also examined. Further information is provided by country below.

Monitoring methods in the different rivers vary, but several have trapping facilities both for upstream migrating adults and downstream migrating smolts. At several of these localities, sex and size distribution and fecundity relationships have been established for the adults and age distribution of the smolts. Furthermore, estimates of numbers of fish caught after passing the trap are provided. In these rivers stock-recruitment relationships are established based on egg to smolt survival. In the Shelligan and R. Wye the stock-recruitment relationships are based on fry to pre-smolt.

There is wide variation in geographical distribution, size and physical conditions in these rivers and it is a matter of debate if stock-recruitment relationships from one type of stream are generally applicable to other catchments with possibly very different environmental and biological conditions. This issue is considered in Section 6 on transportability of the stock-recruitment curves and targets. However, with respect to information needed, it was clear that there is a general lack of information for larger rivers and this makes it particularly important to urgently enhance the data collection on those large rivers where good systems were either fully in place (North Esk) or in the process of development (Welsh Dee).

The Workshop recognises that monitoring programmes have been undertaken in several rivers that have not been considered here. These include the R. Teno (Finland), the R Axe (UK, England and Wales) and several Icelandic and Russian rivers. The aim of these programmes is not to develop stock-recruitment relationships, but rather to observe fluctuations between years of stock components and life history variables. It is recommended that such projects be assessed for the possibility of developing stock-recruitment relationships.

3.2 France

Stock-recruitment data are collected every year on three French rivers.

1. **Nivelle** (Pays Basque): short coastal stream (37 km long) flowing into the Golfe de Gascogne, close to the Spanish border (the upper reaches are in Spain); catchment area is 238 km^2 and average flow is 5.4 m^{3}s^{-1}.

2. **Oir** (Lower Normandy): spawning tributary (19.5 km long) of the lower part of the Selune river, which is a short coastal stream flowing into the Baie du Mont St Michel; catchment area is 85 km^2.

3. **Bresle** (upper Normandy): short coastal stream (72 km long) flowing into the channel; catchment area is 748 km^2 and average flow is 6.5 m^{3}s^{-1}.

Stock data come from trapping facilities for the adults, and recruitment data are smolt counts derived from trapping facilities (Oir and Bresle) or estimates of the 0+ parr population size in autumn (Nivelle and Oir), this stage being close to smolt stage in France as the majority (on average over 70%) of the juveniles migrates out of the river as 1+ smolts.

Data for 8 cohorts are available on the Nivelle and the Oir, for 3 cohorts on the Bresle. The Nivelle and Oir data suggests that variability increases with increasing levels of egg deposition (Figs. 3.2.1 and 3.2.2)

Although there are certainly not enough data on each river separately to try to fit a stock-recruitment model and use it as a basis to set "spawning targets", an analysis of all the three data sets pooled together could be recommended as a first step. The data set from the R Oir suggests that a likely spawning target for maximum smolt output (based upon domed curve fitted by eye) would lie in the region of 840 eggs $100m^{-2}$ of habitat used by juveniles, equivalent to 2130 eggs $100m^{-2}$ of "first class" habitat. These figures are about twice those proposed by Kennedy and Crozier (1993) for the R Bush.

3.3 Ireland

Data are available from the total upstream and downstream trapping facility on the **R Burrishoole** for the period 1970 to 1993. This facility provides a complete count of spawning escapement and smolt output. The salmon stock is characterised by a predominance of 2+ smolts (95%) and a returning adult component made up principally of grilse (over 90%) with a sex ratio approaching 1:1.

Ranched fish can make a varying contribution to the spawning escapement (1 to 60%) but their contribution to the smolt output is not known.

The Burrishoole catchment area is 110 km² consisting of an accessible fluvial habitat of 155,688 m². The trap location is between two large lakes, a brackish water lake downstream and a freshwater lake upstream. Freshwater lacustrine habitat is approximately 410 ha. Recent habitat degradation has been reported and studies are ongoing to examine the associated problems. Monitoring information has shown a decline in smolt output since the trap has been operated. The catchment is divided into two areas of different productive potential based on geological characteristics:

Total area of the Burrishoole catchment:

Low Acid Neutalising Capacity (ANC)/Poor productivity	49.3%
Medium to high ANC/Good productivity	50.7%

Total accessible fluvial habitat:

Low ANC/Poor productivity	32.1%	(49,998 m²)
Medium to high ANC/Good productivity	67.9%	(105,570 m²)

All lacustrine habitat is contained within the areas of medium to high ANC.

An estimated 30% of the catchment is afforested. Afforestation has been ongoing since 1956. The remaining areas are restricted to hillside grazing of sheep or peat cutting.

Stock-recruitment data were estimated initially comparing adult escapement (spawners) to smolt output after three years on the assumption that the majority of smolts are 2+ years of age (Fig. 3.3.1). These data have been subdivided into time periods from 1972-1979, 1980-1987 and 1988-1993 and show three possible stock-recruitment curves within this period. This is consistent with the observation of severe habitat degradation in recent years and highlights the necessity of examining long-term stock-recruitment data in conjunction with other information (physical, chemical etc.), particularly if changes are known to be occurring in the catchment.

3.4 Norway

River Imsa: Trapping facilities catching the entire run of descending smolts and ascending adults have been in operation on the R Imsa since autumn 1975. The River Imsa has an annual water discharge of about 5.5 m^3s^{-1} and the river is 1 km long. The number of downstream migrating smolts has varied between 477 and 3214. Preliminary assessments indicate an average annual smolt production of 15 smolts $100m^{-2}$. A stock-recruitment relationship is under development and will be completed in 1994 after the final collection of fecundity data.

River Orkla: Salmon smolt production on the R. Orkla has been estimated by mark-recapture and between 1983 and 1993, production estimates has varied from 4.0 to 10.8 smolts $100m^{-2}$. After regulation for hydro-power, the smolt production in this river increased. It was concluded that the increase was mainly due to the increase in the winter water discharge.

Halsa stream: In 1987, a new facility was opened in the Halsa stream, northernmost Norway. Here, traps have been built to catch all descending smolts and ascending adults, but it is still too early to make assessments.

3.5 Sweden

River Ätran: Stock-recruitment data are collected every year in the river Ätran, a tributary of the River Högvadsån on the Swedish west coast. There is a total of 15 ha of rearing area on this stream, with a further 7 ha in the other tributaries and 29 ha in the main river. The river is affected by acidification, but smolt production was improved in the 1980s as a result of liming operations.

Stock data come from trapping of adults, which has been carried out since 1955, and estimates of smolt recruitment have been obtained from partial trapping since 1959. Electrofishing of salmon parr has been carried out in this and other rivers during the autumn, since 1986.

3.6 UK (England & Wales)

The National Rivers Authority (NRA) has responsibility for the management of salmon and sea trout fisheries for UK (England and Wales) and is preparing a national management plan for these species. A central element of this is an assessment of the feasibility and mechanisms for setting spawning targets to optimise spawning escapement. Approaches that have been considered for setting spawning targets and monitoring fisheries performance against such targets (i.e. egg depositions achieved) are outlined below.

Studies are underway to derive targets from habitat based models (e.g. HABSCORE, NRA unpublished). However, these only apply to short (typically 50m) river sections. They define abundance levels of 0+ and >0+ fish to be expected on average in pristine (no artificial environmental constraints and recruitment not limiting) sites. The principal application of these models so far has been in impact assessment. Existing procedures require fairly extensive habitat description at each site, so extensive surveys of whole catchments would be expensive.

Welsh streams: Current levels of egg deposition are being assessed in 21 Welsh streams. The protocol used is described below, based on the data from the Welsh Dee, where a programme of long-term stock assessment has been in hand since 1991 using a partial trap and mark-recapture programme. For the Dee, sea-age composition was measured in the trap catch (Jan-Dec) - a sample representing 28% of the annual run. In-season (Jan 26-Oct 14) exploitation rate on each sea-age was estimated by mark-recapture. The proportion of each sea-age entering in season, their sex ratios and female mean fork lengths were estimated from the trap sample. Fecundity per female was estimated using the overall equation of Pope et al (1961). No allowance was made for in-river natural mortality or illegal fishing, but the final values can be approximately corrected by 7% to account for these losses. The Dee data indicate a virtual egg deposition of 303 eggs 100m^{-2} (corrected to 282 for natural and illegal losses). The result also shows the relatively greater contribution that MSW fish make to egg deposition (47%) compared with their numbers in the run (35%), a feature of the higher proportion of females and their relatively greater fecundity compared with 1SW fish.

The rivers of the west coast of Wales encompass a wide variety of river type and size. The objective of the current programme is to develop a protocol to estimate egg deposition for all of these using, where appropriate, parameter estimates from "monitored rivers" and any general relationships that are helpful. Some of the relationships observed are summarised in Section 6.2.2. Using rod catch as the best available index of run, egg deposition for 21 Welsh rivers has been calculated (Table 3.6.1).

River Conwy, North Wales: In addition to estimating egg deposition from rod catches, it has been possible to derive estimates from the observed abundance of juveniles (fry) in rearing areas by making assumptions about survival from eggs to fry. Extensive survey data are needed and a suitable data set was available from the River Conwy, North Wales. These calculations are summarised in Table 3.6.2).

Overall (virtual) egg deposition was 402 and 126 eggs 100m^{-2} at egg-fry survival rates of 2.5 and 8% respectively. Within river sections deposition ranged from 80 to 3492 and 25 to 1091 eggs 100 m^{-2} at the two rates respectively. The large areas of main stem river render the overall egg deposition particularly susceptible to errors in their fry estimates.

Wye: Stream studies on tributaries of the river Wye have yielded a stock-recruitment relationship based on fry to pre-smolts with an optimal June density of 285 fry 100m^{-2} (Gee et al, 1978).

There are several other sources of adult and juvenile stock data from catch (rod and net) statistics, reported annual resistivity counts and juvenile electrofishing surveys.

Lake District (sea trout): A study on juvenile sea trout recruitment in a small naturally spawned stream in the Lake District (NW England) (Elliott, 1984a, 1984b, 1989) indicated a gently domed or flat-topped relationship for eggs to August/September 0+ survivors, with the asymptote at an egg deposition of 6250 eggs 100m^{-2}. This was noted as further evidence that target egg depositions in localised areas of good nursery habitat and target egg depositions for rivers as a whole are not synonymous, but are highly dependent on the habitat types available.

3.7 UK (Northern Ireland)

In Northern Ireland, a long term study on stock-recruitment in a wild salmon population has been running on the **R Bush** since 1973. In addition, experiments on survival of salmon stocked at various densities have been carried out in an experimental stream in the R Bush headwaters.

Data were presented from the River Bush covering a number of aspects, and comparisons were made with other studies. For wild river Bush stocks the main points highlighted were:

1. The number of smolts per spawner was considerably more variable at low egg depositions than at high egg depositions (Fig 3.7.1).
2. This variability in smolt production at low egg depositions was apparent for both 1+ and 2+ smolt production (Fig. 3.7.2 & 3.7.3). At high egg depositions 1+ smolt production showed reduced variability, with only low outputs found, while 2+ smolt production was apparently maintained at previous levels. However, too few data points were available at high egg depositions to indicate definitive ranges of smolt production here.

3. A Ricker curve was fitted to the overall smolt output for the River Bush. The asymptote of this curve was at an egg deposition of 2.5 million (Fig. 3.7.4).

4. The areas of different habitat types found in the Bush catchment were quantified for the purposes of expressing overall ova deposition on a per unit area basis; these are listed below:

Habitat type	Area
Total river catchment	33,700 ha
Total wetted surface of river	84.55 ha
Total useable salmonid nursery habitat	41.06 ha
Total useable grade A salmonid nursery habitat	23.38 ha
Total area of grade A salmonid nursery habitat normally used	16.91 ha

The asymptote of production of 2.5 million eggs for the catchment was then expressed as a function of each of these habitat definitions. This overall egg deposition equated to 291 eggs 100m^{-2} for the whole wetted surface of the river, 599 eggs 100m^{-2} for all usable salmonid nursery habitat, 1052 eggs 100m^{-2} if only grade A salmonid nursery habitat was the criterion and 1455 eggs 100m^{-2} if only the grade A salmonid nursery habitat normally used by spawners was considered, i.e. the overall target egg deposition derived from the asymptote of the stock-recruitment curve could be interpreted as different egg deposition rates depending on the habitat criteria applied.

5. Comparison of the R. Bush egg-to-smolt survival data with those from the R. Burrishoole (Ireland) (Fig. 3.7.5) indicated that:

   (a) There was a positive correlation between the two systems in most years, but not with total consistency. This was interpreted as indicative of an overlying regulating mechanism influencing egg-to-smolt survival similarity in both rivers, but that this could be over-ridden by local factors in some years. This mechanism was presumed to be environmental.

   (b) The maximum and average survival from egg to smolt on the R. Burrishoole is less than half that on the R. Bush. This was taken to be an indication of different levels of productivity in the two catchments.

   (c) Despite the lower productivity levels on the Burrishoole, it was noted that the maximum smolt output per unit of catchment was higher here (1.75 smolts ha^{-1}) than the maximum smolt output from the R. Bush (1.09 smolts ha^{-1}). The difference appeared to be the result of production arising from lake dwelling parr in L. Feeagh (410 ha) in the Burrishoole catchment, the Bush having no comparable standing water in its catchment. It was noted that no data on lacustrine salmon production are available in Ireland.

6. The results of stocking experiments on a tributary of the R. Bush using a range of stocking densities from 100 to 3000 swim-up fry 100m^{-2} were also presented. The fitted curves mirrored a stock-recruitment relationship which could be either flat topped or gently domed (Figs. 3.7.6 and 3.7.7). Density independent variability had the greatest relative impact at low egg depositions (Fig 3.7.8) as in the R. Bush as a whole. The asymptote of the relationship appeared to be in excess of 30 m^{-2}. This is similar to the findings of Elliott (1984a, 1984b, 1989) in studies of juvenile sea trout.

3.8 UK (Scotland)

Girnock Burn: Stock data for the Girnock Burn (a tributary of the R. Dee, Aberdeenshire) come from full trapping facilities, plus redd counts in some years. Recruitment data comes from a full smolt trap, plus, for some years, trapping of migrant autumn parr and electrofishing surveys.

Various types of stock-recruitment data are available for the Girnock Burn with varying numbers of data points, e.g.

Eggs to summer 0+
summer 1+
smolts
autumn parr plus smolts.

Detailed electrofishing estimates of the summer populations of each age class exist for 1968-1977. The recruitment data show that density dependent control of numbers must still be continuing after the summer sampling of age 0+ fish and that maximum recruitment to summer 1+ requires about 1000 eggs 100m^{-2} (Fig. 3.8.1)

Shelligan Burn: Frequent electrofishing of one well-studied sample area on the Shelligan Burn (a tributary of the R.Tay) allows good survivorship lines of some cohorts to be plotted from emergence to pre-smolts. These survivorship lines suggest that a stock of about 1000 fry 100m^{-2} (this time as emergent fry) will again be required for maximum recruitment (Fig. 3.8.2).

Stock-recruitment data are available from artificial stocking with eggs or unfed fry in the Fender Burn, a tributary of the River Garry, not accessible to adult salmon. A fitted Ricker curve (Fig. 3.8.3) suggests that maximum recruitment to the end of the first growing season was achieved at a stocking density of about 1500-2000 eggs/fry 100m^{-2}.

North Esk: Egg deposition estimates are available for a number of years on the R North Esk, a monitored river, but data on smolt production are incomplete and a stock-recruitment relationship has not yet been established.

River Garry: An example was also presented where adult counts, habitat area measurements and juvenile survey data can be used to examine the appropriateness of a particular target level could be examined in the absence of a stock-recruitment relationship for the river:

It may be possible to roughly estimate the adult spawning populations on the Perthshire River Garry from annual counts at the hydro-electric dams, corrected for fish removed by anglers. Over the period 1951 to 1992, the nuber of fish ascending the River garry has ranged from about 2,000 to 12,000 fish. At least half the run is apparently 2SW female fish with an average fecundity of about 7,000 eggs. The accessible area is clearly defined due to impassable falls and has been surveyed to produce an estimate of 1.14x10^{6}m^2 (total accessible running water). It seems likely that the egg deposition has varied from about 600 eggs 100m^{-2} (1991) to about 3700 eggs 100m^{-2} (1973). Juvenile surveys in 1980 and 1985 suggest reasonably stable densities of juveniles, but electrofishing survey work in the summer of 1992 showed some patchiness in 0+ salmon distribution because one freely accessible stretch of stream which had been used previously, contained only a few 0+ salmon. These observations suggest that egg depositions below around 600 egg 100m^{-2} overall result in some under-utilisation of habitat, and an appropriate target would be a little above this level.

4. ESTABLISHING STOCK TARGETS

4.1 Reference Points from Stock-recruitment Data

The Workshop considered methods for defining objectively the point on a stock-recruitment curve at which the stock production will be optimised. The optimum spawning stock, which will provide the 'target egg deposition level', can be defined on the basis of a variety of criteria in order to maximise the sustainable advantage to the stock. The management of Canadian Atlantic salmon stocks is based on an optimum reference point to achieve "conservation" (as adopted by CAFSAC, 1991).

The generalised shape of the stock-recruitment curve for Atlantic salmon is compensatory rather than linear. The recruit/spawner ratio is maximum at the point closest to the origin and decreases at increasing spawner levels. The stock-recruit curve can take many forms:

1. recruitment continuing to increase with increasing level of spawners;
2. an asymptotic form, where the recruitment tends towards a maximum; or
3. a form which is over-compensatory where recruitment reaches a maximum but then decreases with increasing spawner level beyond that point.

All compensatory curves, regardless of their shape, have a clearly defined point where the level of recruitment equals the level of spawners required to produce that recruitment, called the **replacement level** (Fig. 4.1.1). This point is a stable equilibrium point; over a very large number of generations it is the point which defines the average recruitment level. This point could define the upper bound to target spawning requirement.

A second definable reference point is the point of **maximum gain** defined as the spawner level which generates the maximum surplus recruitment (recruitment - spawner required = surplus). This point, like the first, can only be derived if the recruitment and spawner axes are in similar units (e.g. eggs or adult fish).

The over-compensation curve (e.g. Ricker model) has a third clearly definable reference point which is the spawner level which generates **maximum recruitment**. The spawners for maximum recruitment are always greater than or equal to the spawners for maximum gain. The extent of the difference between the two levels is dependent upon the initial productive capacity of the stock. The spawners for maximum gain can be considered as the lower limit of possible target spawner levels. Somewhere in between this lower limit and the upper limit (replacement level) lies an optimum which will minimise the risk of recruitment over-fishing while maximising the gain.

Defining these reference levels may not be immediately obvious if the stock-recruitment curves consider only a portion of the life cycle. The following example shows the process of completing the stock-recruitment curve through the life cycle and how to calculate some of the possible reference levels. The data presented here are used for illustrative purposes only.

4.2 An example case from the River Bush (UK, Northern Ireland)

An overcompensation (Ricker) egg to smolt stock-recruitment curve was modelled for the River Bush Atlantic salmon stock. The maximum production of smolts is obtained at a spawner level of 2.7 million eggs (Fig 4.1.1). The replacement level and the point of maximum gain can only be defined if the smolts are carried through to recruiting eggs. This is done by using the following values for the River Bush stock obtained from experimental observations. (These values are typical, but are not to be taken as averages.)

1. smolt to adult sea survival to the coast = 31.6%,

2. fecundity of female salmon = 3,400 eggs per fish,
3. sex ratio = 60% female.

With these parameters fixed, the smolts are converted to recruitment eggs which results in a rescaling of the recruitment axis without any change in the form of the curve.

The reference points can be estimated directly from this curve (Fig. 4.1.1) as follows:

Reference Point	**No. Eggs required at reference point** x (10⁶)	**No. Recruited Eggs at reference point** x (10⁶)	**Gain at reference point** x (10⁶)
Maximum gain	2.3	15.3	13.0
Maximum recruit	2.7	15.5	12.8
Replacement	7.5	7.5	0

The target egg deposition level on the River Bush is therefore bounded by reference levels of 2.3 and 7.5 million eggs.

4.3 Variability in stock-recruitment data

All stock-recruitment relationships examined have shown considerable variation in the level of recruitment whether measured as numbers of smolts produced or numbers of adults returning. In addition to measurement errors, the error around the average egg-to-smolt stock-recruitment curve may be derived from density independent effects in the freshwater environment. These largely result from variation in environmental factors. However, concern was also expressed about the possible effects of variation in spawning success.

The success of spawning may be influenced by the dispersion of returning adults between spawning areas. This may occur as a result of variation in spawner abundance or access. It is possible that in some years, although spawner abundance is high, river conditions may prevent full utilisation of spawning territory. In some rivers, partial obstructions may exist, such as weirs or falls, which may not be impassable but may restrict access to upstream areas. In years of high spawner abundance, fish may be stimulated to ascend these obstacles even if river conditions are not ideal. In years of low spawner abundance, fish may be reluctant to ascend these obstacles even if river conditions are suitable, and this may result in clumping of spawners in the lower reaches of tributaries.

The availability of suitable spawning territory is also important in determining egg deposition. Changes in the physical characteristics of river catchments may have important effects both between years and in the longer-term. Inter-annual variations in rainfall and discharge levels are of obvious importance in determining areas available for spawning between years. More long-term changes such as habitat degradation, stream bed siltation or compaction, water quality changes as a result of alterations in land-use, acidification, etc. will also constrain the numbers of eggs which may be deposited. Such changes have been reported for the River Burishoole in Ireland (section 3.3).

Variability in the marine phase of the life cycle may also occur for a number of reasons. For example, the level of natural mortality in the sea may be affected by marine environmental conditions, and the level of fishing mortality on the high seas and in coastal waters may vary between years. Data from, for example, the River Imsa (Norway) have indicated that post-smolt survival in the sea may vary between 4.3% and 21.3% (Table 4.3.1; Fig. 4.3.1). There is also some indication of auto-correlation in the data; a year showing poor survival is more likely to be followed by another year of poor survival than by a year of high survival.

Returning adult salmon populations from different rivers, and different stock components within rivers, will vary in their age structures and the different age classes will vary in sex ratio. For example, in the net catch taken in the North Esk in the period 1984-1993, the percentage of the catch comprising 1SW salmon varied between 45.8% and 76.8% (mean 63%), the comparable figures for 2SW salmon being 21.9% and 52% (mean 35.4%)(Table 4.3.2; Fig. 4.3.2). In the 1SW stock component, females accounted for 37.2% to 52.9% (mean 46%) whereas in the MSW component, females accounted for 51.6% to 70.6% (mean 62.17%) (Table 4.3.2; Fig. 4.3.2). Different age classes will also vary in fish size distribution. In North Esk salmon in 1984-1993, inter-annual variation in size was small. For 1SW salmon, annual mean length varied between 58.4 cm and 62.9 cm (Table 4.3.2; Fig. 4.3.3). Comparable figures for 2SW salmon were 73.2 cm to 77.1 cm and for 3SW salmon, annual mean length varied from 86.4 cm to 90.6 cm (Table 4.3.2; Fig. 4.3.3). However, such consistency between years may not occur with other populations.

Numerous investigations have demonstrated relationships between fecundity and fish size, the latter either in terms of fish length or weight. It has also been shown that fecundity in repeat spawners may be different from that of maiden fish of similar size. Total egg deposition will, therefore, depend not only on the numbers of fish returning but also on these various biological characteristics. Data from France suggest that the fecundity of fish of given length might vary considerably between some years (Fig. 4.3.4). In the North Esk, significant differences in fecundity values of fish of a given length have been demonstrated in some but not all years but the differences have not been as large as shown in France.

It has been established in the North Esk that female salmon entering the river at different times of year have different fecundity relationships. Those fish entering early in the year lay fewer eggs per unit length than those entering later in the year (Fig. 4.3.5). Total egg deposition has been calculated for the North Esk using (A) a single fecundity relationship value (that for late running fish) and (B) a range of values bounded by the low fecundity of early running fish and the high fecundity of late running fish. In all years examined, method A gave a higher estimated egg deposition value but the percentage difference between the results from the two methods varied between 8% and 14%.

Among the implications of the differences in fecundity in different fish are that changes in run-timing or selective exploitation on particular stock components may affect egg deposition levels. The matter is further complicated by the fact that although early running fish lay fewer eggs than late runners, the eggs are larger and post-hatch survival may be higher.

Fisheries may be selective for sea-age classes and/or sex. For example, in the case of high seas fisheries, the fish taken are likely to be those which, had they returned, would have done so as MSW salmon. It is possible, therefore, that female salmon may be selectively exploited as a result of fisheries being targeted on MSW salmon. Furthermore, it was found in the Faroes fishery that there was a higher proportion of female fish in catches in the north of the EEZ than in the south (*ref*). Thus, the level of egg deposition may be affected rather more than would be apparent simply from observed changes in the numbers of fish.

Different age classes of fish may return at different times of year. Some fish may return outwith fishing seasons and, therefore, not be subject to exploitation in in-river fisheries while others may contribute greatly to catches. It is important, therefore, to define clearly what is meant by the number of returning adults and where and when this is measured.

The impact of fish farm escapees on spawning levels is not clear. In some years, large numbers of fish farm escapees may ascend some rivers. There is evidence, however, that spawning success in these fish may be low and the fitness of the progeny may be lower than for wild stocks. (*ref*). The Workshop recommended that more research is needed to define the possible effects on productivity of wild salmon populations consequent on interbreeding with escaped farmed salmon. Similarly, the consequences of biologically-based targets set for wild salmon being met in part by spawning of reared salmon need considered.

4.4 Incorporating uncertainty in setting targets

The previous section lists a number of factors which will result in variability in the stock-recruitment relationship. Where egg-to-egg stock-recruitment curves are derived from field data, all such variability should be incorporated within the error bounds about the average curve. In practice, such errors introduce an element of risk into the assessment, and it is a matter for managers to decide whether they wish to adopt a risk neutral or risk averse strategy. The risk neutral approach is to use the mean recruitment data, but a risk averse strategy may be adopted by using a larger number of recruits (e.g. using the mean curve plus one standard error).

Where egg-to-adult curves are derived, additional errors arising from variation in spawning success and fecundity may have to be taken into account. Similarly, egg-to-smolt stock-recruitment curves will include only the variability in the juvenile phase of the life cycle. Once again a risk neutral approach may be adopted using mean parameter values or a risk positive or risk negative approach by using the mean plus or minus one standard error.

Some variability is indicated by the scatter of points and the confidence limits for the average stock-recruitment curve (Fig. 4.4.1). The Workshop considered a method for defining a possible optimum point on the stock-recruitment curve which would incorporate the uncertainty caused by this variability. The objective would be to reduce the risk of the number of recruits in any generation giving an egg deposition level below the lower reference level, in this case the maximum gain. This new reference point is calculated as follows:

1. The exploitation rate (ER) of the fishery is calculated as if the maximum gain is harvested. In this example, ER = 13.0/15.3 = 0.85.

2. The upper and lower limits of the predicted recruitment for the spawner level at maximum gain are calculated. In this example, we use +/- 1 std error lines (this represents about 67% of the predicted recruitment distribution). These limits provide a measure of the uncertainty in the freshwater portion of the life cycle.

3. Calculate the escapement at the upper (3.1 million) and lower (1.5 million) predicted recruitment based on 85% exploitation (from 1).

4. Transpose these escapements onto the spawner axis.

For a risk averse strategy, the target egg deposition could be set at 3.1 million eggs, 135% of the maximum gain and 115% of the maximum recruitment level. The risk neutral strategy is, of course, to set target escapement at the level for maximum gain.

It is important to check that the target egg deposition chosen in this way does not generate recruitment levels which, if exploited at the maximum allowable exploitation rate, would result in escapement levels which are below the lower reference point (maximum gain). In this case, the risk averse strategy gives the predicted recruitment bounds of 1.5 to 3.1 million and no additional apparent security has been gained.

The Workshop also considered a more flexible approach to the minimisation of risk, which would involve resampling techniques (e.g. bootstrapping) to estimate and incorporate uncertainty. Resampling can be used to recalculate the stock-recruit curve, from which the 15% escapement value is determined. These estimated escapement levels can be cumulated and their probability distribution plotted. The median and percentiles of interest can be extracted from the plot. A strategy may be to try various target levels, in steps, and determine the effectiveness of the selected strategy in minimising the probability of obtaining escapement levels, after exploitation, which are below the target escapement which maximises the gain. In the resampling exercise, the proportion of the escapement values which are below the desired values indicate the effectiveness of the strategy in achieving the objectives.

The above optimisation exercise was based on the exploitation rate which can be applied to recruitment when spawner levels are at the point of maximum gain . Other optimisation strategies can also be considered, and managers may need to take other factors into consideration when setting targets, such as the need to allow sufficient fish to enter freshwater to satisfy angling demand.

Some of the variability in stock-recruitment curves will be specific to particular rivers or groups of rivers and must be considered separately to allow "tailoring" of any general model to particular rivers. Data available to the Workshop from various rivers around the N Atlantic (Fig. 4.4.2) may indicate different stock-recruitment relationships. This would mean that an egg deposition level which appears to be risk averse on one river, might give different levels of risk in other rivers.

The Workshop recommended that further attention should be given to objective methods of providing risk margins for setting spawning targets.

4.5 Modelling variability in stock-recruitment

The temporal variation in the factors affecting survival from smolt to egg can be incorporated into the optimisation process using the same resampling procedure performed for the freshwater variability.

A simple model was developed, employing the following assumptions based on R. Bush data. The assumptions of the model were as follows:

1. The relationship between egg deposition (S) and the smolts produced (R) is:-

   $R = 0.0262 * S * e^{-0.4052.S}$

   where S and R are in millions.

2. Smolt output is assumed to comprise one cohort. (In practice it comprises two cohorts, S1 and S2, with S1s comprising 0.17-0.57 of output from a given spawning.)

3. The variance of smolt output around the stock-recruitment line is assumed to be constant, normally distributed with a standard deviation of 0.00708 million smolts.

4. Marine survival from smolt to adult at the coast is taken as normally distributed with a mean of 0.316 and S.D. of 0.0457.

5. The yield taken from the adults returning to the coast is defined by the exploitation rate associated with the target egg deposition being examined. This exploitation rate is the theoretical yield that could be taken (assuming no variance about the stock-recruitment line) as a proportion of the number of returning adults.

6. The number of spawners is assumed to be the number of returning adults less yield.

7. The number of eggs deposited is calculated by assuming that 60% of the spawners are female, with an average fecundity of 3400 eggs.

The model was used to examine the stability of (i) the annual catch and (ii) spawning escapement at different spawning targets between the points of maximum gain and replacement. It was run for 20 generations at each target level.

Reducing the exploitation rate in order to meet higher spawning target resulted in the stability of both the annual catch and spawning escapement decreasing markedly (Figs 4.5.1 and

4.5.2). Thus the effects of setting a level of exploitation below that appropriate to meet a spawning target at the point of maximum gain would be to reduce the size and stability the annual catch, although it would not reduce stock sustainability.

The Workshop recommended that this approach be developed further to assess the effects of multiple cohorts and different patterns of density independent variance in the stock-recruitment relationship on different spawning target levels.

5. ESTABLISHING NEW STOCK-RECRUITMENT RELATIONSHIPS

Stock-recruitment relationships may be expressed in several forms (eggs deposited to smolt output; eggs to pre-smolt; eggs to eggs; early fry to pre-smolts; spawners (male and female) to smolts; spawners to spawners; etc.). The Workshop considered that the most useful form is that of eggs deposited to smolt output (egg-to-smolt). The general shape of the stock-recruitment relationship often appears to be controlled by density dependent regulation before and/or during the first summer after emergence. It is therefore clear that to define the form of the stock-recruitment relationship will require data covering this density dependent control period. (Fig. 5.1)

The eggs-to-smolt relationship can be assessed directly (D) or indirectly (I):

Basic Parameter	Methods of assessment
Eggs deposited	From adult runs, sex composition and fecundity data (D)
	By sampling of fry soon after emergence (perhaps by extensive semi-quantitative sampling) (I)
	Redd counting and sampling (I)
Smolt output	Complete trapping (D)
	Partial trapping combined with mark-recapture estimates (I)
	Electrofishing surveys of older parr (I)

For transportability of data, it is essential that data be referenced to a common standard. The Workshop suggested that this should be the grade of nursery habitat available in the catchment.

The assessment of adult numbers may be carried out directly or indirectly viz:

Complete trapping (D)

Electronic or acoustic counters (D)

Direct visual counts - bank based/by diving (D) (e.g. Norway)

Angling catch and exploitation rate; catch-effort analysis (I)

Partial trapping combined with marking and creel census of anglers to provide mark-recapture estimates (I)

Redd counts (I)

It is noted that both direct and indirect methods of assessing adults are prone to errors of measurement or rely on assumptions. For example, redd counts are affected by river levels, angler exploitation rates may vary through the season, and acoustic or resistivity counts need to be calibrated. However, adult counts based on these methods are available for many more rivers than direct counts, and it is recognised that they may represent the only data available on many managed rivers for which it is desired to set targets.

6. TRANSPORTING TARGETS BETWEEN FLUVIAL SYSTEMS

6.1 Applicability of stock-recruitment data to other river systems.

Even if the recommendations above are fully implemented, collection of data will take many years. It is also unlikely that definitive stock-recruitment data will ever be available for more than a small minority of the systems where stock targets are required. Therefore, the Workshop recognised the need to examine the transportability of stock-recruitment data between systems.

Initial analyses of stock-recruitment data available to the Workshop indicated that care was needed in trying to extrapolate relationships, and thus stock targets, from one system to another. There is evidence that stock-recruitment relationships are not just stock specific (in terms of ratio of 1SW/MSW fish, fecundity levels, genetic potential for growth etc.), but are also habitat specific. Hence, studies from single tributaries with ideal habitat may yield different stock-recruitment curves from the whole river stock. Even assuming that productivity in ideal salmon producing habitat is approximately equal in all systems, a target deposition level derived for a whole river will reflect the balance of optimal and sub-optimal habitat present. Hence there is a need to have habitat inventory data available for rivers where stock-recruitment relationships have been defined and rivers where they are to be applied, in order that like is applied to like.

6.2 Fluvial systems

6.2.1 The problems

The Workshop considered that the problems associated with transporting stock-recruitment information from one area of fluvial habitat to another could be considered on three levels:

1.	Within catchments	- from tributaries to whole rivers
2.	Between catchments	- tributaries to tributaries - whole rivers to whole rivers

This approach attempted to take account both of differences in the biological characteristics of stocks and the greater likelihood of tributary studies being based on areas containing higher proportions of suitable salmonid habitat than whole river studies.

The Workshop recognised that a number of habitat models were available in the literature, ranging from the 'broad brush' approach (based largely on the subjective knowledge of survey personnel as to what constitutes good, fair and poor salmonid nursery habitat), through to quantitative predictive models (e.g. Heggenes, J. and Saltveit, S.J. , 1990; Baglinière and Champigneulle, 1986; Baglinière and Maisse, 1993).

There was general agreement that there was a need for guidelines for the transport of stock-recruitment information between systems. A table was therefore drawn up covering all the aspects which were regarded as having a potentially important impact on stock and recruitment in a system. An example data set for the R. Nivelle (France) is given in Table 6.2.1.

A number of these factors have been examined in attempts to set targets in Welsh rivers and streams. Some of the findings are summarised below:

River size (mainstem river length) explained up to 54% of rod catch (17 yr mean) variation in a sample of 34 rivers (Fig. 6.2.1). Similar correlations were found with total stream length and average daily flow.

The proportion of 1SW fish also varies systematically with river size (Fig. 6.2.2).

Stream area gave a significant ($R^2 = 87.7$, $P>0.001$, $df = 6$) regression of area on stream length (Table 3.6.1) was used to estimate areas for other rivers.

The accuracy of rod catch recording may differ between rivers of different size and fishery characteristics. River flow often explains a significant part of rod catch variance and correction of rod catches by flow should be feasible for most of the rivers here.

Systematic variation in exploitation rate (U) between different types of river is highly likely. Large differences occur according to the time of entry on the Dee (Fig. 6.2.3) and this timing may differ across the variety of rivers, as well as river-specific variation in fish accessibility and vulnerability. The Dee data also illustrate the effect of river flow on U.

Run timing on the river may also vary. There may be significant differences in the proportion of salmon entering the river outside the fishing season. This is more likely to be the case for 1SW salmon than 2SW fish.

Female length may vary in response to a number of factors. Long term reduction has occurred in lengths of 1SW fish caught at West Greenland (Friedland et al, 1993). There is also evidence of reduction in size at age of salmon returning to the river Wye.

Proportion of females is well known to vary with sea age, with generally higher values in older age groups.

It was recommended that the catchment, habitat and biological details listed in Table 6.2.1 should be provided for all index stocks which may be used as a basis for deriving targets. In addition, an inventory of habitat types should be developed, using this agreed approach, for all rivers with managed salmon populations for which it is intended to set spawning targets.

6.2.2 Examination of some examples

It became apparent that one of the main factors influencing transportability of data is the relative proportions of salmonid habitat, and specifically grade 'A' nursery habitat, in index rivers compared to target rivers. Several examples were available to the Workshop, and an initial attempt at comparing egg deposition and stock-recruitment information on two groups of data sets was undertaken:

(a) Stock-recruitment curves for smaller streams;

(b) Stock-recruitment curves for "whole river" large systems

Smaller stream and tributary based studies

Data were available from the Girnock and Shelligan Burns in Scotland and the three tributaries of the River Wye in Wales. These data were expressed as emergent fry or nearest approximation (= spawners) and late summer 1+ parr (= recruits) (Fig.6.2.4). There were some difficulties ensuring comparability of data because of the different methods used in the three studies. The Wye data covered a much smaller range of fry densities (20-230 fry 100m^{-2}) compared with the Scottish sites (250-3400 fry 100m^{-2}). This difference reflected real variation in population densities between the streams which may result from differences in the environments, or inter-specific or intra-specific interactions.

The relationship between instantaneous loss rate and starting density was not significantly different amongst the three Wye tributaries, so these data were combined. Regressions of loss rate (Log e (parr/fry)) against fry density were similar for the Shelligan and Girnock, but the Wye appeared to be different (Fig. 6.2.5). Estimated maximum parr outputs, according to Ricker fits to these data, occurred at emergent fry densities of 585, 629, 1011 and 1253 fry 100m^{-2} in the Wye, Girnock, Shelligan and combined data respectively. The Workshop concluded that while all data sets could be described by the same relationship the possibility that the Wye represented a different type of population could not be discounted and that further work was needed to resolve this.

An important factor that needs to be taken into account when comparing spawner-recruit relationships is intercohort competion, which may have significant effects especially in small streams (Bohlin, 1977; Heggenes and Borgstrom, 1993)

Whole river studies:

Stock-recruitment information is available from a number of larger index rivers, River Bush (UK, N. Ireland), River Burrishoole (Ireland), Girnock Burn (UK, Scotland). [The Girnock Burn is a relatively small stream (length 9.5 km, mean width 6.6 m, peak discharge 22m^{3}s^{-1}) which joins the River Dee some 80 km from its mouth at Aberdeen. It was felt that this data set could be considered in both groups and provided a cross reference.]

The data have been standardised by determining fecundity per female from each source population and estimating the adult stock composition and numbers from trap data. Smolt output was estimated directly by trap counts. The data have been standardised to smolts 100m^{-2} and eggs deposited 100m^{-2} on the basis of the known fluvial habitat available in the catchment.

These data are compared initially using untransformed data (Fig. 6.2.6) and transformed data (Fig. 6.2.7). Unlike the analyses of the individual stock-recruitment relationships, and without fitting curves statistically, the usefulness of these combined data are questionable because of the wide variation in egg deposition to smolt output. The data indicate variability both within and between systems, which may be due to various factors including possible differences in interspecific competition and predation. This must be considered with regard to the transportability of index stock-recruitment curves to describe other catchments.

Linearising the data (Fig. 6.2.4) did not resolve the overall relationship, but differences in elevations and slopes of the individual data series (fitted by eye) are evident. The Workshop recommended that these data should be further analysed using analysis of covariance to establish whether there are statistical differences between these data series. Further research is required to invetsigate density independent variation.

7. TRANSPORTING TARGETS BETWEEN LACUSTRINE SYSTEMS

7.1 Targets for lacustrine systems in Canada

In Newfoundland, Canada, juvenile anadromous Atlantic salmon make extensive use of lacustrine habitat for rearing. This situation probably results from the lack of potential predators and competitors, such as members of the families Esocidae, Cyprinidae, and Percidae. Other salmonid species present include Eastern brook trout, Arctic charr, and in some cases, brown trout. Also found are species of stickleback and the American eel.

Juveniles are found in lakes throughout the year. The lakes typically possess boulder/rubble shorelines and vary in size from < 10 ha to 300 ha. The littoral zone has been shown to be the dominant area utilised for rearing; the other contributory areas are the pelagic zone and deeper benthic areas. There is a tendency for older and larger parr to be found in the pelagic zone and in deeper benthic areas. The extent of the littoral zone (determined on the basis of average Secchi disc depth) can encompass the entire bottom area in shallow lakes or vary according to depth, slope of basin, and shoreline development in deeper lakes (up to 15-20 m). There is no hypolimnetic oxygen depletion in these lakes in either summer or winter.

Because of the substantial contribution of lacustrine habitat to total smolt production in Newfoundland river systems, target spawning requirements were defined in terms of the relative contribution of fluvial and lacustrine habitats. This was done using the best information available at the time. Complete smolt counts were available for 2 rivers characterised by fluvial habitat and 3 rivers dominated by lacustrine habitat (all rivers located in southern Newfoundland). These data formed the basis to derive a smolt production value of 3 smolts $100m^{-2}$ for fluvial habitat and 7 smolts ha^{-1} for lacustrine habitat, which were recommended for general application in Newfoundland. Smolts were converted to eggs using egg-to-smolt survival values (0.0125 for fluvial habitat and 0.019 for lacustrine habitat). The egg-to-smolt value for fluvial habitat was calculated by dividing 3 smolts $100m^{-2}$ by 240 eggs $100m^{-2}$. The value for lacustrine habitat was derived in part in relation to a stock-recruitment relationship for a river in Northern Newfoundland. It is not known if the smolt production values for both habitats and the egg-to-smolt value for fluvial habitat reflect optimal smolt production.

The following limitations apply to the use of fixed values on a broad scale in Newfoundland:

1. There could be inter-annual and inter-river variation in such values as a result of differences in geographical location of rivers, physico-chemical characteristics, and overall productivity;

2. Fluvial smolt production was defined in terms of boulder/rubble/gravel (good) habitat, the relative proportion of which can vary among rivers; lacustrine production was expressed in terms of total lake surface area and does not account for variation in the relative proportion of littoral zone among lakes;

3. It is assumed that the location of spawning substrate is such that under natural mechanisms of distribution, juveniles will have access to all the specified fluvial and lacustrine habitat, a condition that will be met to varying degrees in different rivers;

4. Fluvial and lacustrine environments were treated as dichotomies in terms of juvenile residence when in reality there could be a dynamic interaction between the two; the extent of movements of juveniles of different age and size classes among lacustrine habitats is not known.

7.2 Targets for lacustrine systems in Europe

No data were provided to the Workshop on salmon production from lacustrine habitat in the NE Atlantic region. Historical salmon stocking trials have been carried out in Welsh lakes (Harris, 1973; Pedley & Jones, 1978) where non-migration of the smolts was identified as a problem associated with lack of suitable outflow conditions. This problem was confirmed by studies in Norway (Hansen, 1987; Hansen et al., 1984) which further suggested that smolts which were delayed in their migration out of or through lakes had considerably reduced sea survival, apparently as a result of missing their 'window' of migration. One recent study into natural lacustrine production in the NE Atlantic region has been carried out in Lake Medalfellsvatn in Iceland (Einarsson, Mills & Johannson, 1990), where estimates of smolt production were at a similar level to those in Canada (approx. 7 smolts ha^{-1}). Work carried out in Norway also suggests that lacustrine habitat may make a major contribution to smolt production (Halvorsen, in press).

However, it became apparent to the Workshop that much of the lacustrine habitat in the NE Atlantic region did not meet either the physical criteria necessary for salmon production and/or had indigenous predatory fish species which were incompatible. It was recommended that surveys of the physical characteristics of lakes in this region should be undertaken in conjunction with sampling to determine the presence or absence of juvenile salmon. The Workshop underlined the need for lacustrine salmon production estimates to be developed over the NE Atlantic range of the species.

The following steps should be considered in any attempt to integrate the contribution of lacustrine habitat into target spawning requirements in European rivers. Surveys are required to :

1. establish the presence or absence of juvenile salmon in lacustrine areas;
2. determine the community composition of fish species in lakes;
3. determine surface area of lakes and substrate type of the shoreline littoral area (If the lacustrine area is a regulated impoundment, the range in fluctuation in the level of the littoral area must be considered).

Following this, application of the Newfoundland parameter values should only be considered if the lakes possess a similar shoreline substrate to Newfoundland lakes and do not possess the non-salmonid families of fishes listed above. Most of the sources of error or risk outlined above for Newfoundland could also apply to Europe as well as others unique to Europe.

An examination of information for some lakes in Europe suggested that the Newfoundland model would be inappropriate. The following is a suggested approach to determine river-specific estimates of smolt production for lacustrine habitat in Europe, which might be considered for transport to other systems (subject to the error factors listed above):

1. If production is determined on the basis of an entire river system or tributary encompassing many lakes, then the overall contribution of lacustrine habitat can be determined as the difference between total production and that estimated for fluvial habitat.
2. If smolt production estimates are to be determined for individual lakes, the location of a lake in relation to spawning areas must be considered. In Newfoundland, estimates of smolt production from a lake immediately below a spawning area were substantially higher than from a lake remote from spawning areas.
3. If mark-recapture estimates are employed, it would be wise to attempt capture of fish in the deeper benthic area and the pelagic zone. This is because it is not known at

present if the tendency of older and larger parr to occupy these areas is a random or fixed process in terms of movements.

4. Conversions of smolts to eggs will require the use of egg-to-smolt values derived from European rivers.

The virtual absence of salmon production estimates from lacustrine habitats in Europe is a serious deficiency which must be corrected before targets can be considered for systems where lacustrine habitat is present. This is reinforced by the probability that lacustrine production data derived from Newfoundland cannot be exported for use in Europe (because of differing physical criteria and fish species composition). The Workshop recommended that efforts should be made to collect these data.

8. STOCK COMPOSITION FOR SPAWNING TARGETS

The Workshop considered to what extent the Canadian methodology of setting composition of spawning targets with respect to different stock components would be applicable to the NE Atlantic. Several possibilities exist for allocation, ranging from splitting the target on the basis of present sea-age composition of the stock, to using historical composition as a basis for allocation. The simplest method would be to set allocations on the basis of present stock composition, taking account of the higher egg yield per fish for MSW compared to 1SW individuals.

Where the majority of the stock comprises one sea-age group, and especially if most of the numerically dominant sea-age group are females, then the target may be based on one sea-age group alone. The other sea-age groups may then be treated as top-up or buffer against poor. density independent survival.

Whatever method of allocating target numbers of female fish is chosen, it is necessary to match these with an equivalent number of males for spawning.

There is also a requirement to consider the genetic implications of the different strategies of setting target composition. This arises because of the recognition that all reproductively-viable components of a population contribute to the gene pool, hence managing over a period of time with respect to a target comprising mainly or solely one sea-age type may lead to a loss of genetic diversity. This risk is particularly strong if managers allow increased exploitation on parts of the population not considered important in achieving the defined target. The possibility is recognised however that if targets are set with respect to historical proportions of sea-age types, then the management action taken to achieve those targets (e.g. restriction of rod exploitation on MSW fish) may help preserve those parts of the gene pool that are perceived to be threatened.

Spawning targets will normally be based on characteristics of wild populations of salmon and are intended to have a biologically meaningful relationship to stock productivity in the natural environment. In certain situations artificially-reared salmon may contribute to spawning in a river. This is particularly true in areas prone to influxes of escaped farmed salmon (e.g. Norway and north and west Scotland), where it can be envisaged that a significant portion of the spawning target could be met by spawning of these fish. If the reproductive potential of adults or fitness of offspring differ substantially from the wild stock, this will have implications for the productivity of the river and will impact stable management with respect to net gains in the wild population. The Workshop recommended that more research is needed into the consequences for the productivity of wild salmon populations of interbreeding with escaped farmed salmon.

Although composition of targets with respect to stock characteristics should ideally be set for each river system, it unlikely that the stock characteristics of more than a few river stocks will be known in each area. Hence, some assumptions will need to be made in setting targets on many river systems. Comparison of physical data between rivers and/or habitat data in a manner analogous to that proposed in Section 6 along with catch data will provide some guidance on likely stock characteristics and hence appropriate composition of the spawning target.

An additional factor to be considered in allocating composition of targets is the geographical level at which the target is applied: *viz* one target per whole catchment vs. targets applied separately to each tributary etc. As stock composition is likely to vary within a catchment, especially in large river systems, the setting of an overall river target may need to take account of this, but may not be able to do so in the absence of detailed stock information. Monitoring stock performance against targets for component parts of large catchments would probably be resource limited in any case. The Workshop recommended that spawning targets could best be initially applied to whole rivers, unless evidence of suitability of more local targets was available and means existed to monitor them separately.

The Workshop recommended that composition of spawning targets would in most cases be best approached in relation to present sea-age composition of stocks, but recognised that in certain rivers managers may wish to apportion targets on a different basis. In the former situation it is recognised that target composition may change as stock composition changes in response to fishery or other factors.

9. APPLYING SPAWNING TARGETS IN EUROPE

The Workshop, in reviewing stock-recruitment and salmon productivity data available for Canadian and European stocks considered that the 240 eggs 100m^{-2} standard applied to Canadian fluvial habitat could not be applied to European salmon rivers. This stems largely from the evidence from European salmon stock-recruitment studies that egg depositions for maximum juvenile recruitment (in some cases expressed as parr, in others smolts) were on average higher (sometimes by a factor of 2 or more) than the Canadian targets. In addition, there was evidence of a large spread in optimum egg deposition rates postulated for European rivers (ranging from 1052 eggs to 2130 eggs 100m^{-2} in terms of first class nursery habitat). This variability in productivity is thought to reflect the greater latitudinal and environmental variation inherent in the range of European stocks examined in comparison to Canadian stocks. A corollary of this is that smolt production estimates for European stocks examined also varied greatly among stocks (e.g. <3- >20 smolts 100m^{-2}).

The Workshop concluded that while individual whole river stock-recruitment studies could be used to set targets for those rivers (without regard to habitat components involved), these could not be exported to other rivers without further careful comparison of the quantity and quality of the available habitat. An additional factor to be considered in transporting of targets from one river to another is the apparent difference in the form of the stock-recruitment relationships that have been defined for different stocks so far. These differences and the underlying dynamic reasons for them need to be examined in greater detail. It is likely that such differences reflect a combination of differing stock productivity parameters and also the physical scale of the studies involved (whole river vs. localised habitat area).

Because uncertainties remain as to the nature of the underlying stock-recruitment relationships in most European salmon stocks, it is not yet clear to what extent an egg deposition target (perhaps objectively defined with respect to criteria given in Section 4) derived from one river could be applied to other systems. However, since answers to many of the uncertainties lie some way off, it is important to attempt to develop stock targets for individual European rivers wherever possible.

Monitored rivers, where trapping facilities allow counting and biological sampling of the adult run, will provide the most reliable source on information to establish target egg deposition levels and assess whether they are being achieved. A lesser degree of confidence will be apparent in rivers where data on run size and composition is based on partial trapping or extrapolation from angling catches or some other proxy as there will be uncertainties about sex ratio, fecundity, exploitation rates, etc. Managers should also attempt to apply methods to estimate egg deposition rates and set targets which do not rely upon stock-recruitment data, such as those described in Sections 3.6 and 3.8.

It is recommended that spawning targets should be objectively defined for rivers where stock-recruitment relationships are available. These should be defined initially as whole river targets, but work should be undertaken to define them as habitat specific targets to facilitate their future use on other rivers. This approach has the advantage that the targets for the several rivers involved can be defined and can then be fine-tuned in the light of observed productivity in future years. They will in addition provide a first set of targets to compare status of stocks trends in European salmon stocks.

10. RECOMMENDATIONS

1. There is an urgent requirement to enhance stock-recruitment data sets from larger rivers, because much of the European data are derived from smaller rivers or tributaries. In this regard, it would be of great value to enhance collection of stock-recruitment data on the rivers N Esk (UK, Scotland) and the Dee (UK, England and Wales).

2. Monitoring programmes are known to be in place in several rivers not considered here (e.g. Teno (Finland), Axe (UK, England and Wales), and several Icelandic and Russian rivers). Although these programmes are not specifically designed to yield stock-recruitment data, consideration should be given to developing stock-recruitment relationships for these rivers. Data required would include adult escapement and smolt counts, together with characteristics of the fish (age, size, sex ratio, fecundity).

3. There is a need to supplement the stock-recruitment data already existing for several rivers, with particular attention being given to assessing effects of density-independent variance right across a wide range of egg depositions as well as its causes. The effects (on spawning success) of distribution of adults at the time of spawning should also be considered, especially on larger rivers.

4. The stock-recruitment data available from existing studies in the North East Atlantic should be further analysed using analysis of covariance to define the extent and basis of variability among stock-recruitment curves within and between systems. This has implications for transportability of stock-recruitment information to rivers where such relationships have not been established.

5. Catchment and biological details (as per Section 6) should be provided for all monitored stocks for which it is intended to set targets.

6. Surveys of the physical characteristics and juvenile salmon productivity of a variety of lakes in Europe should be carried out to enable salmon production estimates for lacustrine habitat to be developed over the North East Atlantic range of the species.

7. Spawning targets should be applied on a whole river basis unless evidence of suitability of more local (i.e. tributary based) targets was available.

8. Further attention should be given to objective methods of providing risk margins for setting spawning targets.

9. Modelling should be continued to assess the effects of multiple cohorts and different patterns of density independent variance in the stock-recruitment relationship on different spawning target levels..

10. Composition of spawning targets would in most cases be best approached in relation to present sea-age composition of stocks, but it is recognised that in certain rivers, managers may wish to apportion targets on a different basis. In the former situation, it is recognised that target composition may change as stock composition changes in response to fishery or other factors.

11. More research is needed to define the possible effects on productivity of wild salmon populations consequent on interbreeding with escaped farmed salmon. Similarly, the consequences of biologically-based targets set for wild salmon being met in part by spawning of reared salmon need to be considered.

12. Spawning targets should be defined objectively for rivers where stock-recruitment relationships are available. These should be defined initially as whole river targets but work undertaken to define them as habitat specific targets in preparation for future transport to other rivers. This approach has the advantage that the targets for the several rivers involved can be defined with reasonable confidence now and can be fine tuned in the light of observed productivity in future years.

APPENDIX 1: DOCUMENTS SUBMITTED TO THE WORKSHOP

1. Chaput, G. The use of target spawning requirements for Atlantic salmon in Canada.
2. Chaput, G., Allard, J., Claytor, R.R. and Chadwick, E.M.P. A generalized Atlantic salmon smolt production model for Canadian rivers.
3. Claytor, R.R. and Chaput, G. Dynamic and Bayesian probability models for investigating target spawning escapement.
4. Kennedy, G.J.A. and Crozier, W.W. Juvenile Atlantic salmon - production and prediction.
5. Kennedy, G.J.A. and Crozier, W.W. Variation in survival from a range of salmon stocking densities in Northern Ireland.
6. Kennedy, G.J.A. and Crozier, W.W. An assessment of the impact of recent salmonid stock-recruitment data on the Elson model of target egg deposition.
7. MacLean, J.C. North Esk Salmon Studies.
8. MacLean, J.C. Egg deposition in the North Esk.
9. Milner, N.J., Davidson, I.C. and Scott, M.D. Development of salmon spawning targets for some English and Welsh rivers.
10. O'Connell, M.F. Target Spawning Requirements for Atlantic salmon (Salmo salar L.) in Newfoundland Rivers.
11. Prévost, E. Background information on salmon rivers and stocks in France.

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Table 3.1.1 European rivers for which stock-recruitment data are available.

Country	River	Method	Type of index	Smolt output range	Physical characteristics
France	Bresle	US/DS trap	Egg - smolt	690 - 2,550	
	Nivelle	US trap + electrofishing	Egg - parr	850 - 11,800	
	Oir	US/DS trap	Egg - presmolt	147 - 1,450	
Ireland	Burrishoole	US/DS trap	Spawner - smolt Egg - smolt	3,794 - 16,136	lacustrine 450 ha fluvial 155,688 m^{-2}
Norway	Imsa	US/DS trap	Spawner - smolt Egg - smolt	477 - 3,214	width 10 m
UK (E.& W.)	Dee	Partial US trap + electrofishing	Spawner - smolt Egg - smolt		width 60 m
	Wye	Electrofishing	Fry - presmolt		width >8 m
UK (N.Ireland)	Bush	US/DS trap + semi-quantitative electrofishing	Spawner - smolt Egg - smolt	10,006 - 33,365	Catchment 340 km^{-2}
UK (Scotland)	Girnock Burn	US/DS trap	Spawner - smolt Egg - smolt intermed. stages	1,132 - 3,679	width 10 m
	North Esk	Partial US/DS trap + US counter	Spawner - smolt Egg - smolt	93,000 - 275,000	width 45 m
	Shelligan Burn	Single site electrofishing	Fry - presmolt		width <3 m

Table 3.6.1 Spreadsheet calculations of egg deposition in 21 streams in Wales (UK)

River	catch average	River length (main)	1SW/MSW (P1sw)	estimat SPAWNERS 1SW	SPAWNERS MSW	TOTAL EGG DEPN millions)	EGG DEPN (N/100msq
DEE	573	139.4	.41	2003	2087	14.16	338
CLWYD	132	51.5	.61	682	318	2.88	486
CONWY	445	35.5	.65	2433	973	9.48	1414
SEIONT	85	25.3	.67	481	174	1.78	465
OGWEN	95	17.7	.69	552	184	1.97	928
GLASLYN	54	34.7	.65	296	117	1.15	511
DYFI	327	59.5	.59	1639	825	7.22	1068
DYSYNNI	14	30.1	.66	78	30	.30	71
MAWDDACH	265	12.2	.59	1318	676	5.87	1319
TEIFI	675	113.2	.47	2695	2210	16.10	814
TAF	116	56.1	.60	589	287	2.55	521
TWYI	895	110.5	.48	3619	2897	21.27	1346
USK	507	119.4	.46	1965	1704	12.20	665
WYE	2809	252.0	.16	3810	14662	79.80	622
CLEDDAU	100	71.5	.57	478	269	2.25	272
DWYFAWR	64	22.8	.68	365	128	1.34	364
DWYRYD	40	15.0	.69	234	76	.83	256
LLYNFI	34	15.1	.69	199	65	.70	217
ARTRO	5	14.7	.70	29	9	.10	32
AERON	14	35.7	.65	77	31	.30	66
NEVERN	22	22.3	.68	126	44	.46	126
TOTALS						182.72	619

```
VARIABLES:
        propn of true catch de .76
        exploitation rate 1SW( .15
        exploitation rate MSW( .18
                                     intercept    slope
        propn 1SW in total run         .7286    -.0023
        propn run inseason(Psg .90
        propn run inseason(Psm .97
        estimated spawners (S)=(C/U*Ps)-C
        (where C,U,Ps are sea age specific)
        g=1SW, m=MSW values
        MEAN LENGTH 1SW 60.4  MEAN FECUNDITY=        3765
        MEAN LENGTH MSW 81.1  MEAN FECUNDITY=        7491
        Propn Females(P    .51
        Propn Females(P    .66
        lg10(total Area) = 5.40 + 0.007224*(Main river length)
```

Table 3.6.2 Calculations of egg deposition in tributaries and sections of the River Conwy, Wales (UK)

TRIBUTAR SECTION	AREA (m2)	DENSITY 0+ (N/100msq	STANDING STOCK (Aug 0+)	TOTAL EGG DEP egg-aug0+ S=0.02	egg-aug0+ S=0.08	DEPOSITION N/100msq S=0.02	S=0.08
Gyffin	9061	50	4531	181220	56631	2000	625
Roe	9550	87.3	8337	333486	104214	3492	1091
Dulyn	7295	10	730	29180	9119	400	125
Du	3581	8.32	298	11918	3724	333	104
Crafnant	4450	14.1	627	25098	7843	564	176
Llugwy	62600	5.23	3274	130959	40925	209	65
Garreg D	1938	10	194	7752	2423	400	125
Hiraethl	2194	10	219	8776	2743	400	125
Goron	10000	50.3	5030	201200	62875	2012	629
Oaklands	2440	40	976	39040	12200	1600	500
Lledr	155875	20	31175	1247000	389688	800	250
Conwy1	78590	3	2358	94308	29471	120	38
Conwy2	171550	3	5147	205860	64331	120	38
Conwy3	65600	5	3280	131200	41000	200	63
Conwy4	61440	2	1229	49152	15360	80	25
Conwy5	24320	0	0	0	0	0	0
TOTALS	670484		67404	2696149	842546		
		EGG DEP(N/100msq)=		402	126		

Table 4.3.1 Variation in post-smolt survival for wild salm from the River Imsa, Norway (1981 - 1990)

Year	**Percentage survival**
1981	21.3
1982	6.5
1983	14.8
1984	13.9
1985	12.3
1986	8.0
1987	22.9
1988	14.4
1989	10.9
1990	4.3
Mean	12.93
SD	5.66

Table 4.3.2 Data from North Esk Commercial salmon catch sampling programme (1984-93) - showing the proportion female and mean length for each sea-age group and proportion of the catch in each sea age group

Year	1SW Prop'n female %	Length (cm)	Prop'n of run %	2SW Prop'n female %	Length (cm)	Prop'n of run %	3SW Prop'n female %	Length (cm)	Prop'n of run %
1984	48.7	58.4	55.4	51.7	73.4	40.2	-	87.4	4.4
1985	50.8	61.1	45.8	59	72.5	52	-	88	2.2
1986	50.2	62.9	66.9	64.3	75.8	30.9	-	88.2	2.2
1987	43.6	61.6	58.8	68.9	74.9	39	-	87.7	2.1
1988	41.7	61.9	70.5	51.6	77.1	28.7	-	89.5	0.9
1989	40.1	61.3	69	67.8	74.5	29.5	-	90.6	1.4
1990	37.2	59.9	62.1	66.3	73.9	37.3	-	86.3	0.5
1991	42.9	59.9	55.9	61.8	74.3	43.4	-	90	0.7
1992	52.9	59.3	76.8	70.6	72.5	21.9	-	86.7	1.3
1993	51.5	59.1	68.6	59.7	73.2	30.9	-	86.4	0.5
Mean	45.96	60.54	62.98	62.17	74.21	35.38		88.08	1.62
SD	5.21	1.36	8.67	6.38	1.38	8.26		1.43	1.12

Table 6.2.1 Catchment and stock variables which should be considered when transporting stock-recruitment data between rivers.

Catchment variables	**Example data set: River Nivelle, France**
1. Area:	
- Total catchment	238 km^{-2}
- Wetted surface - summer	40 ha
- - winter	N/A
- Lacustrine	Nil
- Fluvial - Total	5 ha
- Grade A nursery	N/A
2. River flow	
- ADF	5.4 m^{3}s^{-1}
- Range	0.9 - 220 m^{3}s^{-1}
3. Abundance indices	
- pre-smolt	850 -11,500
- smolt	N/A
- adult	N/A
4. Water chemistry	Ca 20 - 55 mgl^{-1} Mg 2 - 5.5 mgl^{-1} pH 7.0 - 8.4
5. Land use	50% Agriculture 35% Moors 15% Forest
6. Latitude	43° 21'N
7. Temperature range	3° - 21° C
8. Competing/predating species	brown trout, eel, perch
9. Smolt age composition	1+ 75% - 90% 2+ 10% - 25%
10. Adult characteristics	
- sea age composition	1SW 84%, 2SW 15%, 3SW+PS 1%
- sex ratio (% female)	1SW 54%, 2SW 77%
- fecundity	1SW 4200, 2SW 8500
11. Marine survival range	
- to coast	N/A
- to river	
12. Marine exploitation range	
- grilse	N/A
- MSW	

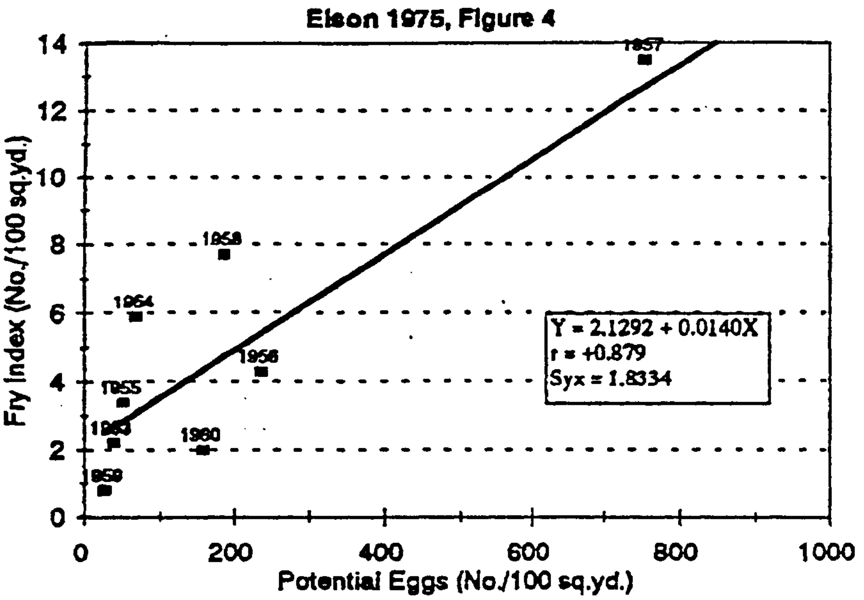


Figure 2.2.1 Potential egg deposition to underyearling (fry) relationship for the Pollett River (from Elson 1975)

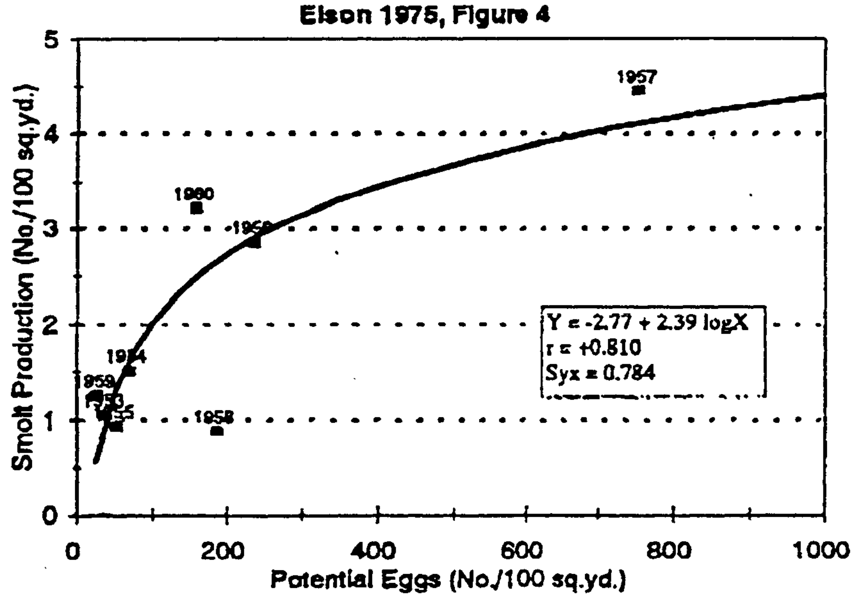


Figure 2.2.2 Potential egg deposition to smolt relationship for the Pollett River (from Elson 1975)

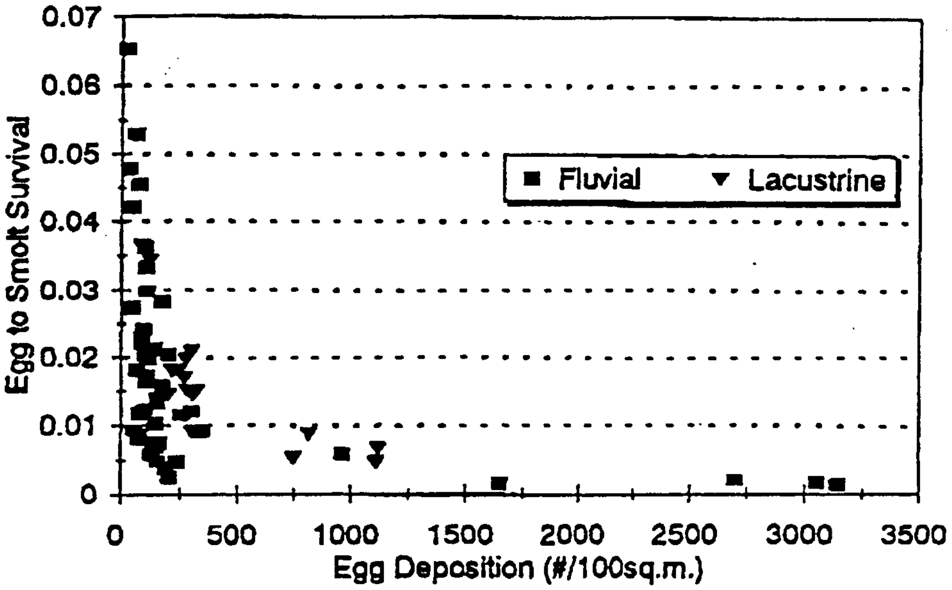
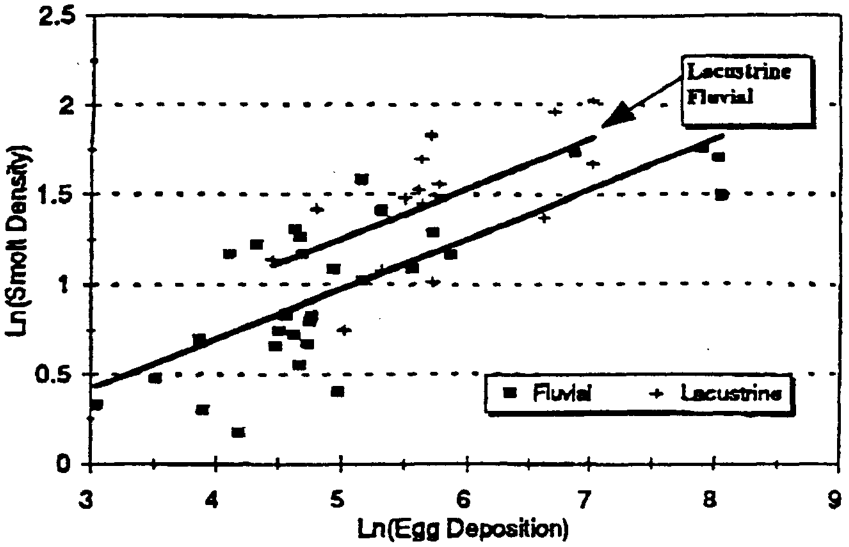


Figure 2.4.1 Egg to smolt survival rates relative to egg depositions for eight Canadian rivers.



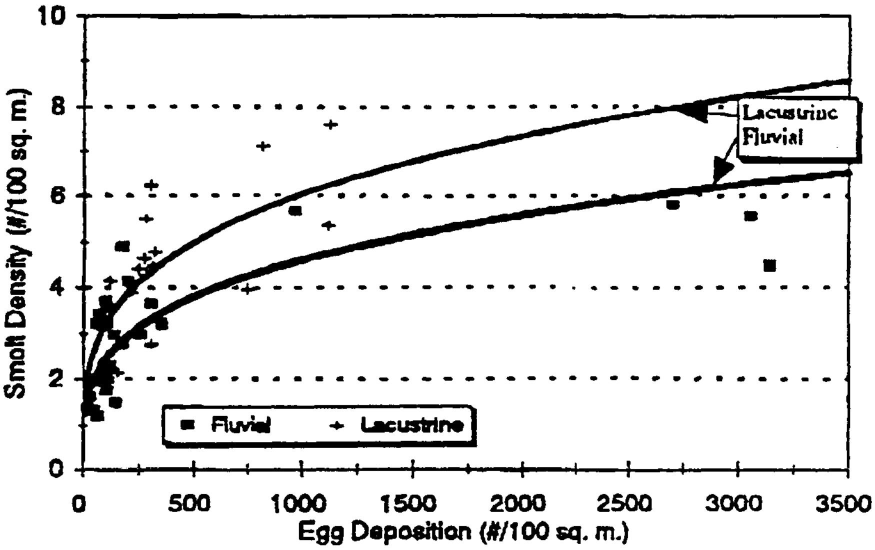


Figure 2.4.2 Log/log fit and back-transformed fit of the smolt density on egg deposition relationship from Canadian rivers.

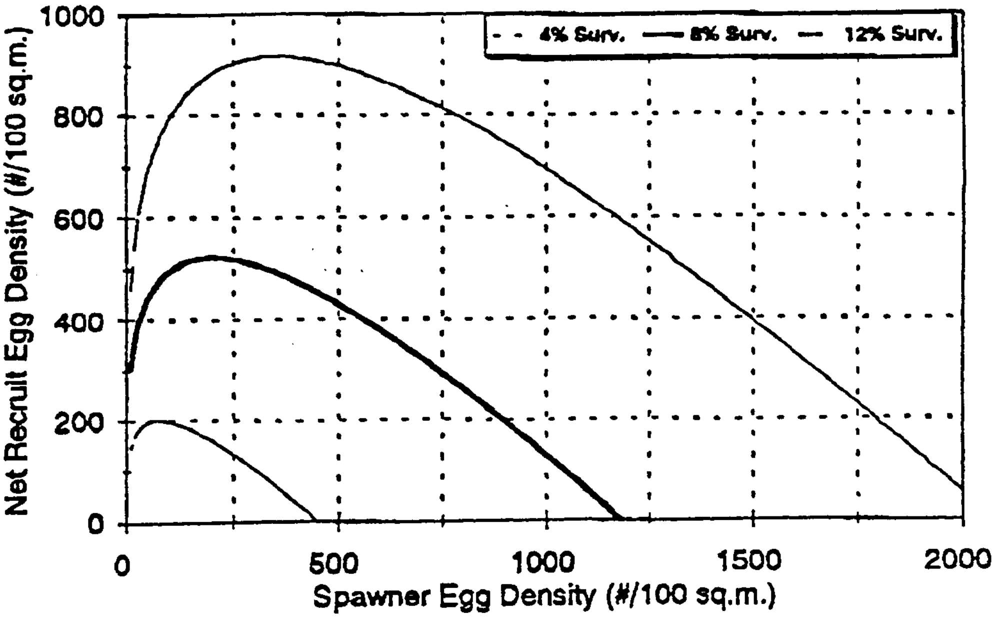


Figure 2.4.3 Predicted net recruit egg density relative to spawner egg depositions for three levels of sea survival for Western Arm Brook, Canada.

Figure 3.2.1 Stock-recruitment relationship (egg to O+ parr) for River Nivelle, France

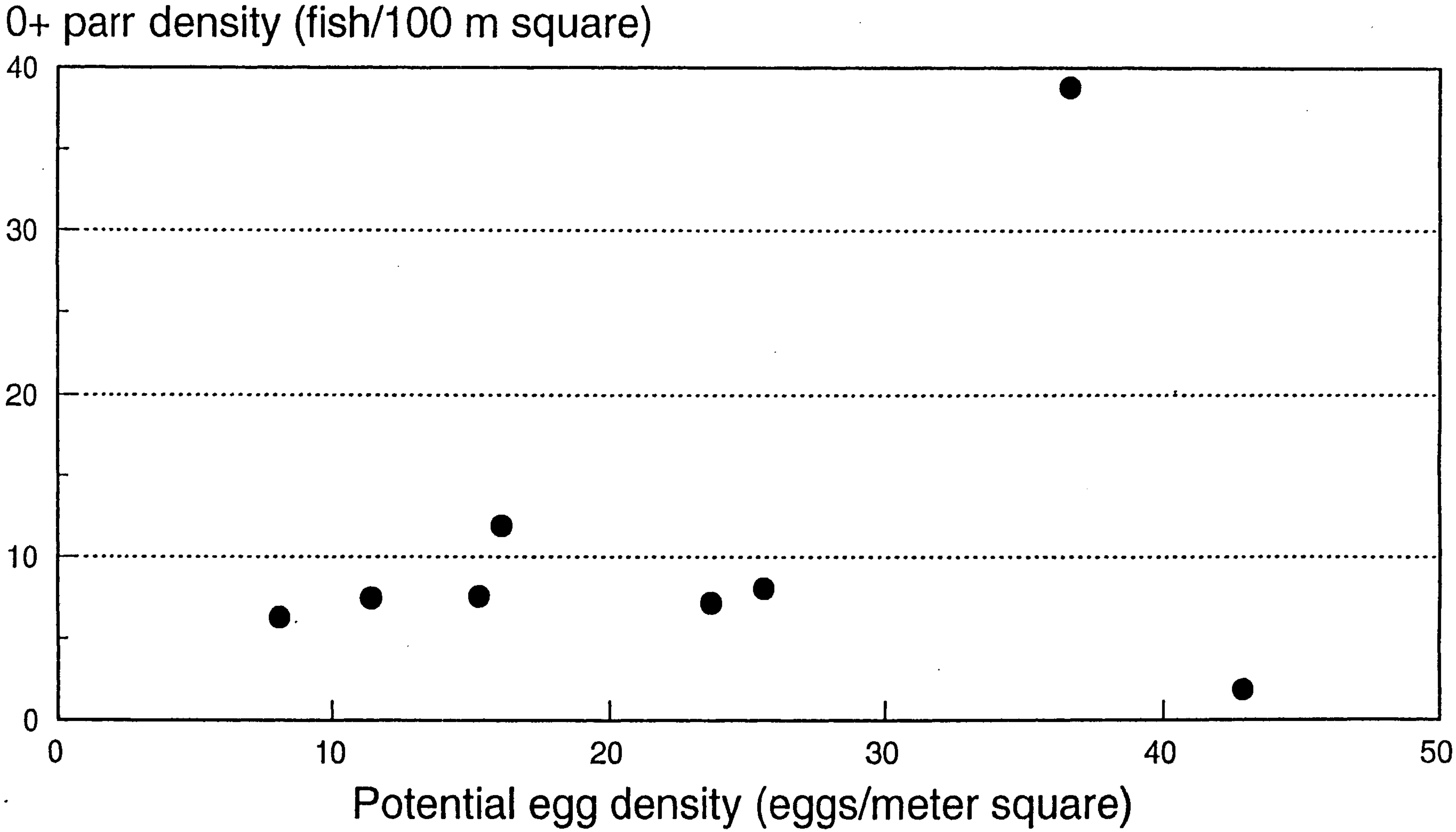


Figure 3.2.2 Stock-recruitment relationship (egg to smolt) for River Oir, France.

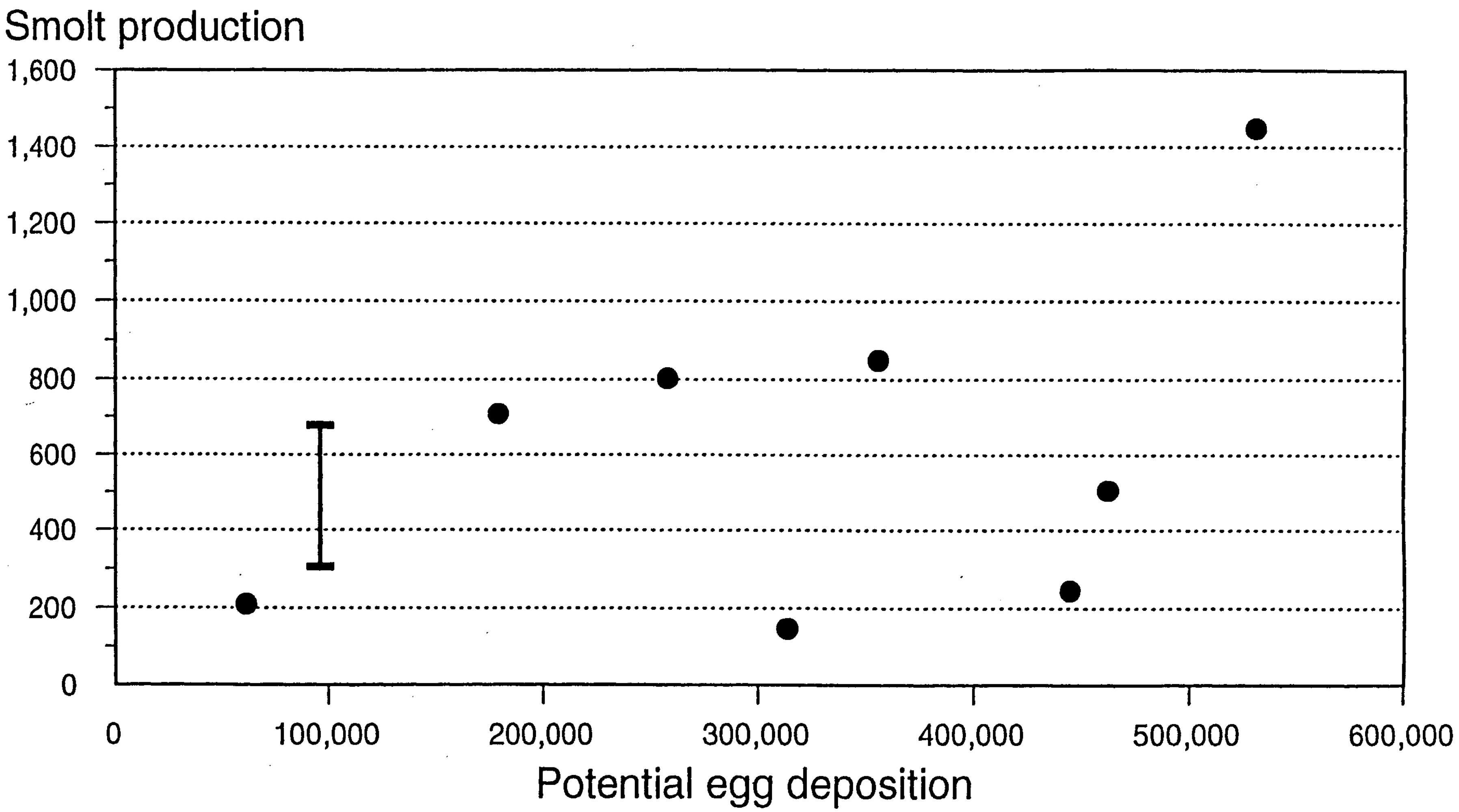


Figure 3.3.1 **Stock-recruitment relationship (adult spawners to smolt) for River Burrishoole, Ireland.**

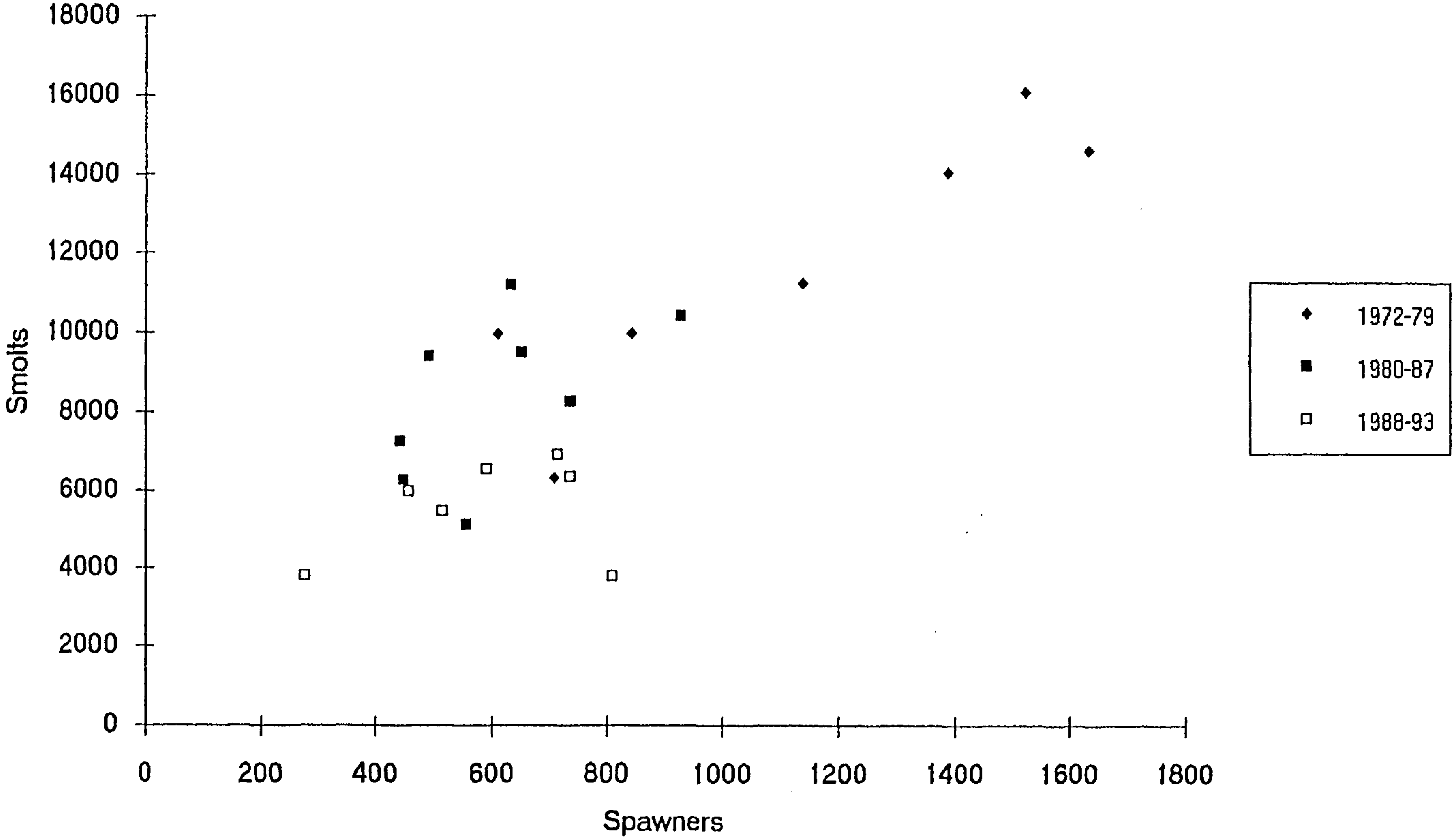


Figure 3.7.1 Numbers of smolts per spawner plotted against varying ova depositions for the River Bush, UK(Northern Ireland), 1973-87.

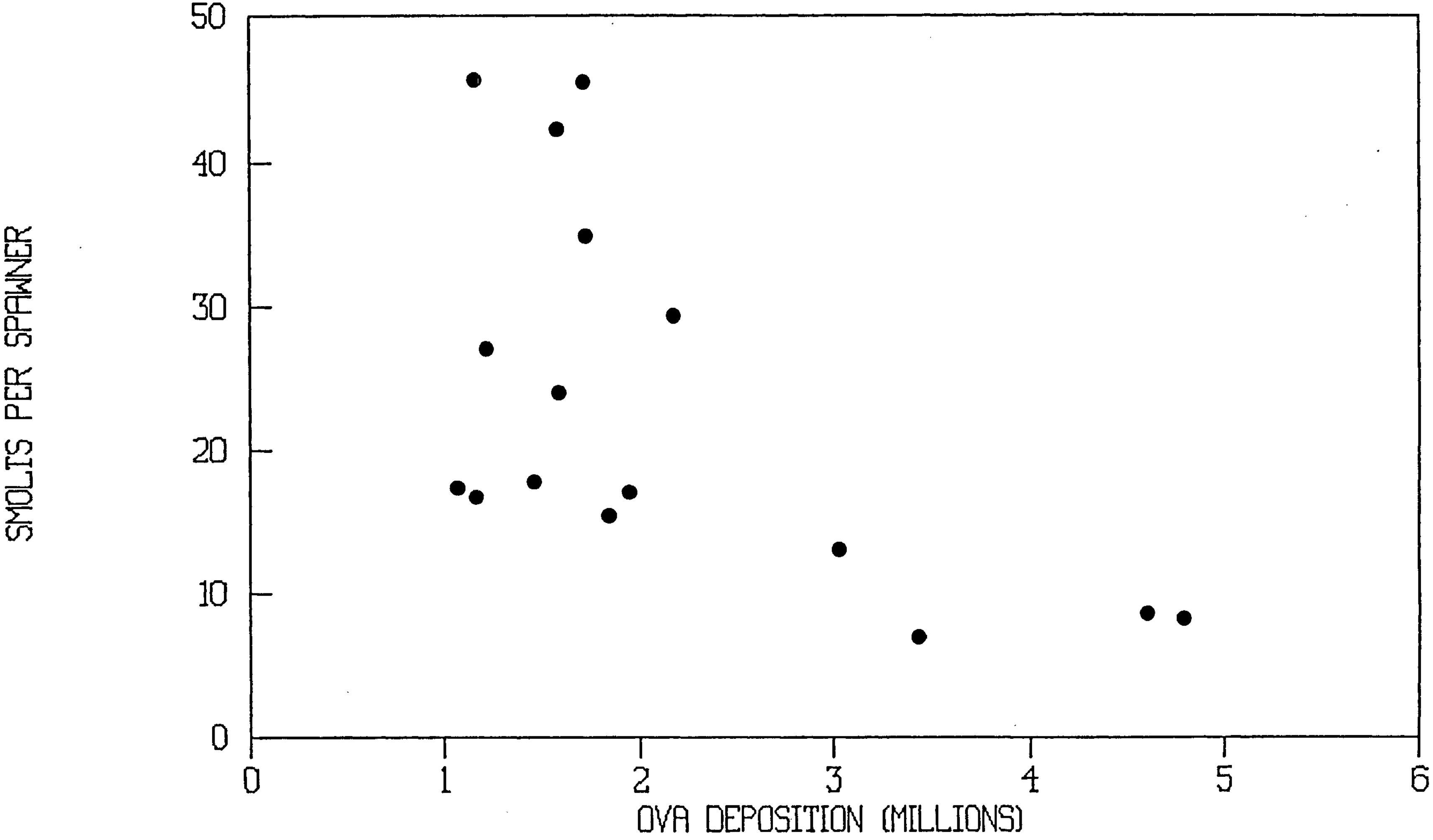


Figure 3.7.2 Counts of 1+ smolts produced from varying egg depositions on the River Bush, UK(Northern Ireland), 1973-88

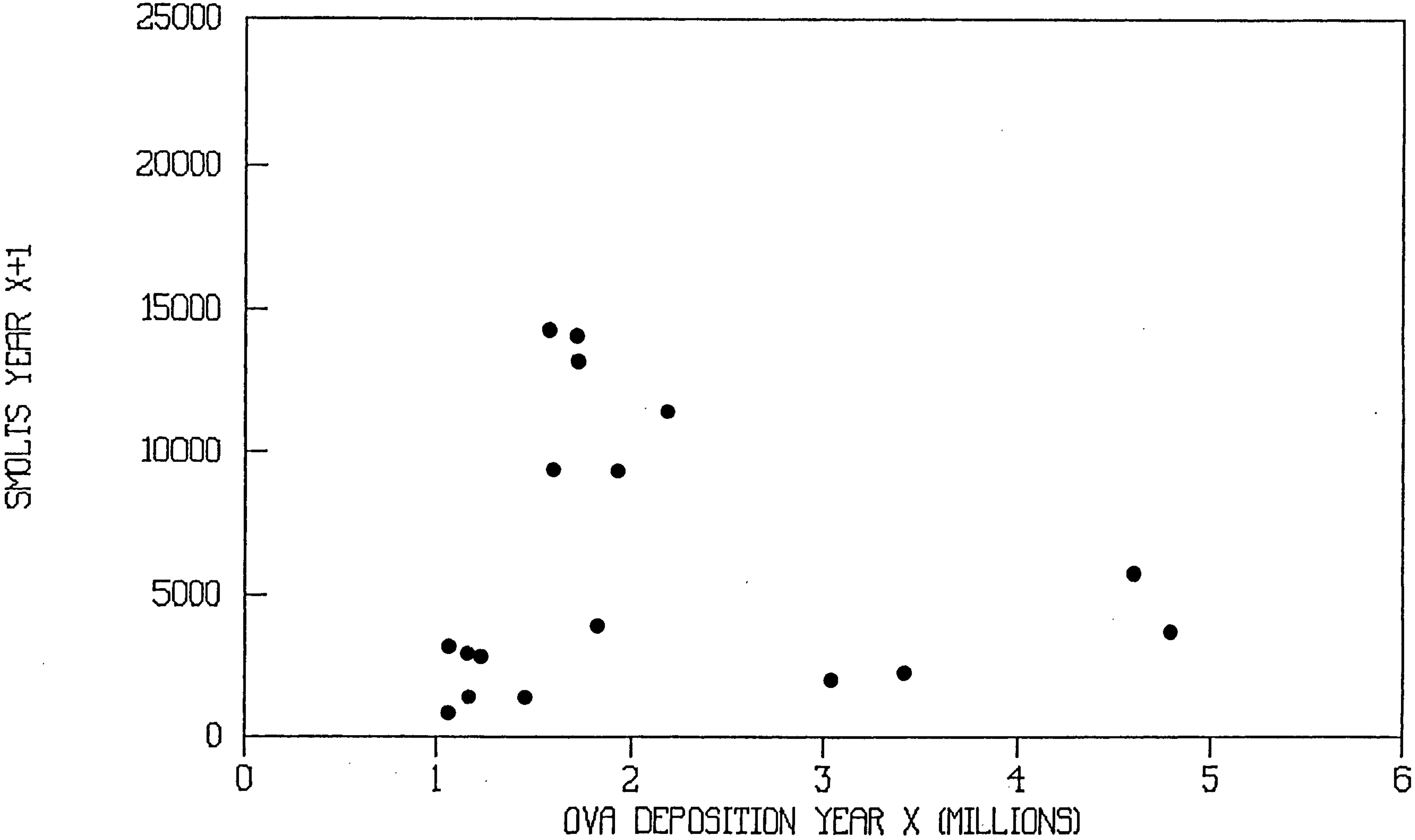


Figure 3.7.3 Counts of 2+ smolts produced from varying egg depositions on the River Bush, UK(Northern Ireland), 1973-88

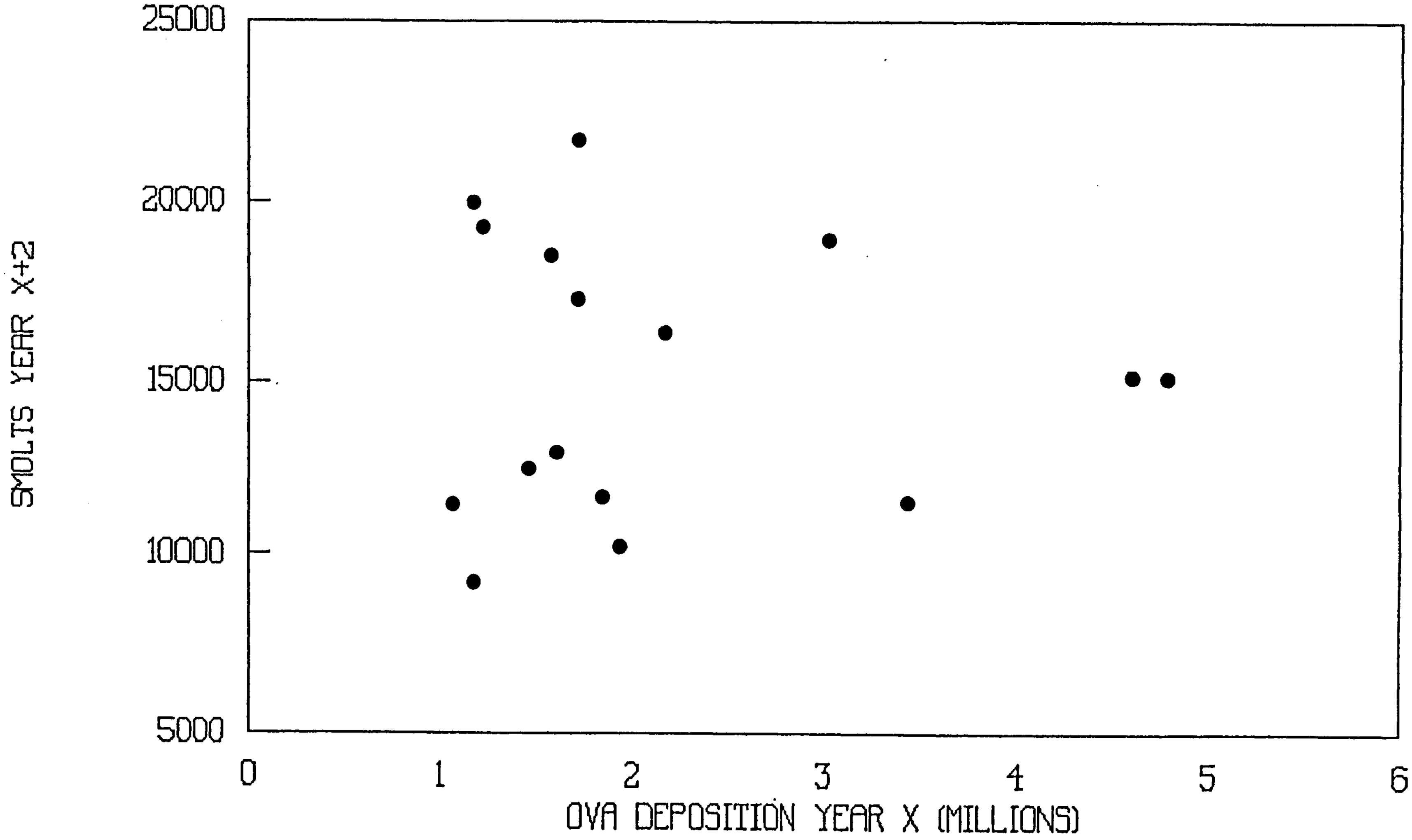


Figure 3.7.4 Stock-recruitment relationship (eggs deposited to total smolts) for the River Bush, UK(Northern Ireland), 1973-89, with a Ricker curve fitted ($r^2 = 0.422$)

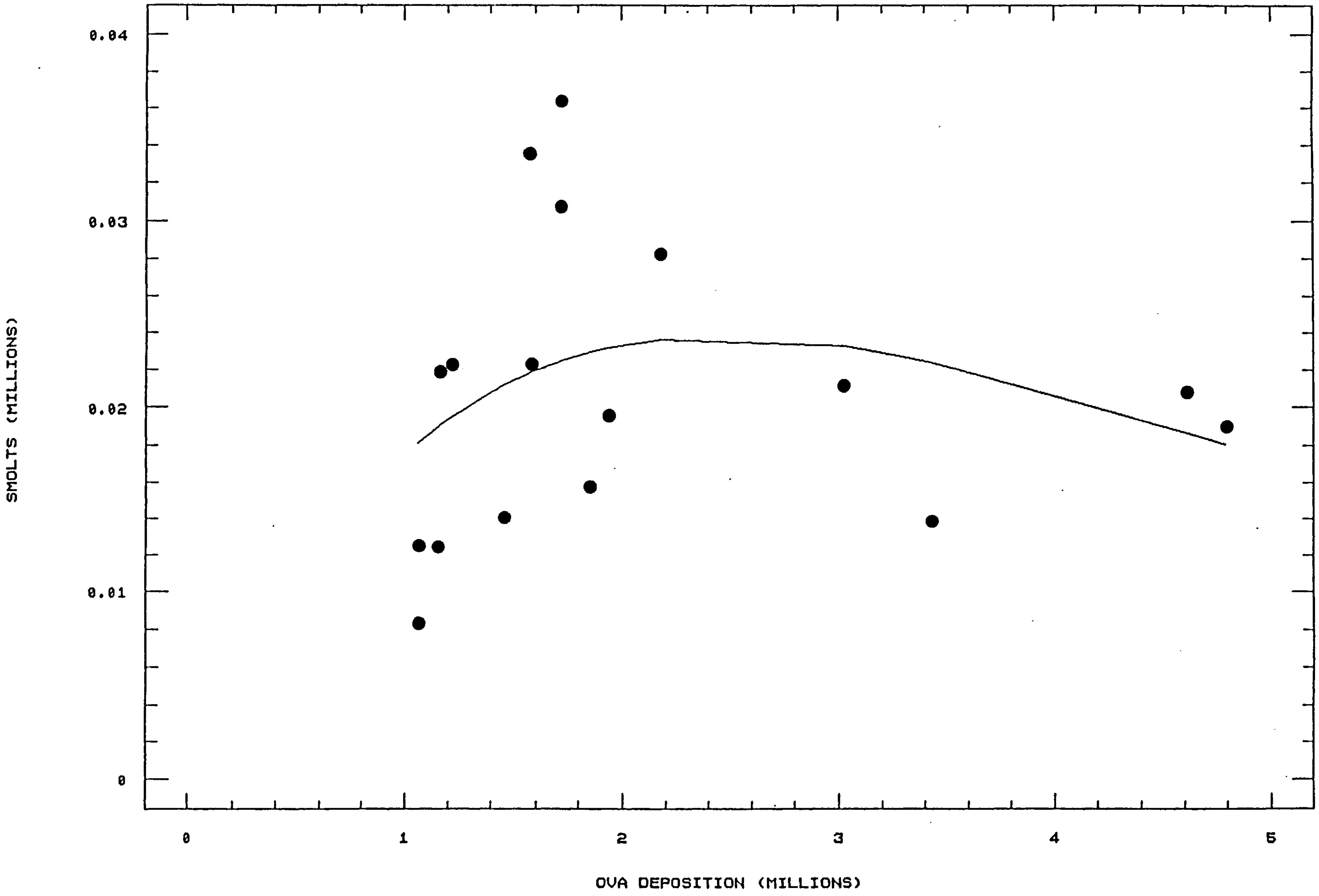


Figure 3.7.5 Percentage survival from egg to smolt for each egg deposition on the River Bush, UK(Northern Ireland), 1973-88 (circles) and on the River Burrishoole, Ireland, 1972-85 (squares). The Burrishoole data are taken from the means of the published ranges of egg to smolt survival for this river.

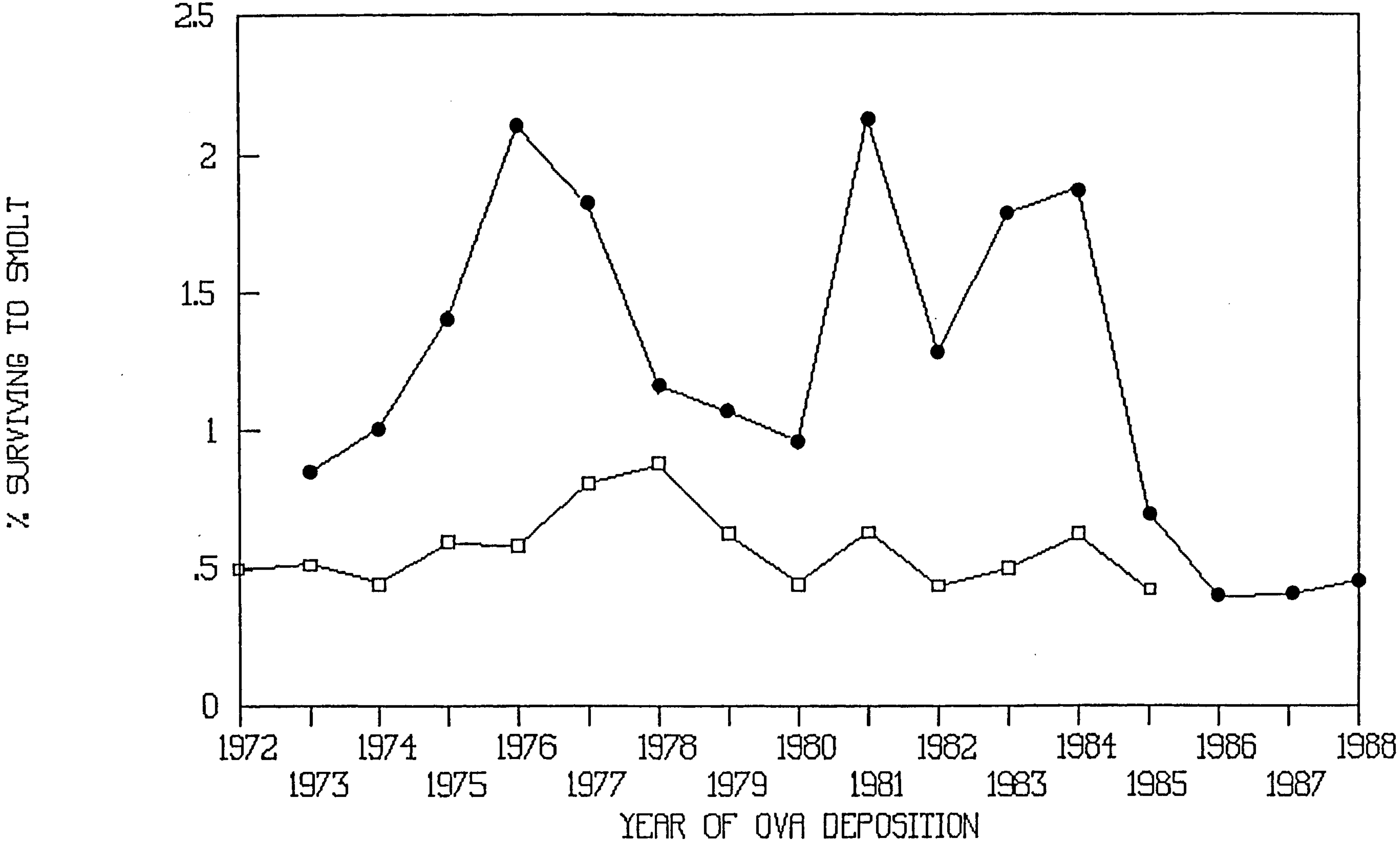


Figure 3.7.6 Densities of Aug/Sept salmon fry produced from stocking densities of eyed eggs and swim up fry ranging from 1 m^{-2} to 30 m^{-2} on the River Bush, UK(Northern Ireland), with fitted Beverton and Holt curve.

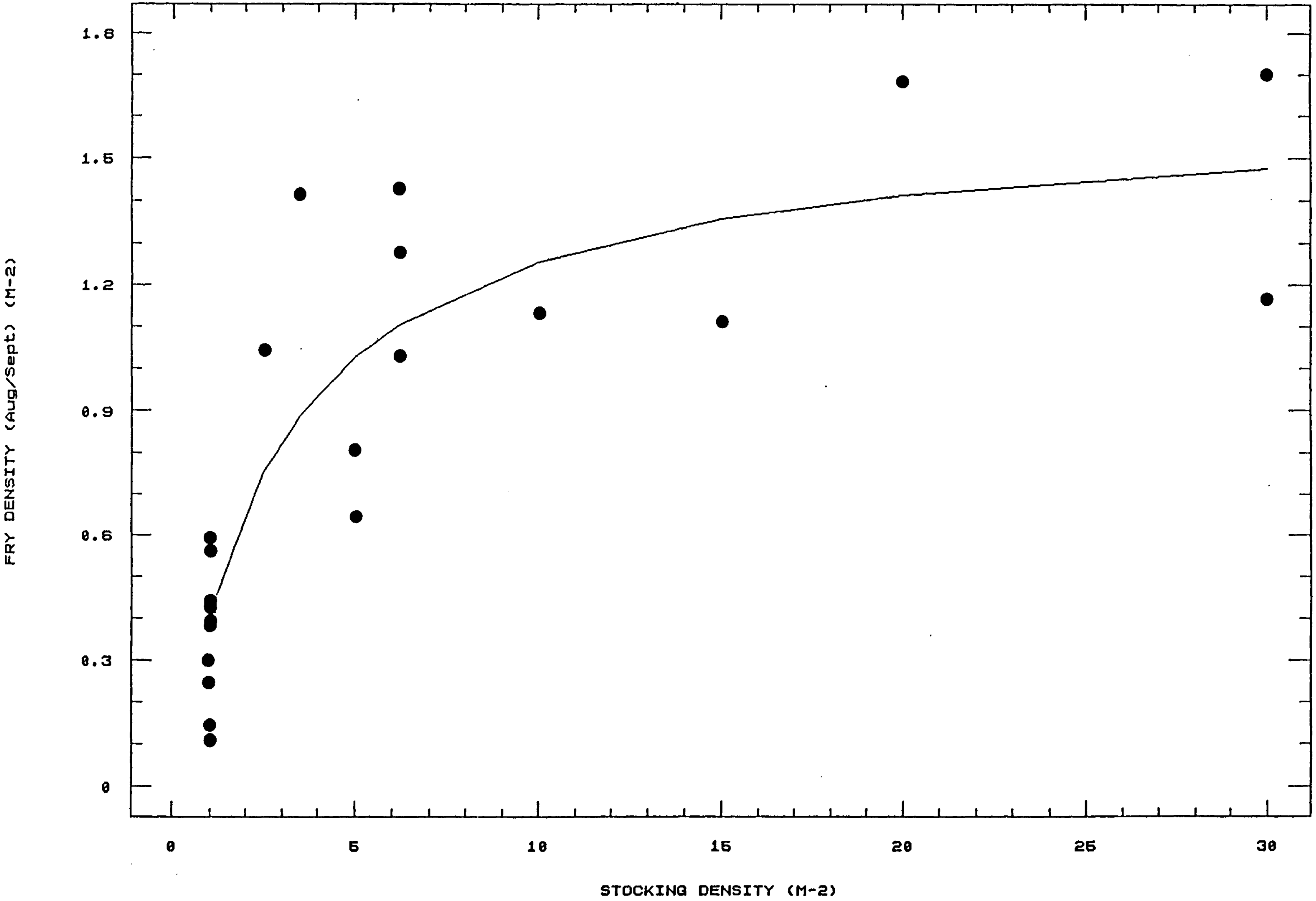


Figure 3.7.7 **Densities of Aug/Sept salmon fry produced from stocking densities of eyed eggs and swim up fry ranging from 1 m^{-2} to 30 m^{-2} on the River Bush UK(Northern Ireland), with fitted Ricker curve.**

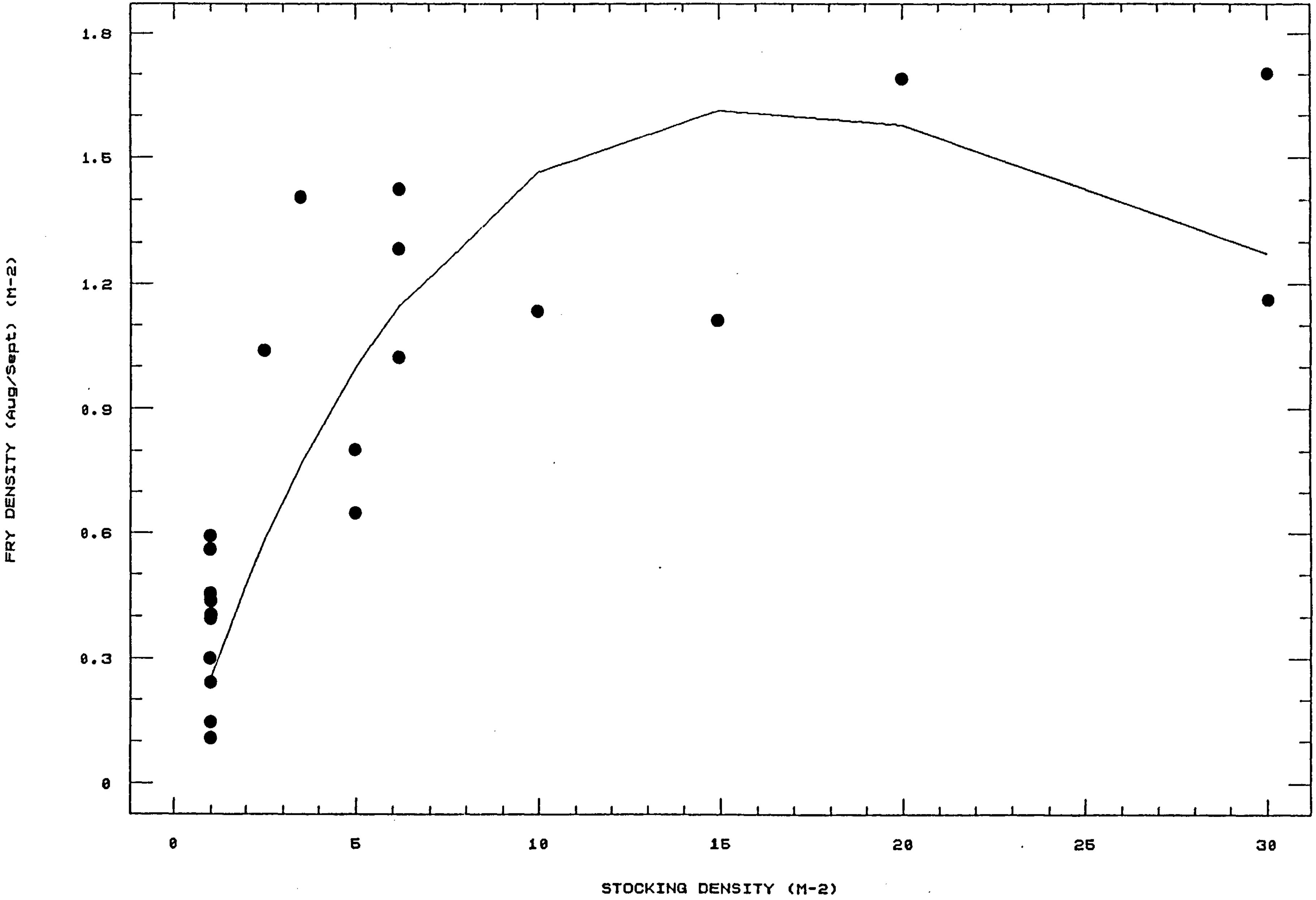


Figure 3.7.8 Percentage survival of stocked salmon to Aug/Sept at stocking densities ranging from 1 m^{-2} to 30 m^{-2} on the River Bush, UK(Northern Ireland).

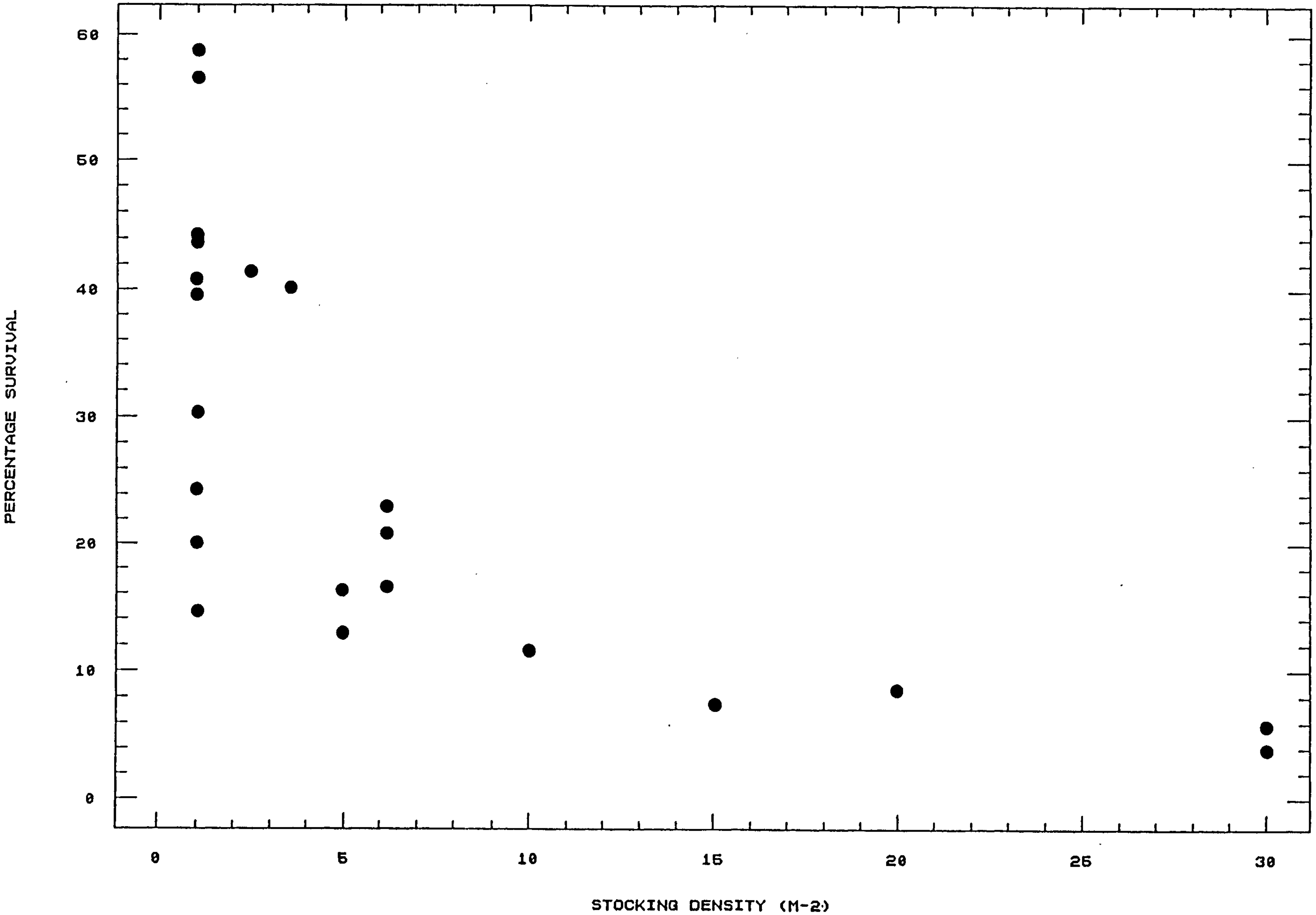


Figure 3.8.1 **Stock-recruitment relationship (egg to smolt) for Girnock Burn, UK(Scotland). (Densities per m²)**

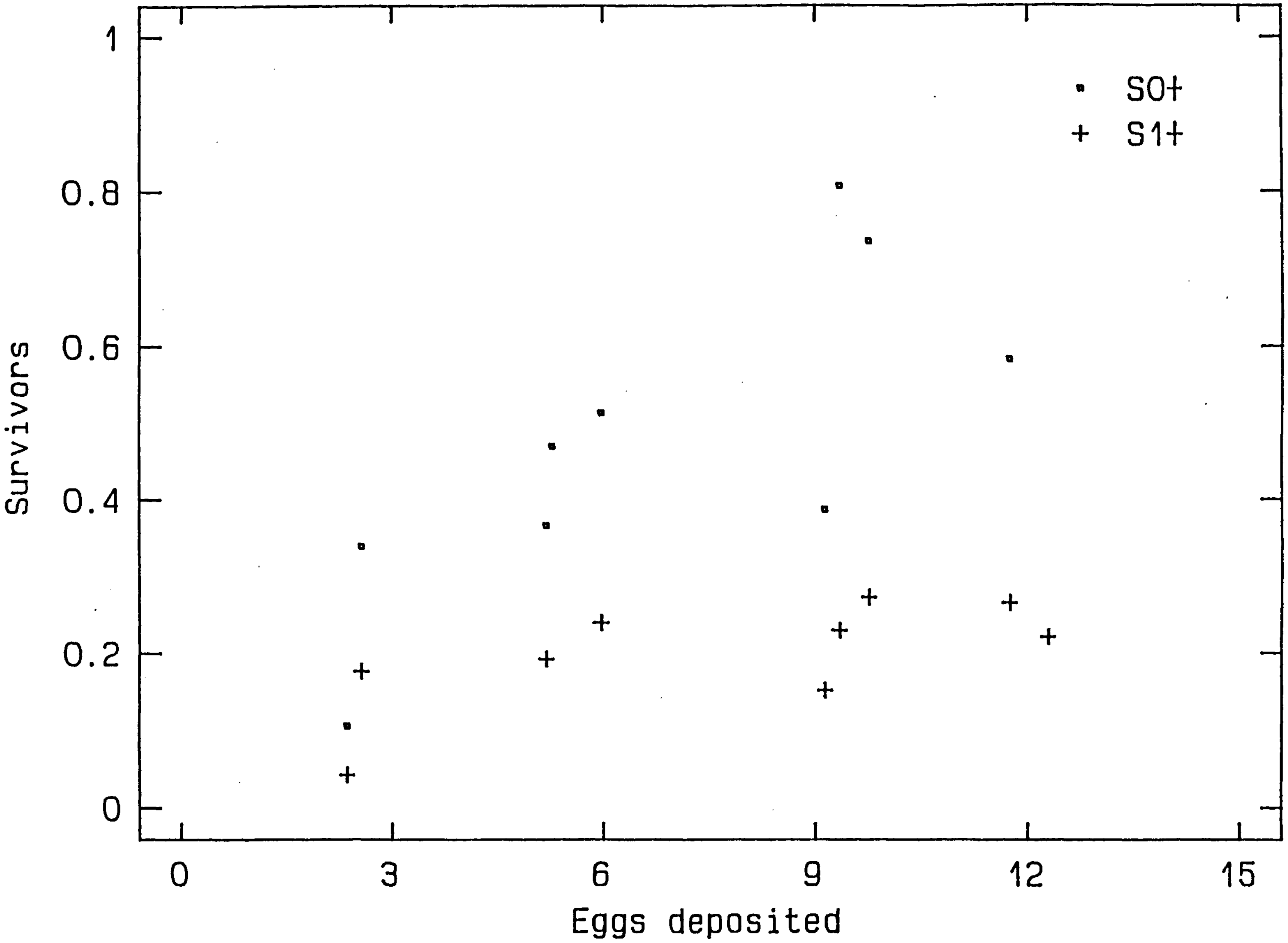


Figure 3.8.2 Stock-recruitment relationship (emergent fry to presmolts) for Shelligan Burn, UK(Scotland), with Ricker curve fitted.

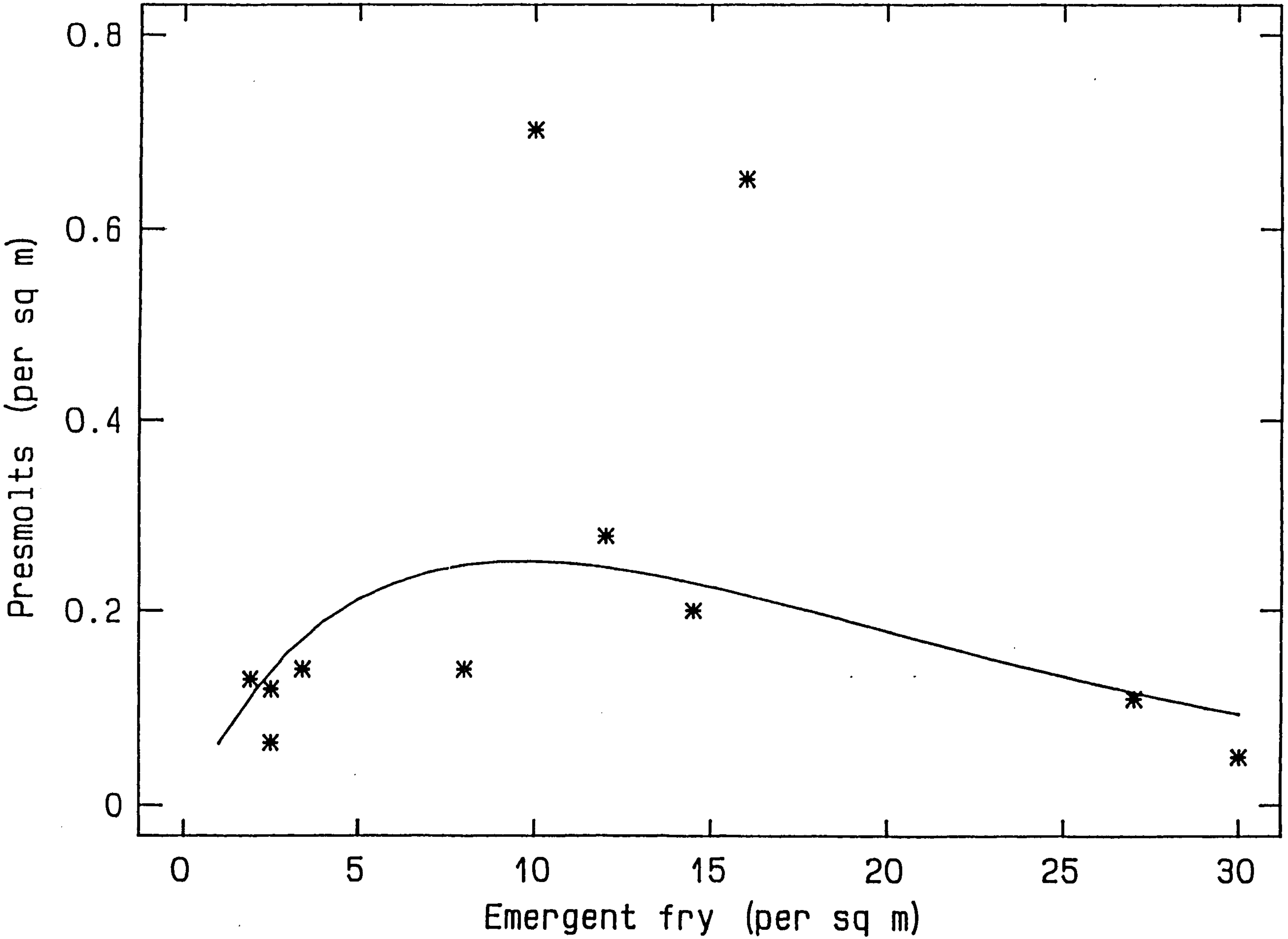


Figure 3.8.3 Stock-recruitment relationship (stocked eggs/unfed fry to 0+ parr) for Fender Burn, UK(Scotland), with Ricker curve fitted.

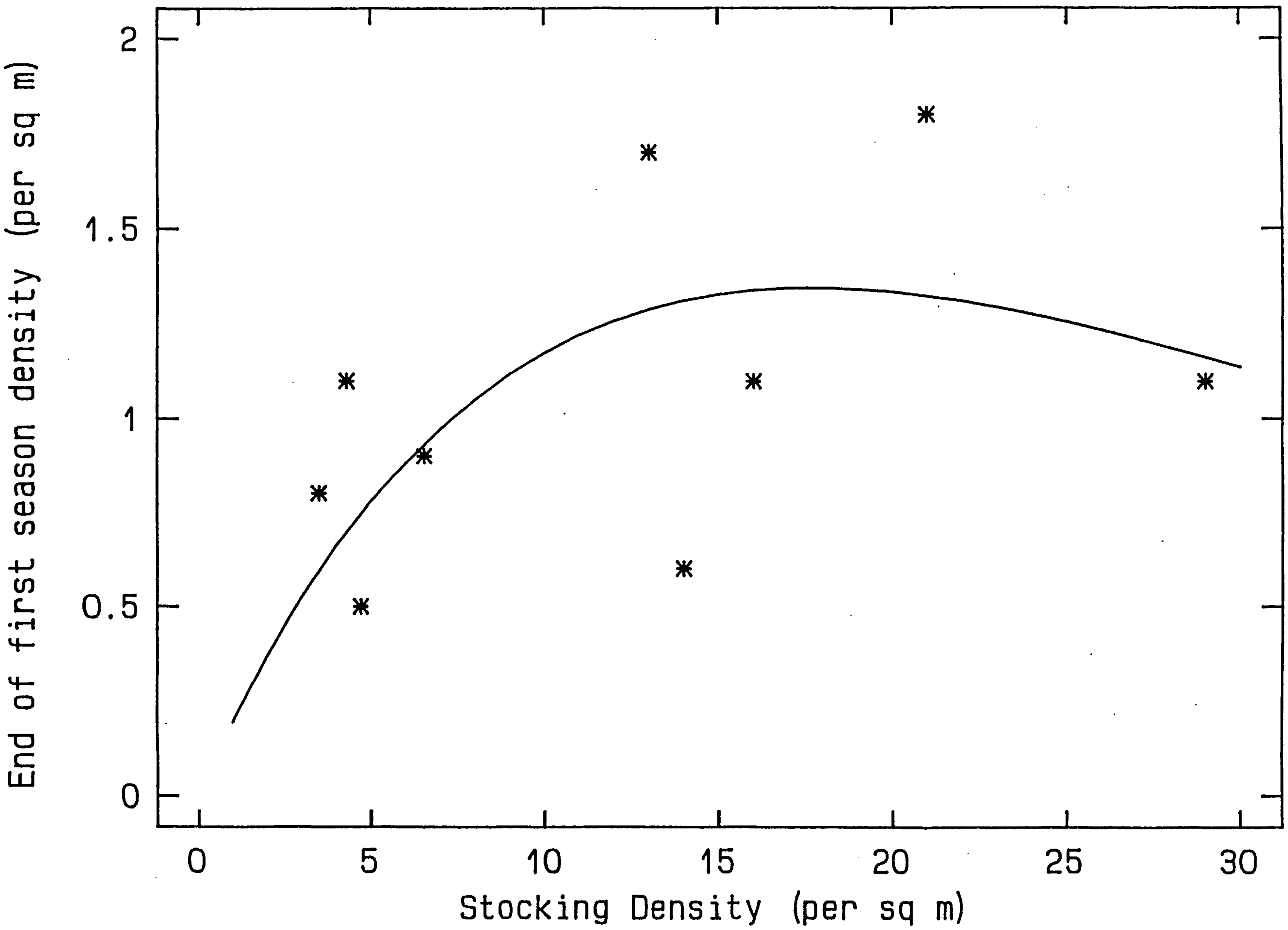


Figure 4.1.1 Stock-recruitment relationship (eggs to recruited eggs) for River Bush, UK(Northern Ireland) with Ricker curve fitted (squares), with stock replacement line (- - -) and net gain (triangles).

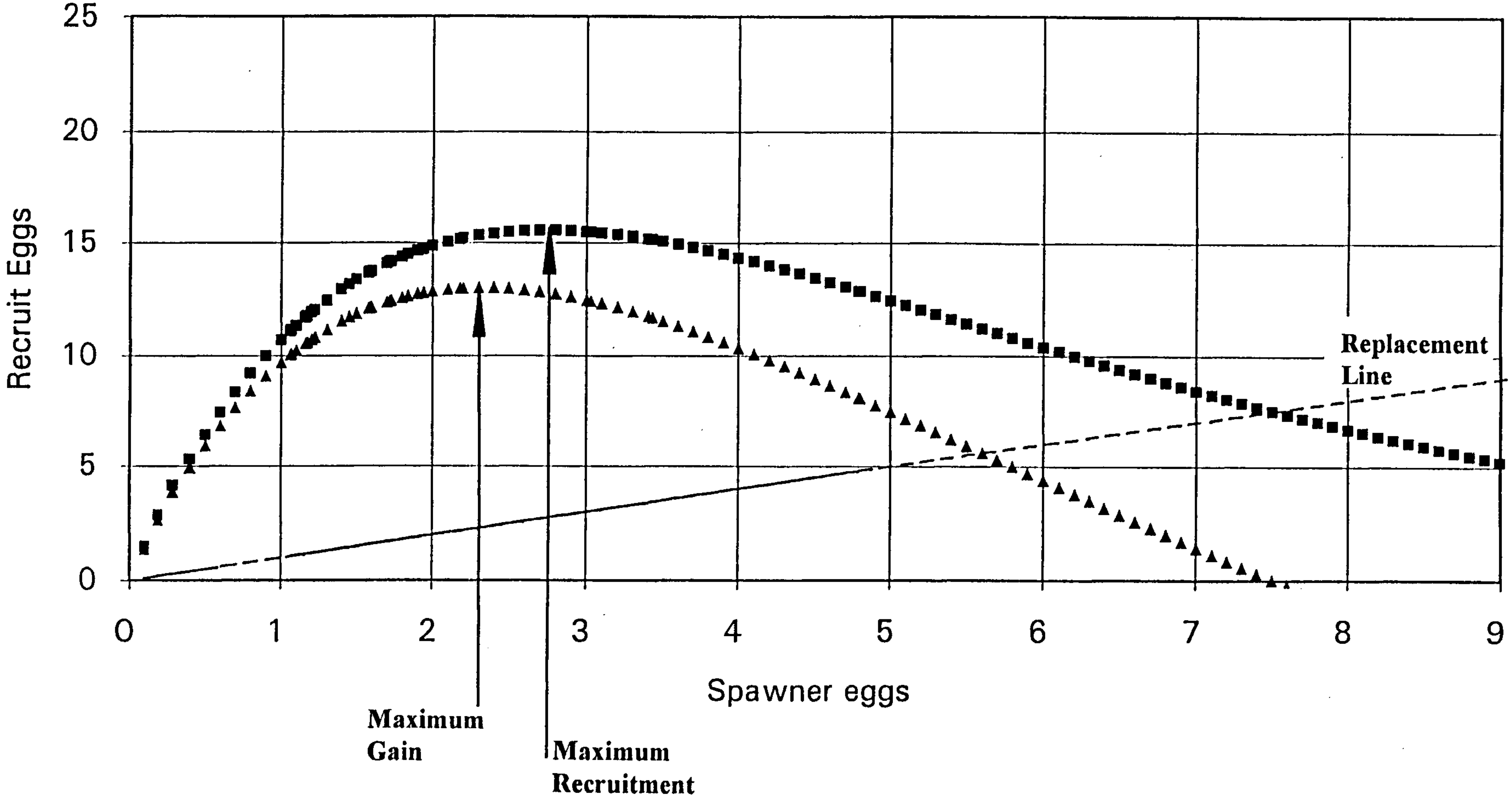


Figure 4.3.1 Marine survival of wild smolts from the River Imsa, Norway (1981-91)

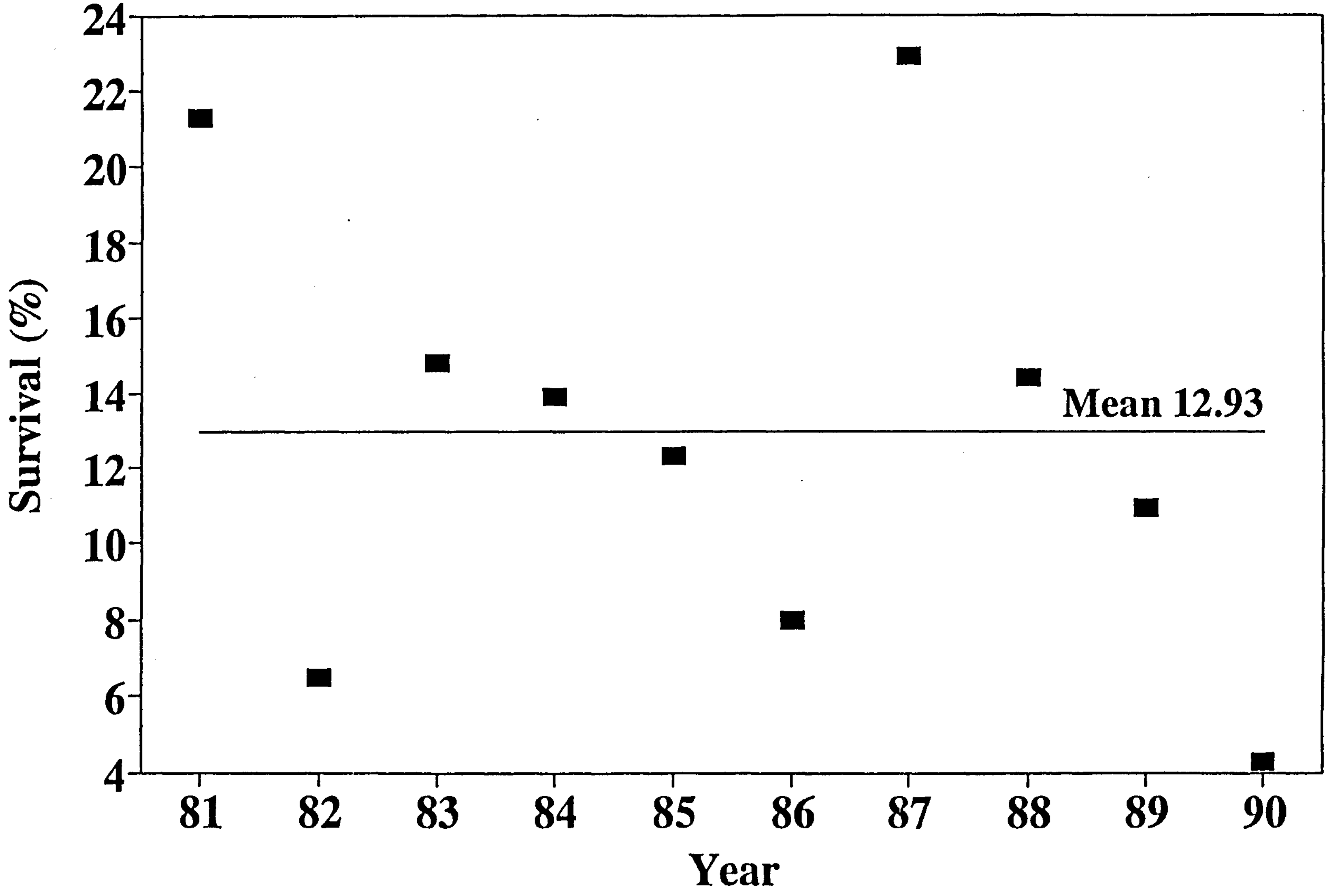
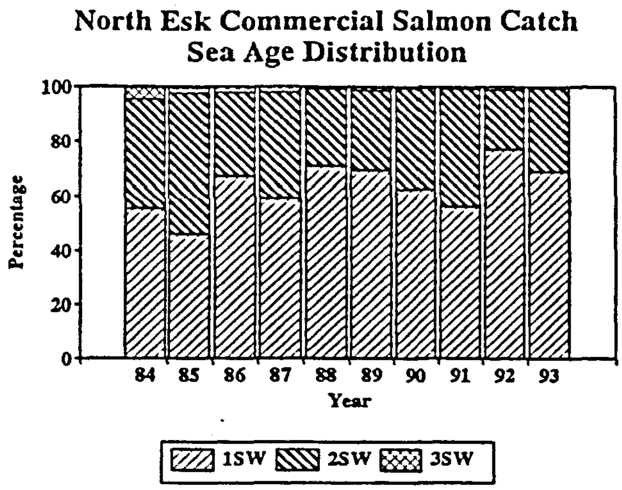
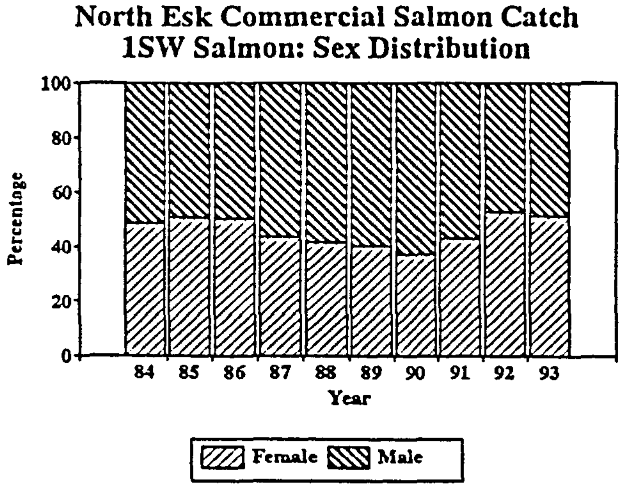


Figure 4.3.2 Age composition of total salmon catch and sex composition of 1SW and 2SW salmon caught on the North Esk, UK(Scotland) (1984-93).


North Esk Commercial Salmon Catch
Sea Age Distribution


North Esk Commercial Salmon Catch
1SW Salmon: Sex Distribution

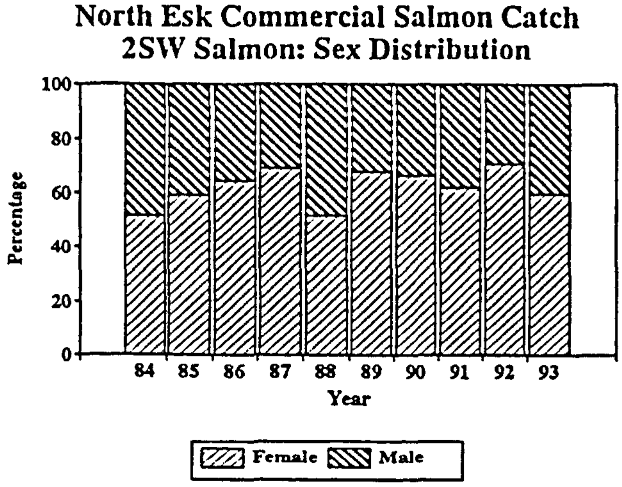

North Esk Commercial Salmon Catch
2SW Salmon: Sex Distribution

Figure 4.3.3 Mean fork length of 1SW, 2SW and 3SW salmon caught on the North Esk, UK(Scotland) (1984-93).

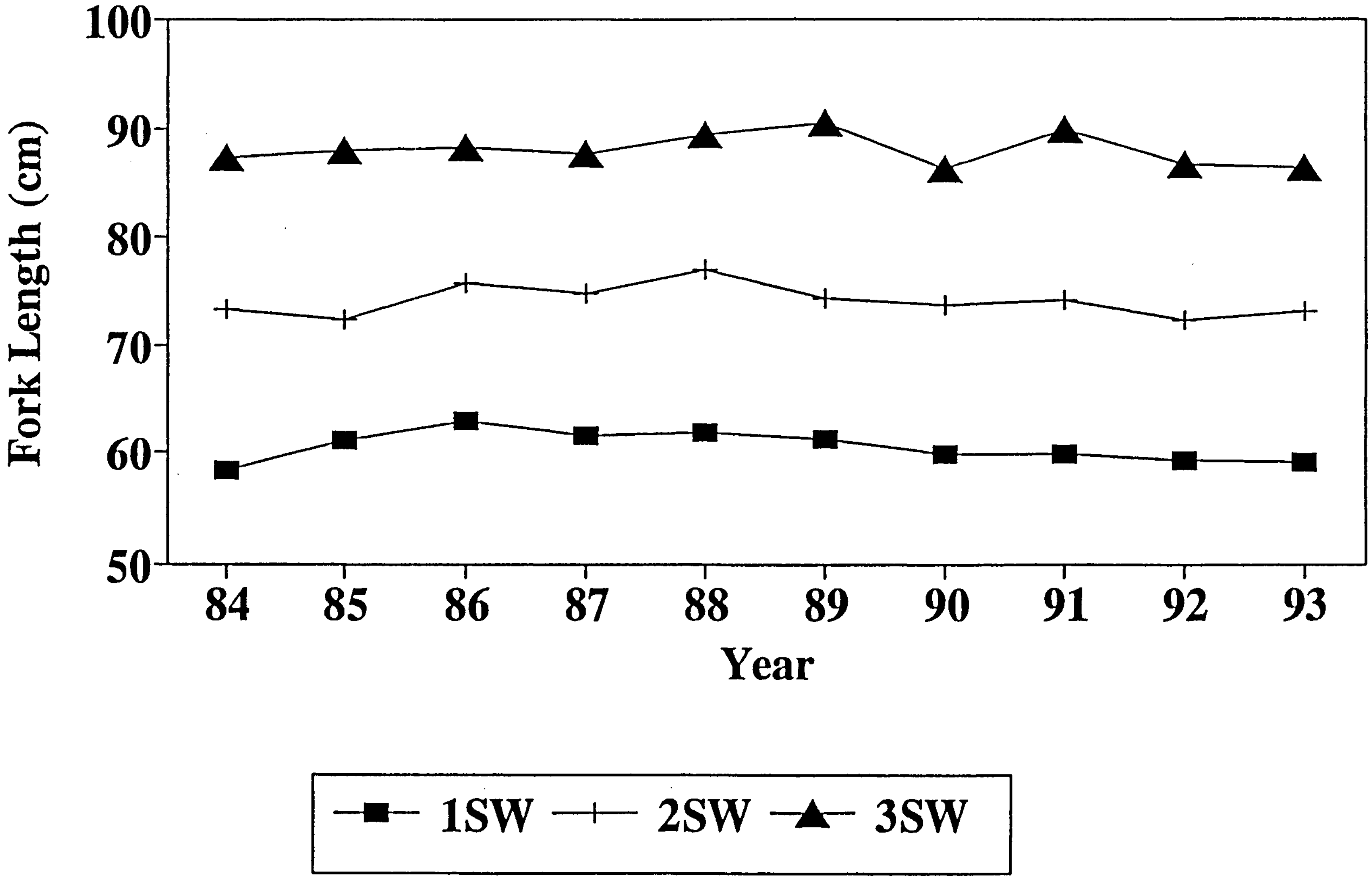


Figure 4.3.4 Relationship between size and fecundity for 1SW and 2SW salmon in 1985 and 1988 on the River Oir, France.

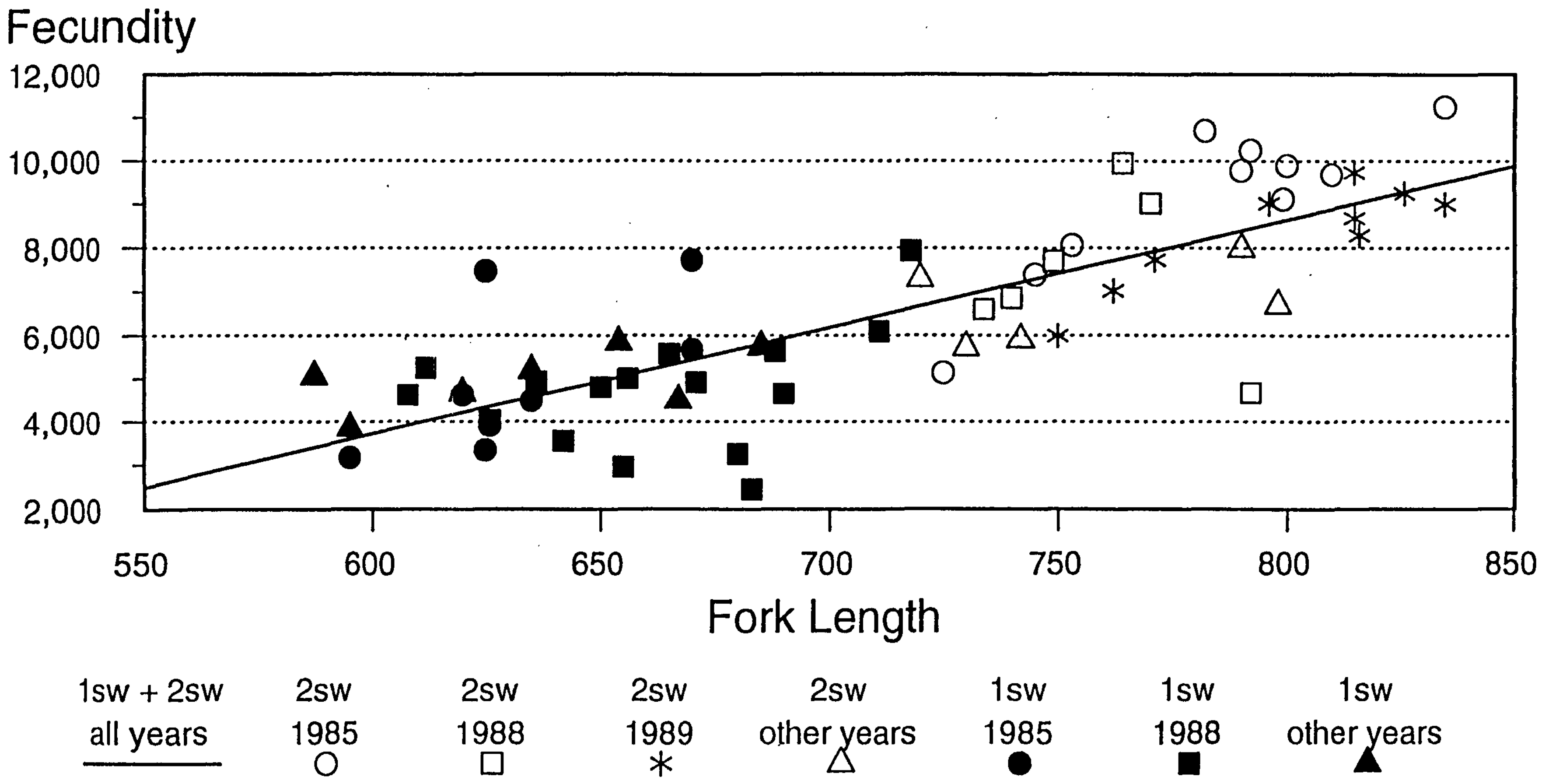


Figure 4.3.5 **Relationship between fecundity and time of entry into freshwater for 1SW and 2SW salmon on the North Esk, UK(Scotland).**

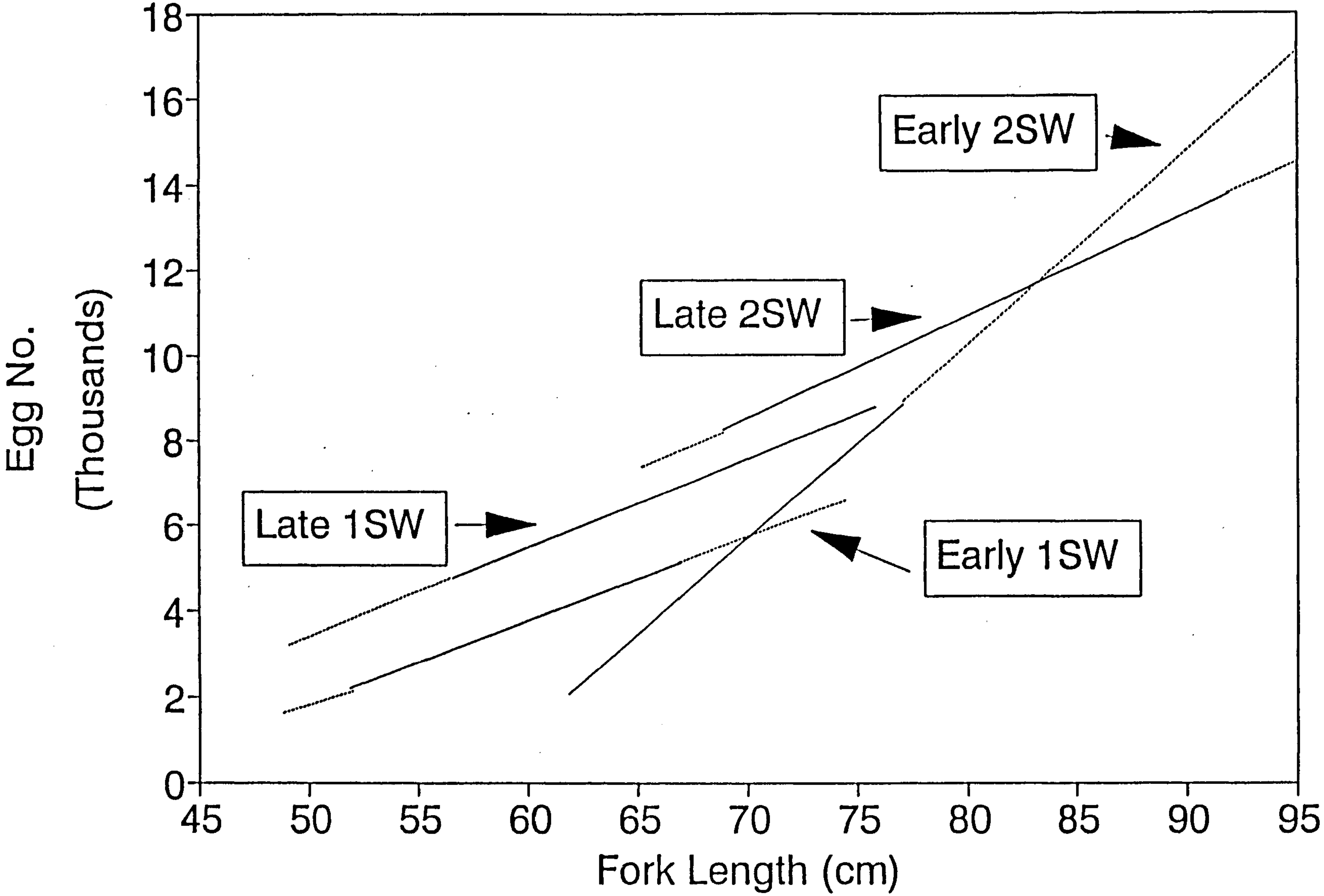


Figure 4.4.1 Stock-recruitment relationship (eggs to recruited eggs) for River Bush, UK(Northern Ireland) with Ricker curve fitted (squares) and confidence limits (+/- 1 standard deviation) (diamonds). Replacement line (- - -).

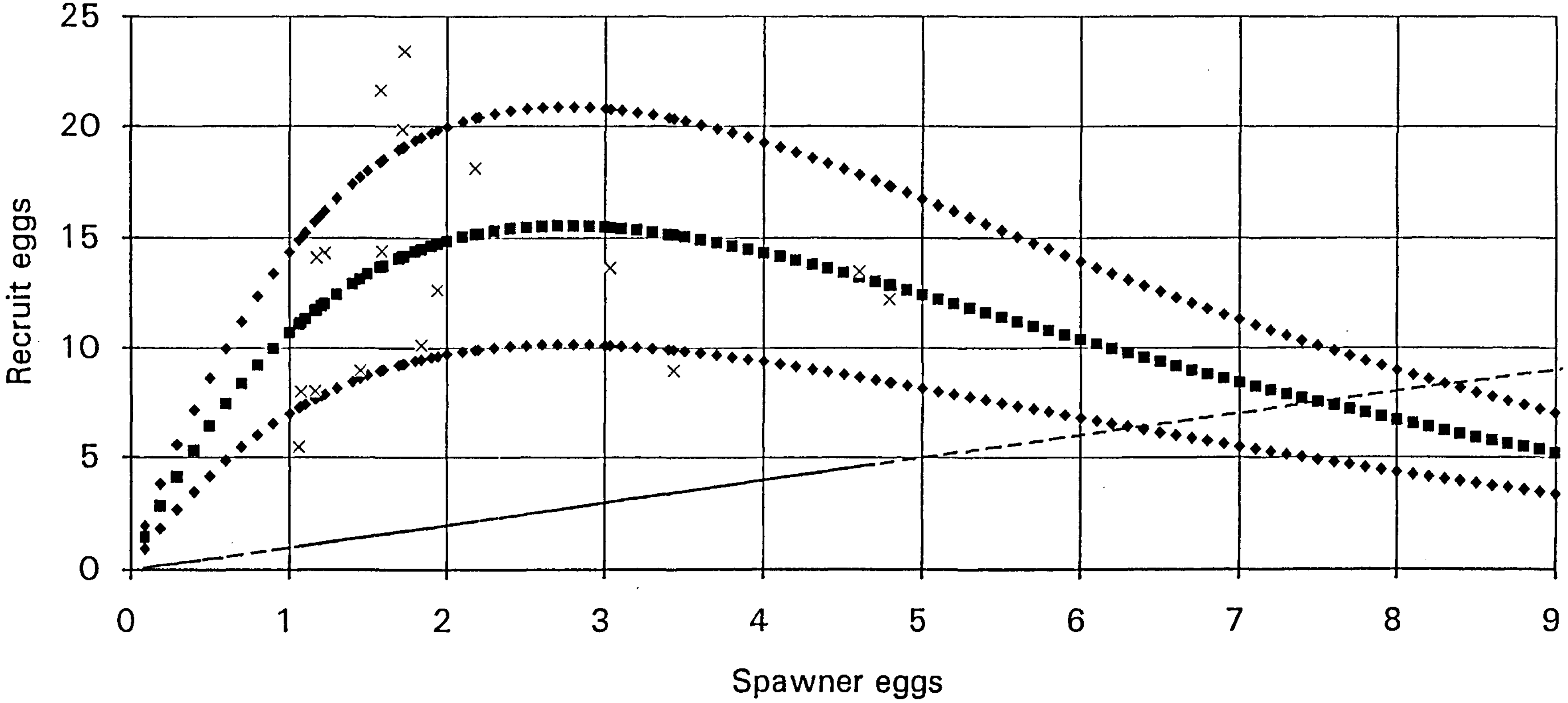
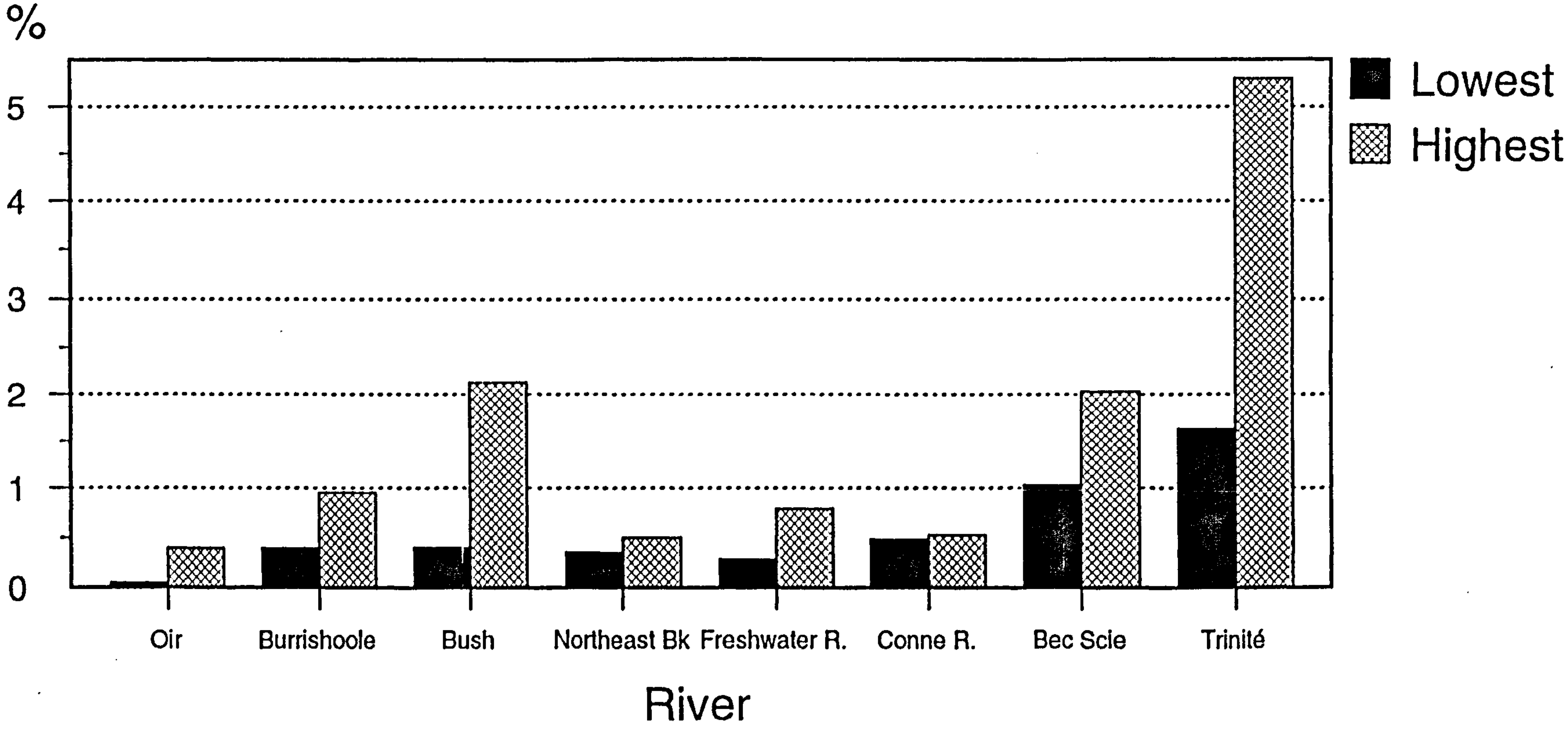


Figure 4.4.2 Comparison between egg to smolt survival rates for rivers in Europe (Oir (France), Burrishoole (Ireland), Bush (Northern Ireland)) and North America (Northeast Bk, Freshwater R., Conne R., Bec Scie., Trinité (Canada)).



Sources: O'Connell et al. 1993; Caron 1992;
Kennedy and Crozier, 1993.

Figure 4.5.1 Results of modelling variability stock-recruitment (see Section 4.5). (a) Mean annual catch and (b) coefficient of variation of catch plotted against spawning target.

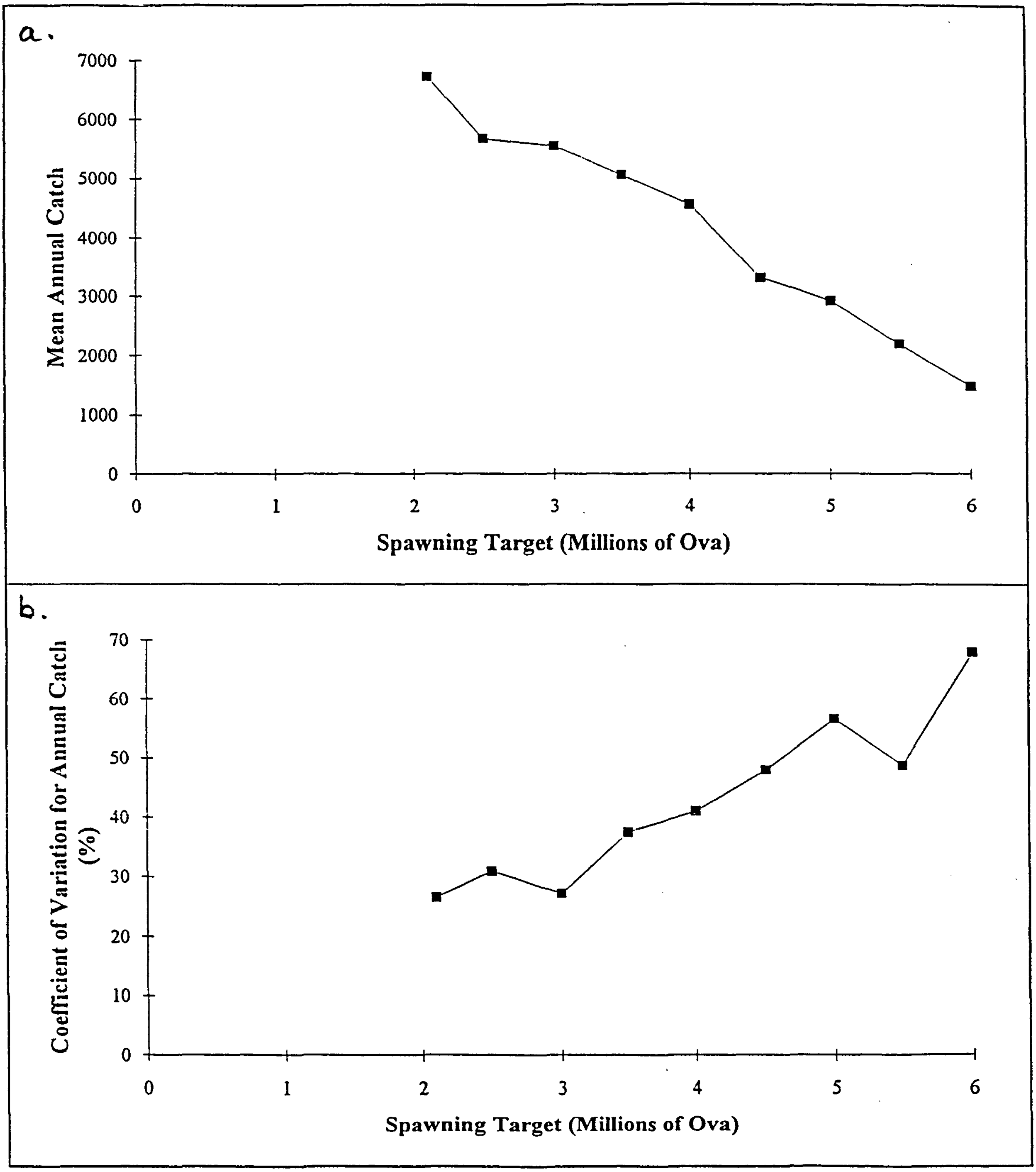


Figure 4.5.2 Results of modelling variability stock-recruitment (see Section 4.5). (a) SD of spawning escapement and (b) minimum spawning escapement plotted against spawning target.

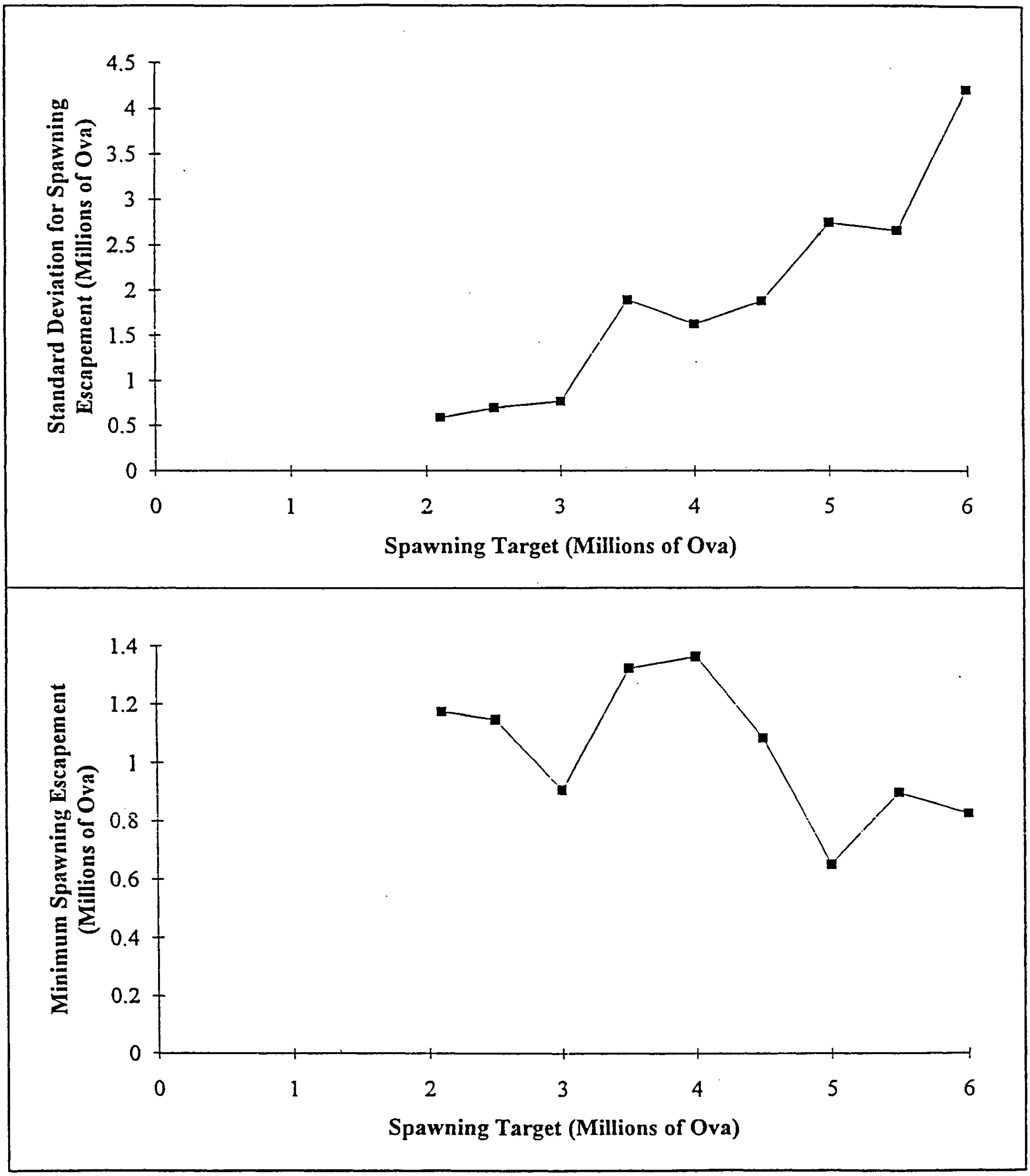


Figure 5.1 Critical periods in salmon life cycle for deriving stock-recruitment relationships.

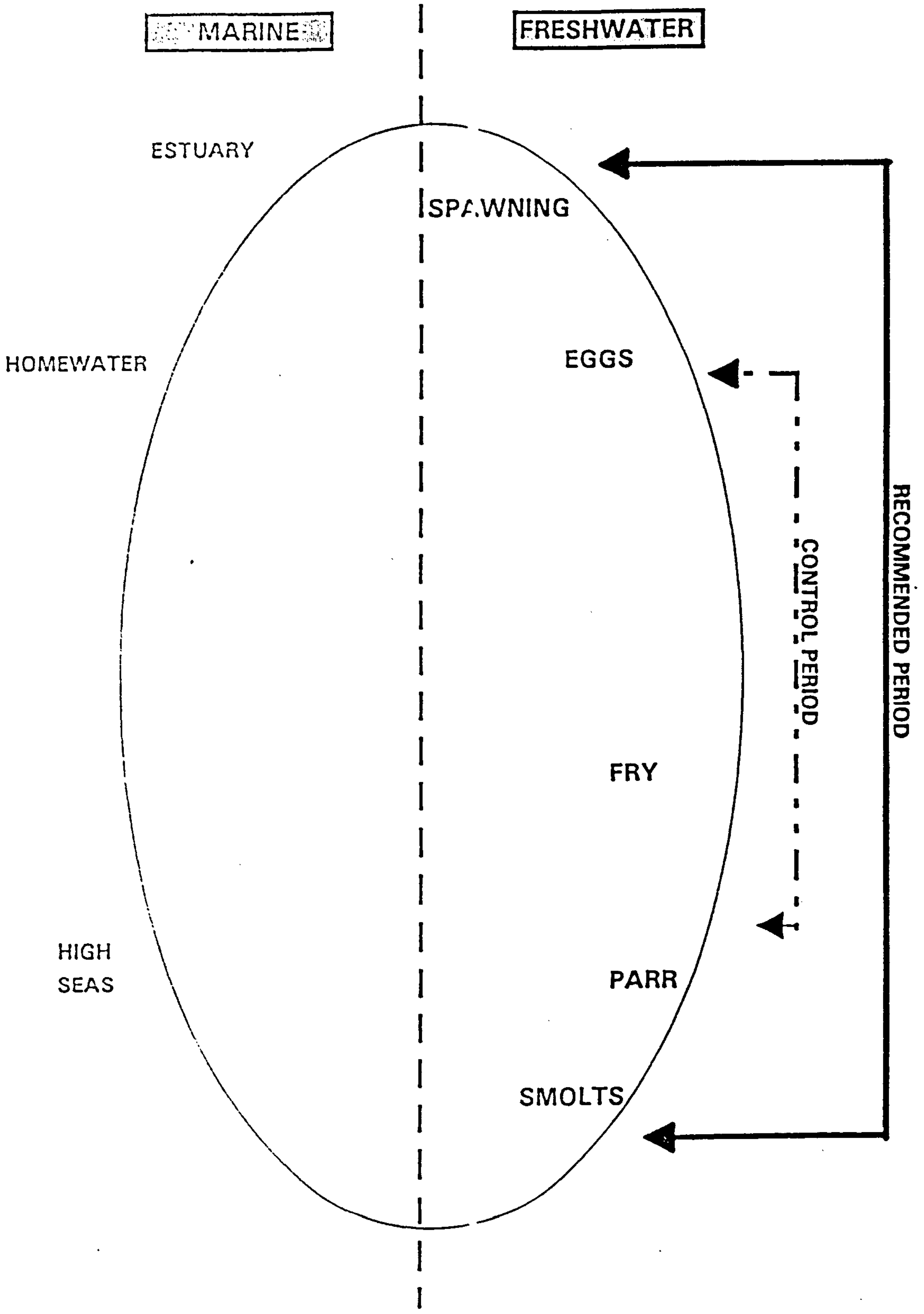


Figure 6.2.1 Relationship between river length and average salmon rod catch for rivers in Wales (UK)

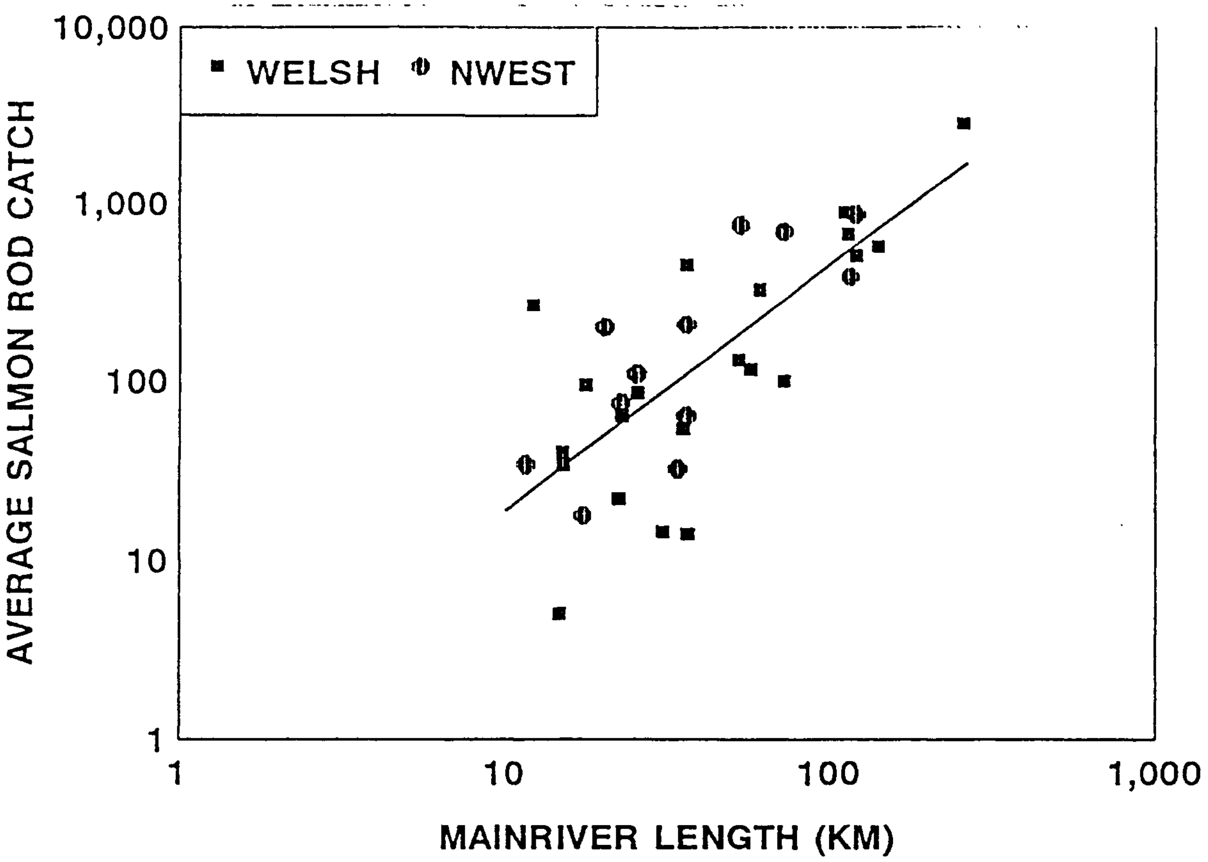


Figure 6.2.2 Relationship between river length and the proportion of the salmon catch that is 1SW for rivers in Wales (UK)

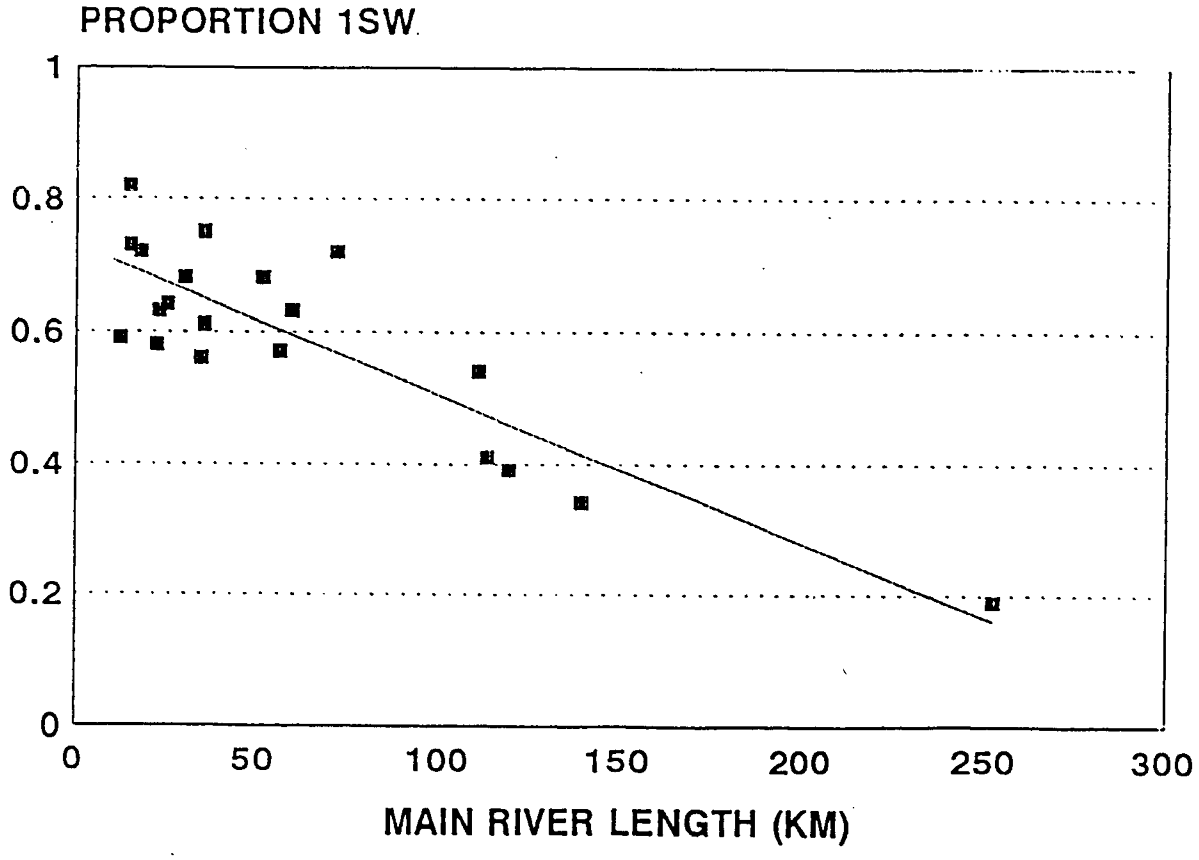


Figure 6.2.3 Variation in angling exploitation rate on fish entering the River Dee, UK(Wales) during different months of the year.

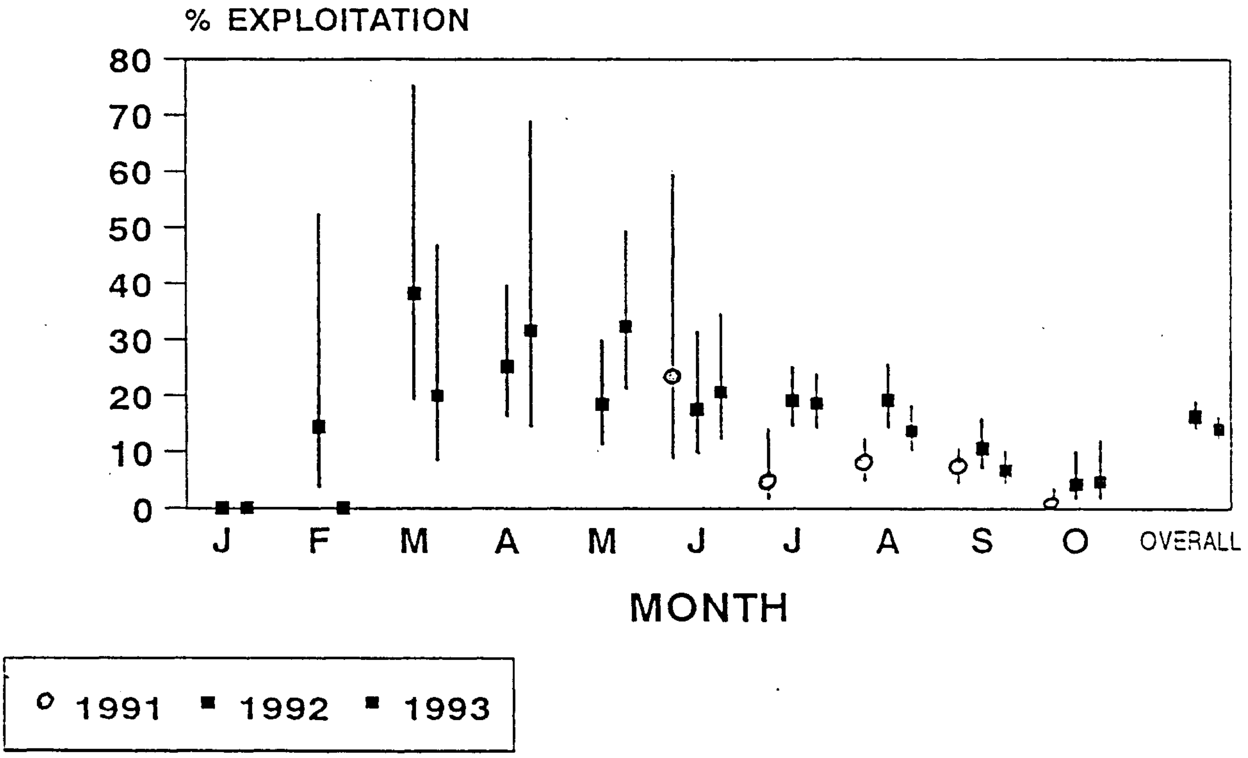


Figure 6.2.4 Comparison of stock-recruitment data for three tributary streams in Europe: the Girnock Burn, Shelligan Burn and a tributary of the Wye.

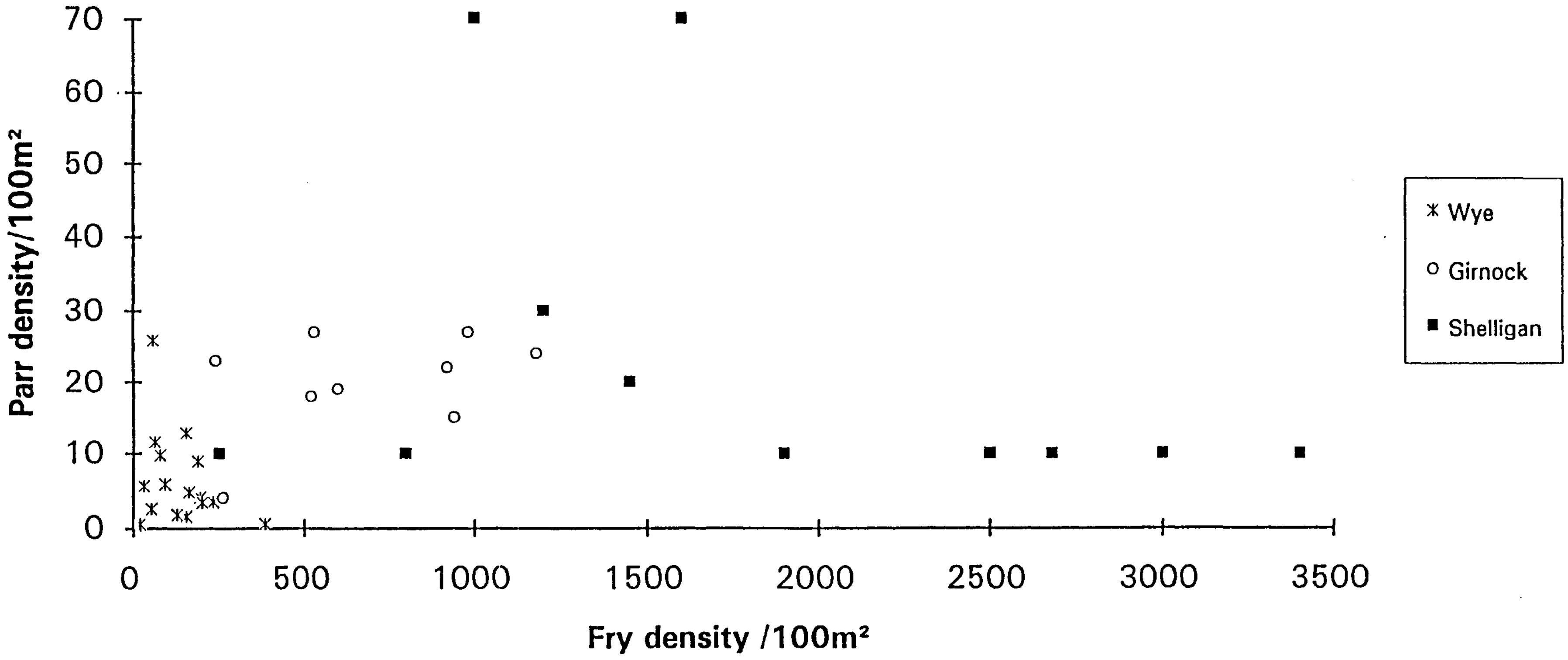


Figure 6.2.5 Transformed stock-recruitment data for small rivers/tributaries

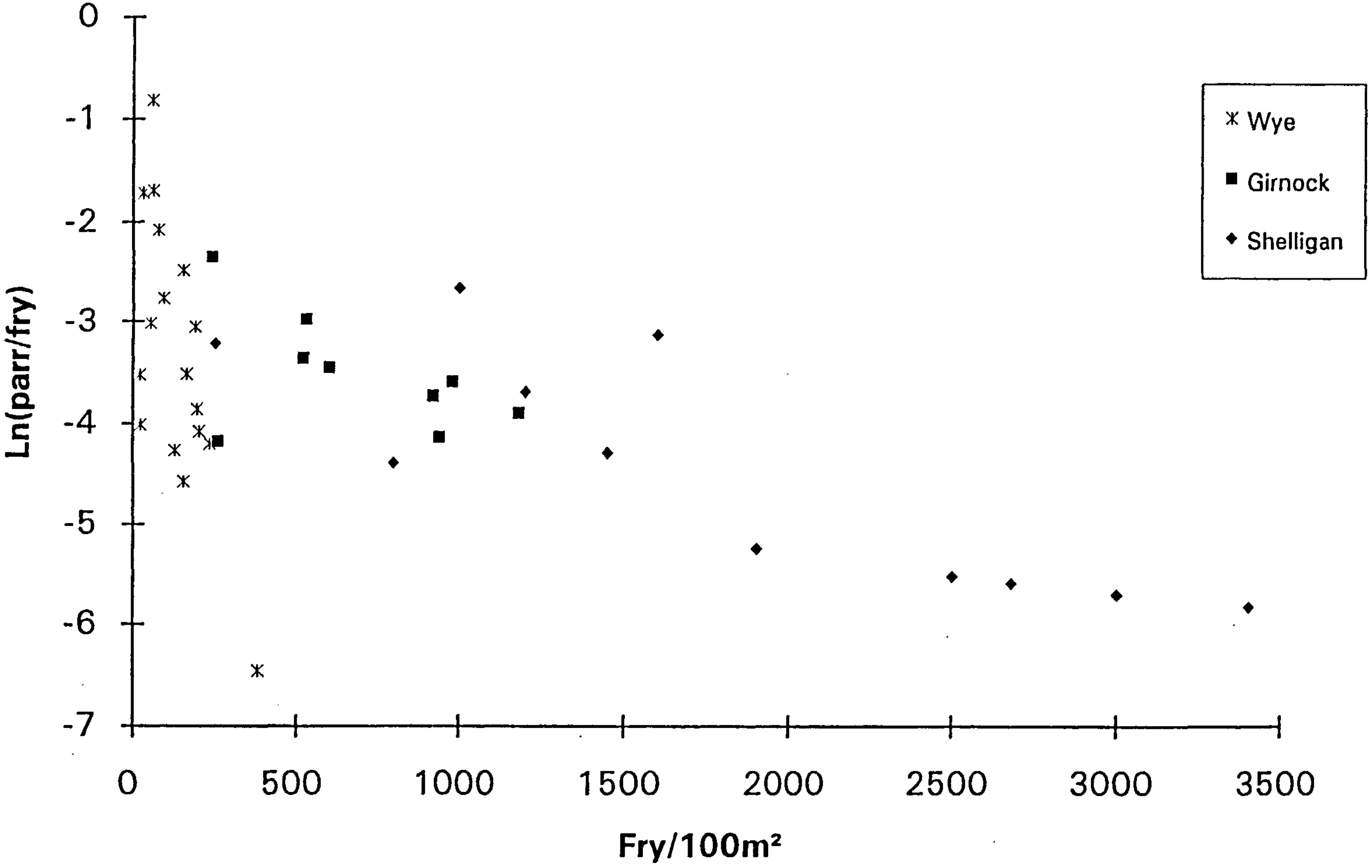


Figure 6.2.6 Comparison of stock-recruitment data for three 'whole' rivers in Europe, the Bush, Girnock Burn and Burrishoole. Burrishoole data are shown for three periods.

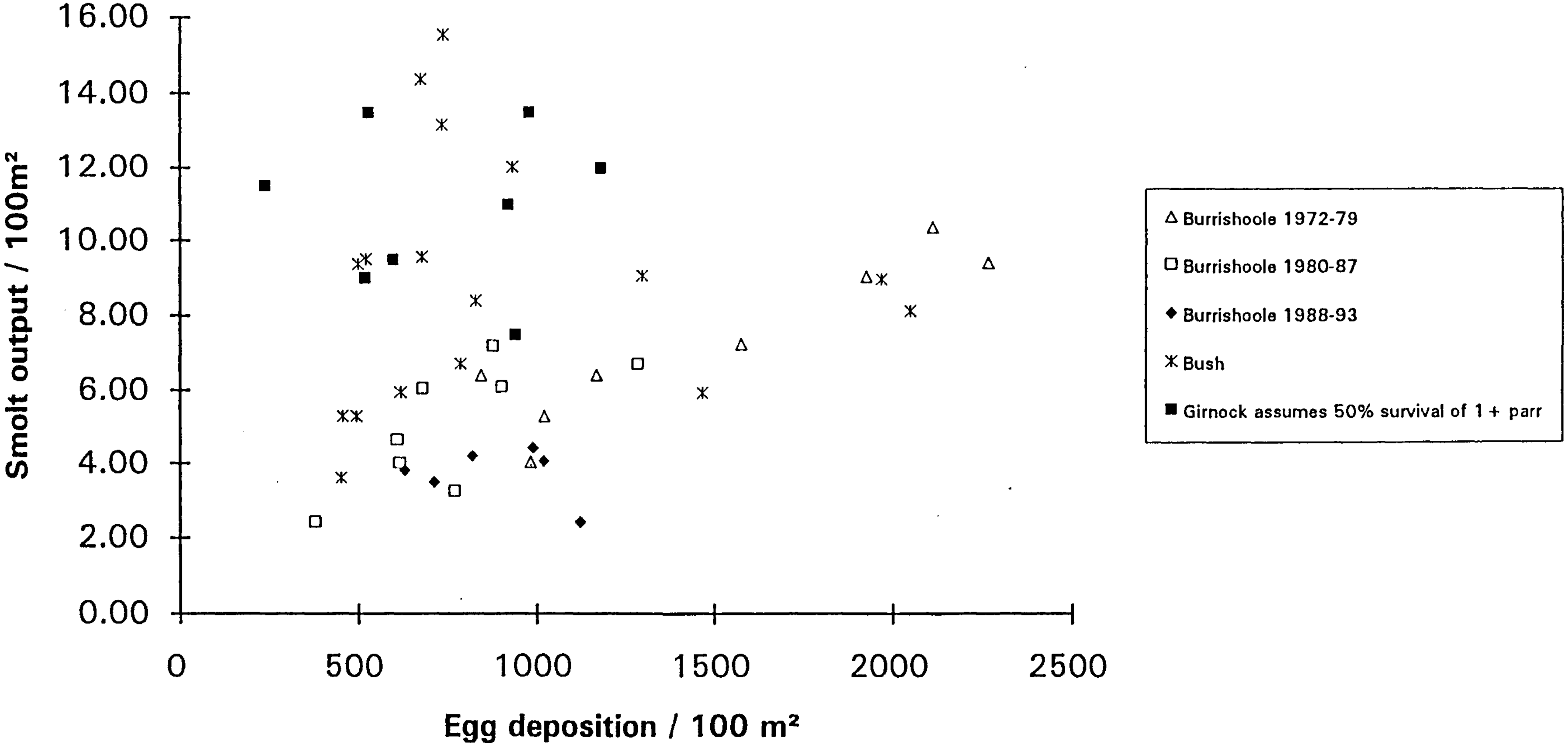


Figure 6.2.7 Transformed stock-recruitment data from whole river systems.