The Transportation of the Maximum Gain Salmon Spawning Target from the River Bush (N.I.) to England and Wales

R&D Technical Report W65

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Publishing Organisation:
Environment Agency
Rio House
Waterside Drive
Aztec West
Almondsbury
Bristol BS32 4UD

Tel: 01454 624400 Fax: 01454 624409

ISBN:BABX

Dissemination status
Internal: Released to Regions
External: Released to the Public Domain

Statement of use
This report describes the refinement of a methodology for transporting salmon spawning targets from a donor river in Ireland to recipient rivers in England and Wales. As a result, spawning targets are derived for 75 principal salmon rivers. Further refinements are likely if an additional phase of the project is progressed.

It will be of interest to Fisheries staff involved in assessing salmon spawning success. It should be read in conjunction with companion report W64.

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WRC Report No.:EA 4390

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Amendments

Any corrections or proposed amendments to this manual should be made through the regional Agency representative on the Water Resources National Abstraction Licensing Group.

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EXECUTIVE SUMMARY

The identification of spawning targets for salmon requires a knowledge of the stock-recruitment relationship, which are derived from long time series of data on egg deposition and smolt output levels for an entire catchment. Such data are only available for a few rivers. There is therefore a need for a robust methodology for transporting targets from rivers with stock-recruitment data to rivers where such data is absent.

The report 'Spawning escapement targets for Atlantic salmon' (R&D Technical Report W64) outlines a possible methodology for transporting targets based on habitat mapping using a GIS, and the use of relationships between different river types and productivity. Targets obtained from rivers with egg and smolt data can be transported to other rivers by adjusting for changes in the relative proportions of the river types present. Using this approach, this report develops a preliminary methodology for transporting targets from the River Bush to rivers in England and Wales.

A methodology for estimating stream areas for each of a series of defined river types is presented, and the calibration and validation of the model on rivers with egg deposition and smolt output data is described. A model of smolt output based on the defined river types is derived and subsequently applied to English and Welsh rivers. Salmon spawning targets are then presented for these rivers. The report concludes by outlining areas for further work.

It must be stressed that the methodology that is presented makes many assumptions, and that further refinements to the approach are required. Other initiatives within the Environment Agency such as the development of a river fisheries habitat inventory, and the development of a salmon lifecycle model are likely to considerably improve on the methodologies outlined here. In addition, many of the parameter values used (e.g. for river widths and juvenile densities) are based on national average values. Target estimates could be considerably improved by utilising river specific estimates where these are available.

All spawning target values that are quoted in this report should be regarded as provisional, and it is recommended that target values for all rivers are reappraised against local information.

KEY WORDS

Stock-recruitment; spawning target; escapement; salmon; River Bush; transport; GIS.

1. INTRODUCTION

1.1 Background

The identification of spawning targets for salmon requires a knowledge of the stock-recruitment relationship. Stock-recruitment relationships are derived from long time series of data on egg deposition and smolt output levels for an entire catchment, and such data are only available for a few rivers. There is therefore a need to develop methodologies for transporting targets from rivers with stock-recruitment data to rivers where such data are absent.

The report "Spawning escapement targets for Atlantic salmon" (R&D Technical Report W64) outlined a possible methodology for transporting targets based on habitat mapping using a GIS, and the use of relationships between different river types and productivity. Targets obtained from rivers with egg and smolt data could then be transported to other rivers by adjusting for changes in the relative proportions of the river types present.

This report develops a preliminary methodology for transporting targets from the River Bush to Environment Agency Rivers. It must be stressed that the methodology makes many assumptions, and that further refinements to the approach are required. Other initiatives within the Environment Agency such as the development of a river fisheries reach inventory, and the development of a salmon lifecycle model are likely to considerably improve on the methodologies outlined here.

In addition, many of the parameter values used (e.g. for river widths and juvenile densities) are based on national average values. Target estimates could be considerably improved by utilising river specific estimates where these are available. The target values quoted in this report should therefore be regarded as provisional, and it is recommended that target values for all rivers are reappraised against local information.

1.2 Objectives

Overall Objective

To produce a working methodology for transporting salmon spawning targets from the River Bush to Environment Agency rivers, and to estimate preliminary target values for a number of river types.

Specific objectives

1. To further develop the habitat model (from map-based HABSCORE data) to estimate 0+ salmon densities. (The initial development of this model concentrated on >0+ salmon.)

2. To validate the use of GIS for running habitat models developed for 0+ salmon (see 1 above) and >0+ salmon (see original project output - published as R&D Technical Report W64) by applying the model to long-term salmon density data from the Conwy.

3. To develop a simple model linking 0+ densities to smolt output and obtain 1:250,000 GIS data for the Bush (N.I.), North Esk (Scotland) and Girnock Burn (Scotland) to calibrate/validate this model by comparison with smolt output data from these rivers.

4. To apply the model developed in '3' (above) to 1:250,000 GIS data for principal Agency salmon rivers to obtain an index of smolt output for each river.

5. To assess estimates of marine survival to enable correction of maximum gain targets

6. To combine 4 and 5 to provide a simple matrix of targets for combinations of marine and freshwater 'production' and assign targets to principal Agency salmon rivers.

7. To investigate interactions between juvenile salmon and sea trout using the HABSCORE data-base and advise on the implications of these for setting salmon spawning targets.

1.3 Overview of report

This report describes a methodology that utilises a simple river reach classification based on juvenile salmon density data. A GIS is used to characterise the River Bush in terms of the river reach classification, and stock-recruitment data from the Bush is used to develop a river-specific stock-recruitment model based on the classification. The model is applied to Environment Agency rivers using a GIS, to obtain river-specific stock-recruitment models. Information on marine survival and adult fecundity is then used to derive targets for each river.

The report starts by describing the theoretical framework used for target setting (Section 2). Sections 3 and 4 describe the development of a simple river type classification and its characterisation in relation to salmon parr densities in England and Wales. Section 5 describes the estimation of stream areas for each river type, and Sections 6 and 7 describe the calibration and validation of the model on rivers with egg deposition and smolt output data. Section 8 describes the application of the smolt model to English and Welsh rivers, and Section 9 the estimation of salmon spawning targets. The report concludes by outlining areas for further work in Section 10. The relationship between the report structure and the specific objectives are summarised in Table 1.1.

Table 1.1 Structure of report in relation to specific objectives

Specific Objective	Section
1. Develop models relating habitat to parr densities	3. Development of river type classification 4. Estimation of carrying capacity for parr in each river type
2. Validate estimates of parr densities on Conwy	Not applicable
3. Develop smolt production model	2. Framework for target setting 5. Estimation of relative stream areas 6. Model calibration on River Bush 7. Validation of model
4. Application of model to Agency rivers	8. Application of model to Agency rivers
5. Assess estimates of marine survival	2. Framework for target setting 9. Transportation of targets
6. Assign targets to rivers	9. Transportation of targets
7. Interactions between salmon and trout	Appendix B

2. FRAMEWORK FOR TARGET SETTING

2.1 Introduction

To estimate the spawning escapement target for a catchment, we need the stock recruitment function that relates the egg deposition (eggs/area) in the hth cohort, to the resulting smolt production (smolts/area). Thus

$$s_h = f(x_h)$$

where

x_h	egg deposition in the hth cohort	eggs/area
s_h	smolt production from hth cohort	smolts/area
f	the stock-recruitment function	

To enable this function to be transported between rivers, it is necessary to include information on the relative proportions of different habitat types within the catchment, and information on the smolt production dynamics within each.

The model for smolt production used in this preliminary methodology is illustrated below in Figure 2.1.

River Type (j)			
1	2	...	m

Reach (i)	Proportion of river type within reach				Area	Spawners
1	τ_{11}	τ_{12}	...	τ_{1m}	ρ_1	σ_1
2	τ_{21}	τ_{22}	...	τ_{2m}	ρ_2	σ_2
:	:	:		:	:	:
n	τ_{n1}	τ_{n2}	...	τ_{nm}	ρ_n	σ_n

Parr age (k)	Carrying capacity (parr density)				Survival	Smolts
1	η_{11}	η_{12}	...	η_{1m}	α_1	θ_1
2	η_{21}	η_{22}	...	η_{2m}	α_2	θ_2
:	:	:		:	:	:
r	η_{r1}	η_{r2}	...	η_{rm}	α_r	θ_r

Figure 2.1 Model of river catchment and smolt production - see text for explanation

2.2 Ages of salmon parr

For the purpose of this model, juvenile salmon are divided into r age classes. The kth age class is characterised by an underlying survival rate from egg to parr (α_k), and the proportion of those parr that successfully leave the river system as smolts (θ_k). The survival rate from egg to parr of age k can be thought of as the survival rate that would operate at very low densities, at which density-dependent factors do not operate. For this simple model, the survival rates and smolt production rates are assumed to be constant throughout the catchment.

2.3 Definition of river types

A fundamental component of the smolt production model and the transportation of spawning targets is definition of different river types, and the existence of an inventory of types for each catchment. A number (m) of river types are defined which are characterised by differences in habitat suitability for different ages of fish. The suitability of habitat in the jth river type for the kth age class of fish is described in terms of the long term average density, or "carrying capacity", of parr (η_{jk}) that could be supported at optimal spawning densities.

2.4 Subdivision of catchment into reaches

The entire river network is considered to be divided into n reaches. These may represent major tributaries or sub-catchments of the river. The main distinction between reaches is that the density of egg deposition is allowed to be different in each.

The ith reach contains a proportion ρ_i of the total wetted area of the river

$$\sum_{i=1}^{n} \rho_i = 1,$$

and each reach receives a proportion σ_i of the total escapement

$$\sum_{i=1}^{n} \sigma_i = 1$$

If spawning occurs at a constant rate in each reach, then for all i

$$\rho_i = \sigma_i$$

Each reach will contain a mix of different river types. The proportion of the jth river type in the ith river reach is τ_{ij}.

$$\sum_{j=1}^{m} \tau_{ij} = 1$$

2.5 Smolt production model within river type and reach

Consider the jth river type within the ith river reach. The relationship between the parr density of age k with the density of eggs laid in the hth cohort is given by

$$p_{hijk} = f(x_{hi};\alpha_k,\eta_{jk})$$

where

p_{hijk}	density of parr of age k in jth river type, ith river reach in hth cohort
x_{hi}	egg density in ith reach, hth cohort
α_k	survival from egg to parr of age k at low densities
η_{jk}	carrying capacity for parr of age k in jth river type
f	the two parameter stock recruitment function (e.g. Ricker, Beverton-Holt)

The survival rate α_k is assumed to be constant across all reaches and river types, whereas the carrying capacity (η_{jk}) varies between river types.

If a constant proportion (θ_k) of these parr turn into smolts, then the smolt output (s_{hijk}) is given by

$$s_{hijk} = \theta_k f(x_{hi};\alpha_k,\eta_{jk})$$

2.6 General smolt production model for entire catchment

The relationship between the egg density in the ith river reach (x_{hi}) and the average egg density for the whole catchment (x_h) and is given by

$$x_{hi} = x_h \frac{\sigma_i}{\rho_i}$$

and the stock recruitment model becomes

$$s_{hijk} = \theta_k f\left(\frac{\sigma_i}{\rho_i} x_h;\alpha_k,\eta_{jk}\right)$$

The area of each river type within each reach as a proportion of the total stream area is given by

$$\rho_i \tau_{ij}$$

The average smolt output per unit area of age k for the entire catchment, s_{hk}, is therefore given by

$$s_{hk} = \theta_k \sum_{i=1}^{n} \rho_i \sum_{j=1}^{m} \tau_{ij} f\left(\frac{\sigma_i}{\rho_i} x_h; \alpha_k, \eta_{jk}\right) \text{ .... Equation 1}$$

The average smolt output per unit area for all ages for the entire catchment, s_h, is therefore given by

$$s_h = \sum_{k=1}^{r} \theta_k \sum_{i=1}^{n} \rho_i \sum_{j=1}^{m} \tau_{ij} f\left(\frac{\sigma_i}{\rho_i} x_h; \alpha_k, \eta_{jk}\right) \text{ .... Equation 2}$$

and this is the basic model relating average egg deposition density in the catchment x_h, to the average smolt density s_h.

2.7 Ricker smolt production model for whole catchment

So far, the catchment model has been developed in terms of a general two parameter stock recruitment model operating within each river type within each reach. If a Ricker model is assumed, then

$$p_{hijk} = \alpha_k x_{hi} e^{-\beta_{jk} x_{hi}}$$

where

p_{hijk}	density of parr of age k in jth river type, ith river reach in hth cohort
x_{hi}	egg density in ith reach, hth cohort
α_k	survival from egg to parr of age k at low densities
β_{jk}	density dependent parameter of Ricker model for parr of age k in the jth river type

We need to reparameterise the Ricker model in terms of the maximum parr density (η_{jk}).

$$\frac{dp_{hijk}}{dx_{hi}} = \alpha_k e^{-\beta_{jk} x_{hi}} \left(1 - \beta_{jk} x_{hi}\right)$$

and so the egg deposition that maximises the parr density is given by

$$x_{hi} = \frac{1}{\beta_{jk}}$$

and therefore η_{jk} is given by

$$\eta_{jk} = \frac{\alpha_k}{e\beta_{jk}}$$

and therefore

$$\beta_{jk} = \frac{\alpha_k}{e\eta_{jk}}$$

Redefining the Ricker model in terms of carrying capacity gives

$$p_{hijk} = \alpha_k x_{hi} e^{-\frac{\alpha_k x_{hi}}{e\eta_{jk}}}$$

and so

$$f(x_{hi};\alpha_k,\eta_{jk}) = \alpha_k x_{hi} e^{-\frac{\alpha_k x_{hi}}{e\eta_{jk}}} \quad \text{.......... Equation 3}$$

Substituting Equation 3 into Equation 1, we get the average smolt output per unit area of age k for the entire catchment,

$$s_{hk} = \theta_k \alpha_k \sum_{i=1}^{n} \sigma_i \sum_{j=1}^{m} \tau_{ij} x_h e^{-\frac{\alpha_k \sigma_i x_h}{e\eta_{jk}\rho_i}} \quad \text{.......... Equation 4}$$

The average smolt output per unit area for all ages for the entire catchment, s_h, is therefore given by

$$s_h = \sum_{k=1}^{r} \theta_k \alpha_k \sum_{i=1}^{n} \sigma_i \sum_{j=1}^{m} \tau_{ij} x_h e^{-\frac{\alpha_k \sigma_i x_h}{e\eta_{jk}\rho_i}} \quad \text{.......... Equation 5}$$

2.8 Target egg deposition for maximum smolt output

To obtain the egg deposition x_{ms} that maximises the smolt output s_h, we get

$$\frac{ds_h}{dx_h} = \sum_{k=1}^{r} \theta_k \alpha_k \sum_{i=1}^{n} \sigma_i \sum_{j=1}^{m} \tau_{ij} e^{-\frac{\alpha_k \sigma_i x_h}{e\eta_{jk}\rho_i}} \left(1 - \frac{\alpha_k \sigma_i x_h}{e\eta_{jk}\rho_i}\right)$$

and thus the egg deposition target x_{ms} for maximum smolt production must satisfy

$$\sum_{k=1}^{r} \theta_k \alpha_k \sum_{i=1}^{n} \sigma_i \sum_{j=1}^{m} \tau_{ij} e^{-\frac{\alpha_k \sigma_i x_{ms}}{e\eta_{jk}\rho_i}} \left(1 - \frac{\alpha_k \sigma_i x_{ms}}{e\eta_{jk}\rho_i}\right) = 0 \quad \text{.......... Equation 6}$$

2.9 Marine survival

To estimate the maximum gain target, it is first necessary to estimate the average number of eggs laid per smolt leaving the river (ϕ), then

$$x_{h*} = \phi s_h$$

where x_{h*} is the number of eggs produced in subsequent years from the hth cohort of smolts.

Data available for the estimation of ϕ included the proportion of females (υ), the average female fecundity (ω), the proportion of grilse (γ) and the marine survival for grilse π_1 and multi-sea winter fish π_2. It is therefore necessary to define the relationship between ϕ and υ, ω, γ, π_1 and π_2.

Consider s_1 smolts destined to return as grilse, and s_2 smolts destined to return as multi-sea winter fish. Let the number of grilse returning be a_1 and the number of multi-sea winter fish returning be a_2. Let the survival rates for grilse and multi-sea winter fish be π_1 and π_2 respectively. Then

$$a_1 = \pi_1 s_1 \quad \text{.......... Equation 7}$$

and

$$a_2 = \pi_2 s_2 \quad \text{.......... Equation 8}$$

Let the proportion of grilse be γ, thus

$$\gamma = \frac{a_1}{a_1 + a_2} \qquad \text{Equation 9}$$

or

$$\frac{a_2}{a_1} = \frac{1}{\gamma} - 1 \qquad \text{Equation 10}$$

The overall survival rate δ is given by

$$\delta = \frac{a_1 + a_2}{s_1 + s_2} \qquad \text{Equation 11}$$

Substituting Equation 7 and 8 into Equation 11, we get

$$\delta = \frac{a_1 + a_2}{\frac{a_1}{\pi_1} + \frac{a_2}{\pi_2}} \qquad \text{Equation 12}$$

Rearranging we get

$$\delta = \left(\frac{a_1 + a_2}{a_1}\right)\left(\frac{1}{\frac{1}{\pi_1} + \left(\frac{a_2}{a_1}\right)\frac{1}{\pi_2}}\right)$$

and substituting Equation 9 and 10 we get

$$\delta = \frac{1}{\frac{(1-\gamma)}{\pi_2} + \frac{\gamma}{\pi_1}}$$

If the proportion of females among the survivors is υ, and the average fecundity of the females is ω, then the number of eggs returning to the catchment from each smolt is

$$\phi = \frac{\upsilon\omega}{\frac{(1-\gamma)}{\pi_2} + \frac{\gamma}{\pi_1}} \qquad \text{Equation 13}$$

2.10 Target egg deposition for maximum gain

Gain (g_h) can be defined as the surplus smolt production at a given egg deposition (x_h) over and above that required to generate the same egg deposition in future generations. Thus

$$g_h = s_h - \frac{x_h}{\phi}$$

therefore

$$g_h = \sum_{k=1}^{r} \theta_k \alpha_k \sum_{i=1}^{n} \sigma_i \sum_{j=1}^{m} \left[\tau_{ij} x_h e^{-\frac{\alpha_k \sigma_i x_h}{e \eta_{jk} \rho_i}} \right] - \frac{x_h}{\phi}$$

$$\frac{dg}{dx_h} = \sum_{k=1}^{r} \theta_k \alpha_k \sum_{i=1}^{n} \sigma_i \sum_{j=1}^{m} \left[\tau_{ij} e^{-\frac{\alpha_k \sigma_i x_h}{e \eta_{jk} \rho_i}} \left(1 - \frac{\alpha_k \sigma_i x_h}{e \eta_{jk} \rho_i} \right) \right] - \frac{1}{\phi}$$

And so maximum gain is given by egg densities (x_{mg}) satisfied by

$$\phi \sum_{k=1}^{r} \theta_k \alpha_k \sum_{i=1}^{n} \sigma_i \sum_{j=1}^{m} \left[\tau_{ij} e^{-\frac{\alpha_k \sigma_i x_{mg}}{e \eta_{jk} \rho_i}} \left(1 - \frac{\alpha_k \sigma_i x_{mg}}{e \eta_{jk} \rho_i} \right) \right] = 1 \qquad \text{.................................. Equation 14}$$

where

$$\phi = \frac{\upsilon \omega}{\frac{(1-\gamma)}{\pi_2} + \frac{\gamma}{\pi_1}}$$

3. DEVELOPMENT OF RIVER TYPE CLASSIFICATION

Following the model laid out in Section 2, a river-reach classification is required that can be used to subdivide a catchment into m river types. The variables used to develop the classification needed to fulfil two criteria:

- they should be important explanatory variables for juvenile salmon densities (η_{jk});
- they should be readily obtained from the GIS system being used.

Identification of important explanatory variables was achieved by means of the HABSCORE model for >0+ salmon. The regression model is shown in Table 3.1, and the accumulated analysis of variance in Table 3.2. The first two variables to be selected by the variable selection procedures were altitude and stream order (Shreve, or "Link Number") (1:50,000). Altitude and measures of stream order are readily available from GIS. The next most important variable that could be obtained on a catchment basis or predicted from a GIS model is conductivity. The inclusion of conductivity was beyond the scope of this project.

Table 3.1 Estimates of regression coefficients for the HABSCORE >0+ salmon model

	transformation	estimate	s.e.	t(195)	t probability
Constant		-3.713	0.619	-5.99	<.001
Altitude	x	0.00483	0.00119	4.08	<.001
Stream order (Shreve)	log x	0.2643	0.0872	3.03	0.003
Cobbles with run	√x	0.1100	0.0462	2.38	0.018
Conductivity	log x	-0.461	0.111	-4.15	<.001
Cross-sectional stream area	log x	-0.509	0.152	-3.35	<.001
Distance from source	log x	0.539	0.222	2.43	0.016

Table 3.2 Accumulated analysis of variance for HABSCORE >0+ salmon model

Change	d.f.	s.s.	m.s.	v.r.	F probability
+ Altitude	1	39.114	39.114	38.42	<.001
+ Stream order (Shreve)	1	16.313	16.313	16.02	<.001
+ Cobbles with run	1	11.567	11.567	11.36	<.001
+ Conductivity	1	9.397	9.397	9.23	0.003
+ Cross-sectional stream area	1	6.117	6.117	6.01	0.015
+ Distance from source	1	5.992	5.992	5.89	0.016
Residual	195	198.546	1.018		
Total	201	287.046	1.428		

The classification developed for target transportation used altitude and the Strahler stream order. Whilst the Shreve stream order was available from GIS, the Strahler stream order was used in preference for a number of reasons:

- data was available (from RHS) to relate Strahler stream orders at different map scales,
- habitat models using just altitude and the two stream orders as predictive variables suggested that Strahler was the better predictor,
- Strahler had fewer classes and formed a better basis for a simple classification system, and
- Strahler is easier to calculate in the absence of a GIS.

The relationship between juvenile salmon abundance and catchment features cannot be assumed to be cause and effect. Altitude, for example, will be related to other factors such as geology, rainfall, distance from estuary, temperature and gradient. The relationship between altitude and gradient in the HABSCORE database is illustrated in Figure 3.1.

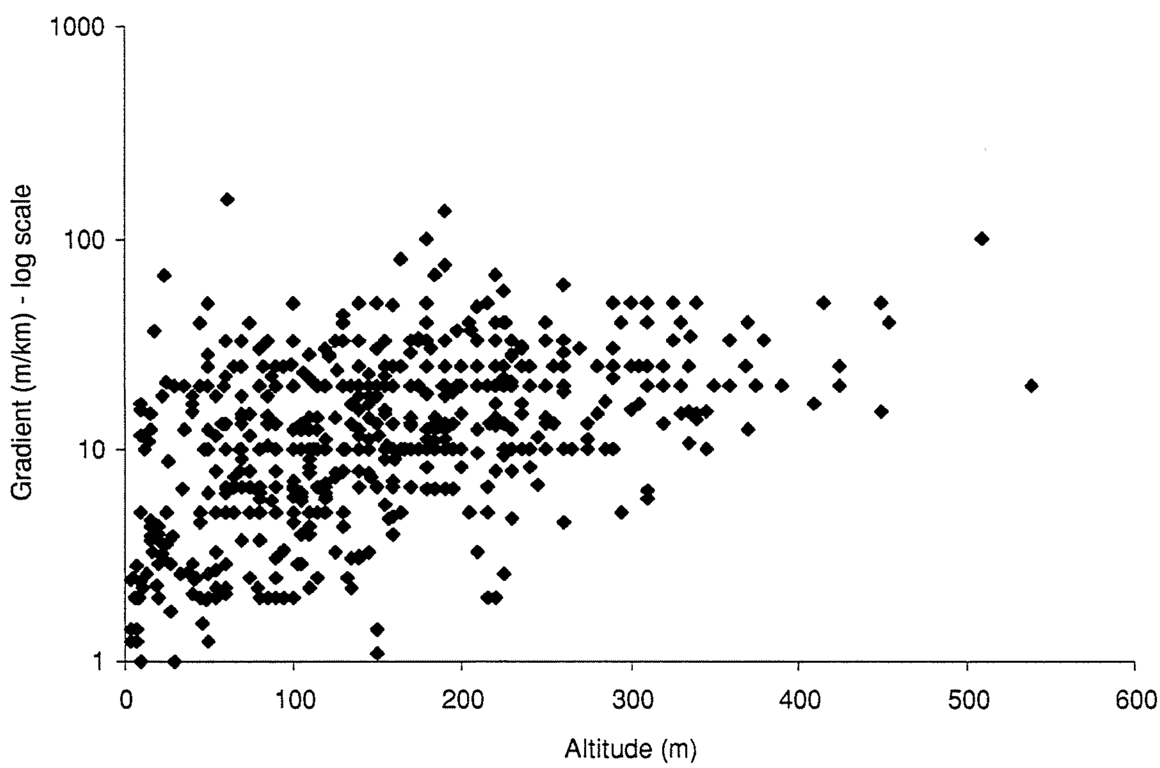

Figure 3.1 Relationship between the altitude and gradient of sites in the HABSCORE database

The GIS river network and altitude data used in this exercise is illustrated in the attached map of Wales, showing the resolution of data and illustrating the differences in river systems in terms of their altitude and stream order composition. This data allows estimation of the length of river within different stream order and altitude classes for salmon rivers in England and Wales. Additional GIS data was obtained from the North Esk and Girnock Burn in Scotland,

and the River Bush in Northern Ireland. The altitude classes for the Northern Irish data were different to those for Scotland, England and Wales, as shown in Table 3.3 (this was a feature of the GIS data that was available for analysis).

Table 3.3 GIS altitude classes for Britain and Northern Ireland

Class	Britain		Northern Ireland	
	Altitude range (m)	Mid-point (m)	Altitude range (m)	Mid-point (m)
A	0-49	25	0-59	30
B	50-99	75	60-119	90
C	100-149	125	120-179	150
D	150-199	175	180-239	210
E	200-299	250	240-299	270
F	300-399	350	300-449	375
G	400-499	450		
H	500-599	550		
I	600-699	650		
J	700-799	750		
K	800-899	850		

The classification of river types was generated from stream order and the classification of altitude as shown in Table 3.4. Thus the interpretation of some of the classes would be:

A5 - a large lowland river
H1 - a small upland headwater
E5 - a main river at moderate altitude
A1 - a small lowland stream

Table 3.4 Classification of river types according to altitude and stream order

Altitude range	Class	Stream order				
		1	2	3	4	5
0-49	A	A1	A2	A3	A4	A5
50-99	B	B1	B2	B3	B4	B5
100-149	C	C1	C2	C3	C4	C5
150-199	D	D1	D2	D3	D4	D5
200-299	E	E1	E2	E3	E4	E5
300-399	F	F1	F2	F3	F4	F5
400-499	G	G1	G2	G3	G4	G5
500-599	H	H1	H2	H3	H4	H5
600-699	I	I1	I2	I3	I4	I5
700-799	J	J1	J2	J3	J4	J5
800-899	K	K1	K2	K3	K4	K5

4. ESTIMATION OF CARRYING CAPACITY FOR PARR IN EACH RIVER TYPE (η_{KJ})

4.1 Introduction

Having defined a classification of river types based on variables likely to explain spatial variation in salmon parr, it is necessary to characterise each river type in terms of the expected parr densities. This work addresses specific objective 1. It was considered inappropriate to "validate" the estimates of national average parr densities (which include data from the Conwy) in each river type, with data from the Conwy (specific objective 2). The validation exercise was focused on rivers with smolt data (Section 7).

4.2 Methods

Two age classes were defined (r=2), 0+ parr and >0+ parr. Data from the extended HABSCORE database for sites with access to salmon (398 sites) were used to estimate the national average 0+ and >0+ salmon densities in each river type defined by stream order and altitude. A program was written for Genstat 5.3 to undertake Generalised Linear Modelling (GLM) with a Poisson error structure, using a forwards stepwise variable selection procedure. The model related counts of fish to stream order (o) and altitude (a) (using a cubic transformation) and sampling site area. The use of a continuous model enables transfer between different altitude classes (Section 3), different map scales (Appendix A), and smoothes out the effects of small sample sizes in some reach classes.

In addition to the influence of river type on salmon parr densities, the relationship between salmon and trout parr densities was investigated (Appendix B).

4.3 Results

4.3.1 0+ parr (η_{1j})

The result of the 0+ salmon parr model are given in Tables 4.1 to 4.5. Deviance, mean deviance and deviance ratios (produced by GLM) can be interpreted in the same way as sum of squares, mean square and variance ratio from an analysis of variance table. Whilst the model is highly significant, a relatively small proportion (24.7%) of the spatial variance is explained (Table 4.2).

Table 4.1 Summary of analysis

	d.f.	deviance	mean deviance	deviance ratio	significance
Regression	7	5955	850.67	10.65	<.0001
Residual	390	31143	79.85		
Total	397	37098	93.45		

Table 4.2 Approximate percentage of 0+ salmon variance explained by the river-type model. Data for variances obtained from HABSCORE

Source		Percent variance	
Spatial	Explained	24.7	14.4
	Unexplained	75.3	44.1
	Total	100.0	
Random			40.7
Measurement			0.8
Total			100.0

Table 4.3 Estimates of regression coefficients

	Estimate	s.e.	t(390)	t pr.
Constant	-1.6113	0.0941	-17.12	<.001
o	0.971	0.167	5.80	<.001
a	0.0983	0.0192	5.11	<.001
a^2o	-0.00779	0.00172	-4.54	<.001
a^3	-0.000506	0.000131	-3.87	<.001
a^3o	-0.0002635	0.0000614	-4.29	<.001
o^2	-0.2572	0.0820	-3.14	0.002
a^3o^2	-0.0001328	0.0000666	-1.99	0.047

Table 4.4 Correlations between parameter estimates

	Constant	o	a	a^2o	a^3	a^3o	o^2	a^3o^2
Constant	1.000							
o	-0.281	1.000						
a	-0.202	0.197	1.000					
a^2o	0.243	-0.815	-0.319	1.000				
a^3	0.038	-0.136	-0.791	0.332	1.000			
a^3o	0.144	-0.343	-0.553	0.502	0.657	1.000		
o^2	-0.163	-0.747	-0.006	0.615	0.024	0.366	1.000	
a^3o^2	0.234	-0.607	-0.143	0.719	-0.136	0.292	0.571	1.000

Table 4.5 Accumulated analysis of deviance

Change	d.f.	deviance	mean deviance	deviance ratio	significance
+o	1	1509.85	1509.85	18.91	<.001
+a	1	1283.92	1283.92	16.08	<.001
$+a^2o$	1	473.61	473.61	5.93	0.015
$+a^3$	1	728.75	728.75	9.13	0.003
$+a^3o$	1	1009.38	1009.38	12.64	<.001
$+o^2$	1	642.30	642.30	8.04	0.005
$+a^3o^2$	1	306.88	306.88	3.84	0.051
Residual	390	31143.24	79.85		
Total	397	37097.94	93.45		

The predicted 0+ density for each river reach class for the Northern Irish and British classes are given in Tables 4.6 and 4.7 respectively. Classes F3 and F4 had insufficient data to produce a reliable prediction.

Table 4.6 0+ parr densities (η_{1j}, numbers per 100m^2), Northern Ireland

			Stream order			
	Altitude class (m)	Class midpoint (m)	1	2	3	4
A	0-59	30	8.62	13.43	18.04	20.90
B	60-119	90	4.56	12.91	22.65	24.63
C	120-179	150	6.40	21.74	44.11	53.50
D	180-239	210	14.69	33.29	41.38	28.22
E	240-299	270	33.82	24.05	5.81	0.48
F	300-449	375	34.03	0.31	-	-

Table 4.7 0+ parr densities (η_{1j}, numbers per 100m^2), Britain

			Stream order			
	Altitude class (m)	Class midpoint (m)	1	2	3	4
A	0-49	25	9.65	14.11	18.73	22.58
B	50-99	75	4.79	12.06	19.62	20.62
C	100-149	125	5.09	17.04	34.15	40.94
D	150-199	175	8.77	27.27	50.20	54.68
E	200-299	250	26.38	30.34	14.83	3.08
F	300-399	350	44.64	1.56	-	-

4.3.2 >0+ parr (η_{2j})

The result of the >0+ salmon parr model are given in Tables 4.8 to 4.12. Whilst the model is highly significant, a relatively small proportion (22.3%) of the spatial variance is explained (Table 4.9).

Table 4.8 Summary of analysis

	d.f.	deviance	mean deviance	deviance ratio	
Regression	5	1446.	289.27	13.02	<.0001
Residual	392	8710.	22.22		
Total	397	10157.	25.58		

Table 4.9 Approximate percentage of >0+ salmon variance explained by the river-type model. Data for variances obtained from HABSCORE

Source		Percent variance	
Spatial	Explained	22.3	13.1
	Unexplained	77.7	45.8
	Total	100.0	
Random			40.4
Measurement			0.7
Total			100.0

Table 4.10 Estimates of regression coefficients

	estimate	s.e.	t(392)	tpr.
Constant	-2.5440	0.0834	-30.52	<.001
a	0.0437	0.0128	3.42	<.001
a^2	-0.002231	0.000988	-2.26	0.025
oa	-0.0575	0.0175	-3.29	0.001
o^2a	0.02189	0.00859	2.55	0.011
a^3o	0.0001881	0.0000888	2.12	0.035

Table 4.11 Correlations between parameter estimates

	Constant	a	a^2	oa	o^2a	a^3o
Constant	1.000					
a	0.080	1.000				
a^2	-0.529	-0.563	1.000			
oa	0.213	0.068	-0.077	1.000		
o^2a	-0.025	-0.646	0.307	-0.397	1.000	
a^3o	-0.221	-0.126	0.293	-0.822	0.363	1.000

Table 4.12 Accumulated analysis of deviance

Change	d.f.	deviance	mean deviance	deviance ratio	
+a	1	837.66	837.66	37.70	<.001
$+a^2$	1	264.19	264.19	11.89	<.001
+oa	1	165.97	165.97	7.47	0.007
$+o^2a$	1	77.70	77.70	3.50	0.062
$+a^3o$	1	100.82	100.82	4.54	0.034
Residual	392	8710.38	22.22		
Total	397	10156.72	25.58		

The resulting >0+ densities for the stream order and altitude combinations in the HABSCORE database are given in Tables 4.13 and 4.14. Classes F3 and F4 had insufficient data to produce a reliable prediction.

Table 4.13 >0+ parr densities (η_{2j}, numbers per $100m^2$), Northern Ireland

			Stream order			
	Altitude class (m)	Class midpoint (m)	1	2	3	4
A	0-59	30	1.96	3.66	4.20	2.96
B	60-119	90	4.04	5.92	6.93	6.48
C	120-179	150	8.73	8.15	7.90	7.96
D	180-239	210	15.49	9.55	7.94	8.93
E	240-299	270	17.72	9.53	9.00	14.92
F	300-449	375	3.74	6.45	-	-

Table 4.14 >0+ parr densities (η_{2j}, numbers per 100m^2), Britain

	Altitude class (m)	Class midpoint (m)	Stream order 1	2	3	4
A	0-49	25	1.87	3.49	3.93	2.66
B	50-99	75	3.33	5.33	6.39	5.73
C	100-149	125	6.39	7.27	7.70	7.59
D	150-199	175	11.51	8.87	7.93	8.21
E	200-299	250	18.06	9.70	8.39	11.68
F	300-399	350	7.02	7.40	-	-

4.3.3 Discussion

Juvenile salmon populations are characterised by a large proportion of random variation (Table 4.2 and Table 4.9), that cannot be explained by habitat models or river reach classifications. However, it is likely that the above models could usefully by improved by introducing additional explanatory variables and using more sophisticated modelling procedures.

5. ESTIMATION OF RELATIVE STREAM AREAS (τ_{IJ})

5.1 Introduction

The model for estimating spawning targets relies on estimates of the relative stream area (τ_{ij}) of each river type within each reach. This section describes the methods for estimating stream areas, which formed the basis of the smolt production model (specific objective 3).

5.2 Methods

The GIS system was used to generate information on lengths of river within each river type. Data for river widths was also required. Data from the 677 HABSCORE sites were used to model the relationship between (logged) wetted widths, altitude (a) and stream order (o). A quadratic model was produced, using a forwards stepwise procedure.

5.3 Results

The results of the analysis are given in Tables 5.1 to 5.4. The percentage variance accounted for was 45.3, and the standard error of observations was estimated to be 0.479.

Table 5.1 Summary of analysis

	d.f.	s.s.	m.s.	v.r.	Fpr.
Regression	3	129.5	43.1766	187.89	<.001
Residual	673	154.7	0.2298		
Total	676	284.2	0.4204		

Table 5.2 Estimates of regression coefficients

	estimate	s.e.	t(673)	tpr.
Constant	1.4329	0.0236	60.72	<.001
o	0.3834	0.0184	20.83	<.001
o^2	0.0926	0.0159	5.82	<.001
o^2a	-0.00388	0.00141	-2.74	0.006

Table 5.3 Correlations between parameter estimates

	Constant	o	o^2	o^2a
Constant	1.000			
o	0.054	1.000		
o^2	-0.607	-0.059	1.000	
o^2a	-0.161	0.077	0.480	1.000

Table 5.4 Accumulated analysis of variance

Change	d.f.	s.s.	m.s.	v.r.	Fpr.
+o	1	112.5970	112.5970	489.98	<.001
$+o^2$	1	15.2019	15.2019	66.15	<.001
$+o^2a$	1	1.7310	1.7310	7.53	0.006
Residual	673	154.6553	0.2298		
Total	676	284.1851	0.4204		

The resulting stream widths for the stream order and altitude combinations in the HABSCORE database are given in Tables 5.5 and 5.6.

Table 5.5 Predicted widths, Britain

			Stream order			
	Altitude class (m)	Class midpoint (m)	1	2	3	4
A	0-49	25	3.29	4.17	7.03	15.72
B	50-99	75	3.22	4.17	6.89	14.56
C	100-149	125	3.16	4.17	6.76	13.49
D	150-199	175	3.10	4.17	6.64	12.49
E	200-299	250	3.01	4.17	6.45	11.14
F	300-399	350	2.89	4.17	6.21	9.55
G	400-499	450	2.78	4.17	5.98	8.20
H	500-599	550	2.67	4.17	5.76	7.03

Table 5.6 Predicted widths, Northern Ireland

	Altitude class (m)	Class midpoint (m)	Stream order 1	2	3	4
A	0-59	30	3.28	4.17	7.01	15.60
B	60-119	90	3.20	4.17	6.85	14.23
C	120-179	150	3.13	4.17	6.70	12.98
D	180-239	210	3.05	4.17	6.55	11.84
E	240-299	270	2.98	4.17	6.40	10.80
F	300-449	375	2.86	4.17	6.15	9.20

5.4 Conclusions

The estimate of widths from altitude and stream order is very approximate. Since the data was obtained from electrofishing sites, the widths for higher order rivers are likely to collected from the smaller examples in which electrofishing is practical. For large river systems, the relative area of high order streams is likely to be under estimated.

Better methods are available for prediction that utilise data on catchment area upstream, rainfall and geology. Alternatively, river-specific site measurements for width could be added to the GIS database. It is recommended that an improved method is developed for width (and thus stream area) estimation that is used for both target transportation and compliance assessment.

6. ESTIMATION OF α_J AND θ_J FOR THE RIVER BUSH

6.1 Introduction

Having developed a river type classification, and characterised it in terms of salmon parr densities, it was necessary to relate this to the smolt production on the River Bush. The stock-recruitment data for the River Bush is likely to have been collected over a period of decreasing smolt production (Gersham Kennedy, *pers. comm.*) At the request of the Agency, the data was assumed to represent a steady state, this assumption is likely to underestimate target values for the Bush, and all target values transported from the Bush. This work fulfils the calibration component of specific objective 3.

6.2 Methods

No information was available on the spawning distribution within the catchment, and so the catchment was regarded as a single reach (n=1), and so $\rho_1=1$ and $\sigma_1=1$. GIS data on the lengths of river in each river type, together with width estimates (Section 5) were used to estimate the areas and proportion of areas (τ_j) in each river type. Given that egg and smolt data were available as total values for the catchment, it was also necessary to estimate the total stream area.

The smolt production models for each age class (Equation 4) were fitted to the long term data on egg deposition (x_h) and smolt output (s_{hk}), and the two unknown parameters (α_k, θ_k) estimated. A major assumption in this procedure is that the parr densities in each river type on the Bush were similar to the average values obtained from English and Welsh rivers (η_{jk}).

The model was too complex to be calibrated using Genstat 5.3, and so a manual procedure was used.

6.3 Results

The length of river on the Bush from GIS (1:250,000) is given in Table 6.1, and using the width estimates in Table 5.6, the stream areas were estimated and are given in Table 6.2. The total area for the Bush is estimated to be 77.91 hectares. The published area of the River Bush is 84.55 hectares; the GIS estimate is 92.1% of this figure. The proportion of stream area within each river type is given in Table 6.3.

Table 6.1 Length of Bush (metres)

	Altitude class (m)	Class midpoint (m)	Stream order 1	2	3	4	Total
A	0-59	30	11,503	5,234	16,061	13,763	46,561
B	60-119	90	36,331	13,208	11,992	0	61,531
C	120-179	150	17,252	1,100	1,478	0	19,830
D	180-239	210	8,902	0	1,131	0	10,033
E	240-299	270	5,591	570	225	0	6,386
F	300-449	375	5,259	0	0	0	5,259
	Total		84,838	20,112	30,887	13,763	149,600

Table 6.2 Area of Bush (hectares)

	Altitude class (m)	Class midpoint (m)	Stream order 1	2	3	4	Total
A	0-59	30	3.77	2.18	11.26	21.47	38.69
B	60-119	90	11.64	5.51	8.22	0.00	25.37
C	120-179	150	5.40	0.46	0.99	0.00	6.85
D	180-239	210	2.72	0.00	0.74	0.00	3.46
E	240-299	270	1.67	0.24	0.14	0.00	2.05
F	300-449	375	1.50	0.00	0.00	0.00	1.50
	Total		26.70	8.39	21.36	21.47	77.91

Table 6.3 Proportion of stream area within each reach class for the River Bush (τ_j)

	Altitude class (m)	Class midpoint (m)	Stream order 1	2	3	4
A	0-59	30	0.048	0.028	0.145	0.276
B	60-119	90	0.149	0.071	0.106	0.000
C	120-179	150	0.069	0.006	0.013	0.000
D	180-239	210	0.035	0.000	0.010	0.000
E	240-299	270	0.021	0.003	0.002	0.000
F	300-449	375	0.019	0.000	0.000	0.000

The stock-recruitment data for the Bush used to fit the model are given in Table 6.4.

Table 6.4 Stock-recruitment data for the Bush

Cohort	Eggs	Smolts				
		S1	S2	S3	S2+S3	Total
1974	1,840,000	4,003	11,714	0	11,714	15,717
1975	1,940,000	9,307	10,318	16	10,334	19,641
1976	1,590,000	9,375	12,910	93	13,003	22,378
1977	1,730,000	14,194	21,802	364	22,166	36,360
1978	1,220,000	2,931	19,284	28	19,312	22,243
1979	1,070,000	855	11,472	85	11,557	12,412
1980	1,160,000	3,037	9,239	164	9,403	12,440
1981	1,450,000	1,455	12,458	0	12,458	13,913
1982	1,580,000	14,346	18,535	742	19,277	33,623
1983	2,180,000	11,474	16,401	229	16,630	28,104
1984	1,720,000	13,371	17,350	69	17,419	30,790
1985	1,170,000	1,487	20,035	388	20,423	21,910
1986	3,030,000	2,052	18,888	276	19,164	21,216
1987	4,790,000	3,718	15,218	72	15,290	19,008
1988	3,430,000	2,318	11,556	19	11,575	13,893
1989	4,600,000	5,726	15,233	4	15,237	20,963
1990	1,060,000	3,219	5,281	110	5,391	8,610
1991	2,440,000	4,736	8,812	0	8,812	13,548

The analysis of variance is given in Table 6.5, and the parameter estimates in Table 6.6.

Table 6.5 Analysis of variance for Bush stock-recruitment model

	df	SS	MS	F	p
0+ Model	2	0.58193	0.29096	2.02131	0.1672
Residual	15	2.15923	0.14395		
Total	17	2.74116			
>0+ Model	2	0.03811	0.01905	0.72480	0.501
Residual	15	0.39435	0.02629		
Total	17	0.43245			

Table 6.6 Parameter estimates for the River Bush

		Parr age (k)	
		1 (0+)	2 (>0+)
Density independent survival (parr/egg)	α_k	0.128	0.0389
Proportion of parr smolting	θ_k	0.0426	0.436

The resultant stock-recruitment curves for each of the 22 river classes are shown in Figure 6.1.

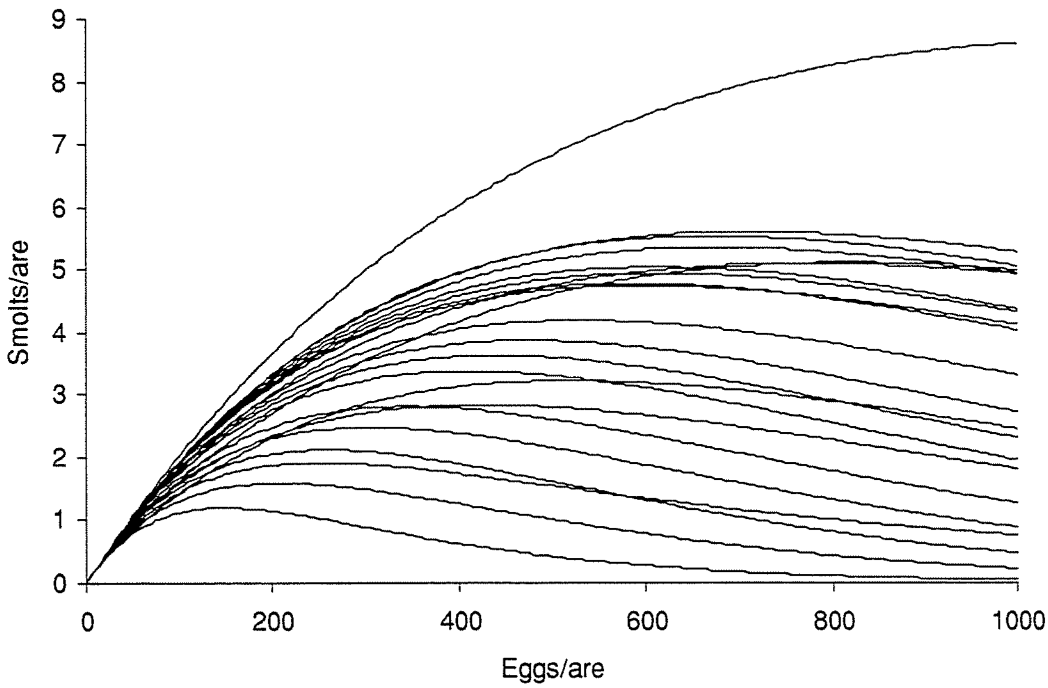

Figure 6.1 Stock-recruitment curves for the 22 reach classes, from which river-specific stock-recruitment curves are derived

Each reach-specific curve is the summation of two Ricker curves (for S1 and (S2+S3)). The river-specific stock-recruitment curve can then be derived by summing the reach specific models according to relative stream areas and spawning distribution as detailed above. The resulting stock-recruitment curve for the entire River Bush is shown in Figure 6.2. The model using aggregated Ricker curves is somewhat less dome-shaped than the single Ricker curve often used to model the River Bush.

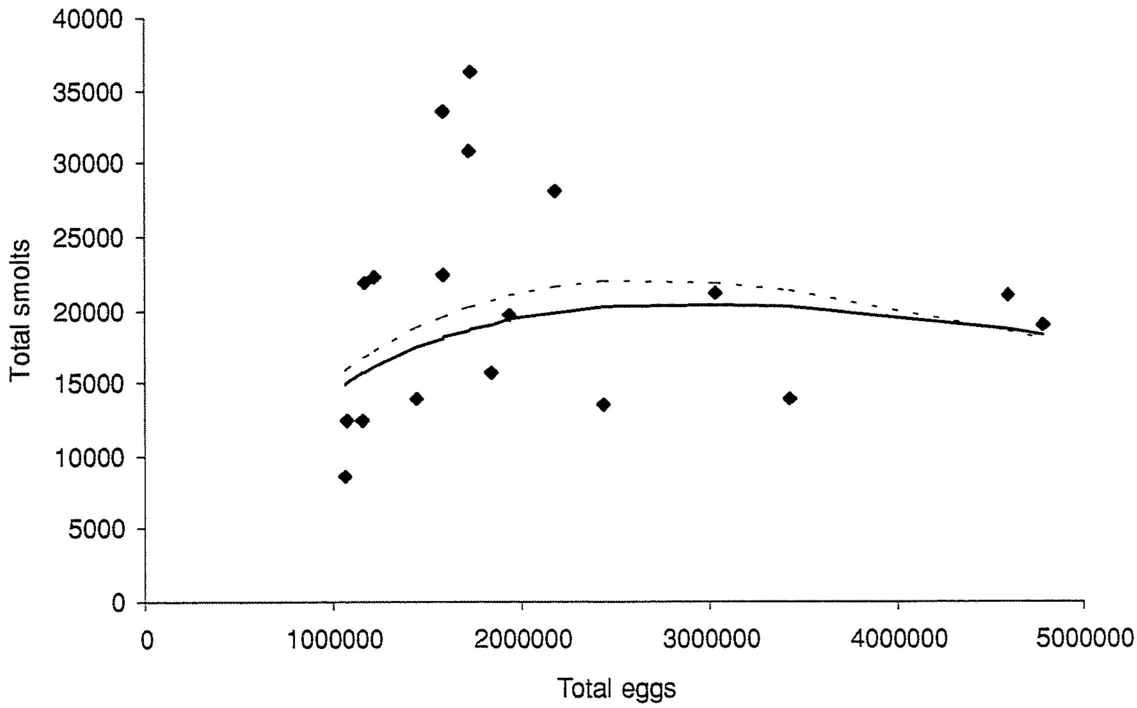

Figure 6.2 Stock recruitment data for the River Bush. Fitted models are Ricker (broken line) and aggregated Ricker models for all river reaches (solid line)

6.4 Discussion

A major assumption in the estimation of α_k and θ_k from the River Bush is that the parr densities in each river type on the Bush were similar to the average values obtained from English and Welsh rivers (η_{jk}). If, for example, the juvenile densities in the River Bush are higher than the average values in England and Wales, then the estimates of θ_k (i.e. estimates of the proportion of parr in the kth age class that successfully leave the river as smolts) will be too low. The implication of this would be over estimates of the targets for English and Welsh Rivers.

Both the aggregated stock-recruitment curve and the Ricker curve explain a only a small proportion of the variation in smolt output on the Bush. The objective for developing the more complex model has not however been to obtain a better fit, but to produce a model that describes the reach-specific dynamics behind the river-specific stock-recruitment curve. This will allow the transportation of the river-specific stock-recruitment curve for the Bush to other rivers with different reach characteristics.

7. VALIDATION OF SMOLT MODEL ON INDEPENDENT DATA

7.1 Introduction

Validation of the model was attempted on the North Esk and the Girnock Burn. However, 16% (by area) of the North Esk is at altitudes higher than in the Agency HABSCORE database, and therefore no data were available on salmon parr densities in these river classes. In addition, the average smolt output from the North Esk is 174,286 from an approximate area of 13,856 ($100m^2$), giving an average smolt output of 12.58 smolts/$100m^2$. This average smolt output is higher than the maximum smolt output from the most productive river class on the Bush (Figure 6.1). Assuming that no errors have been made in these estimates, the North Esk is clearly very different in terms of altitude to any Agency river, and in terms of productivity to the Bush. Further validation of the model was therefore only undertaken on the Girnock Burn, and this is described in more detail below. This work fulfils the validation component of specific objective 3.

7.2 Methods

No information was available on the spawning distribution within the catchment, and so the catchment was regarded as a single reach (n=1), and so $\rho_1=1$ and $\sigma_1=1$. GIS data on the lengths of river in each river type, together with width estimates (Section 5) were used to estimate the areas and proportion of areas (τ_j) in each river type. Given that egg and smolt data were available as total values for the catchment, it was also necessary to estimate the total stream area.

The model for total smolt production (Equation 5) was applied to the Girnock Burn using the estimates α_j and θ_j from the Bush, and assuming the parr densities in each river type (η_{jk}) were similar to the average values obtained from English and Welsh rivers. The smolt output (s_{hk}) was predicted for the data for egg deposition (x_h), and the predicted stock-recruitment curve was visually compared to the actual stock-recruitment data for the river.

7.3 Results

The length of river on the Bush from GIS (1:250,000) is given in Table 7.1, and using the width estimates in Table 5.5, the stream areas were estimated and are given in Table 7.2. The total area for the Girnock Burn is estimated to be 5.62 hectares. The published area of the Girnock Burn is 5.88 hectares; the GIS estimate is 95.6% of this figure.

Table 7.1 Length of Girnock Burn (metres)

	Altitude class (m)	Class midpoint (m)	Stream order 1	2	3	4	Total
A	0-49	25	0	0	0	0	0
B	50-99	75	0	0	0	0	0
C	100-149	125	0	0	0	0	0
D	150-199	175	0	0	0	0	0
E	200-299	250	0	4,398	0	0	4,398
F	300-399	350	8,962	1,528	0	0	10,490
G	400-499	450	1,341	0	0	0	1,341
H	500-599	550	692	0	0	0	692
	Total		10,995	5,926	0	0	16,921

Table 7.2 Area of Girnock Burn (hectares)

	Altitude class (m)	Class midpoint (m)	Stream order 1	2	3	4	Total
A	0-49	25	0.00	0.00	0.00	0.00	0.00
B	50-99	75	0.00	0.00	0.00	0.00	0.00
C	100-149	125	0.00	0.00	0.00	0.00	0.00
D	150-199	175	0.00	0.00	0.00	0.00	0.00
E	200-299	250	0.00	1.83	0.00	0.00	1.83
F	300-399	350	2.59	0.64	0.00	0.00	3.23
G	400-499	450	0.37	0.00	0.00	0.00	0.37
H	500-599	550	0.18	0.00	0.00	0.00	0.18
	Total		3.15	2.47	0.00	0.00	5.62

A small proportion (<10% by area) of the Girnock Burn was in reach classes G1 and H1, for which no salmon parr density data are available. Informal extrapolation of the model (see Table 4.14) would suggest that prediction for these classes would have been low >0+ parr densities, and some of this area is also likely to have been inaccessible to adult salmon. These two reach classes were ignored. The proportion of stream area within each river type is given in Table 7.3.

Table 7.3 Proportion of stream area within each reach class (τ_j)

	Altitude class (m)	Class midpoint (m)	Stream order			
			1	2	3	4
A	0-49	25	0.000	0.000	0.000	0.000
B	50-99	75	0.000	0.000	0.000	0.000
C	100-149	125	0.000	0.000	0.000	0.000
D	150-199	175	0.000	0.000	0.000	0.000
E	200-299	250	0.000	0.362	0.000	0.000
F	300-399	350	0.512	0.126	0.000	0.000

The stock-recruitment data for the Girnock Burn is given in Table 7.4.

Table 7.4 Stock-recruitment data for the Girnock Burn

Cohort	eggs	smolts
1966	723,000	2,791
1967	537,000	1,954
1968	549,000	3,607
1969	139,000	601
1970	151,000	2,877
1971	305,000	3,156
1972	351,000	2,802
1973	691,000	3,735
1974	573,000	3,017
1975	310,000	2,475
1976	465,000	3,330
1977	232,000	2,139
1978	0	0
1979	232,000	2,682
1980	540,000	2,249
1981	161,000	3,029
1982	187,000	2,637

The predicted stock-recruitment for the Girnock Burn is shown in Figure 7.1, together with the actual stock-recruitment data.

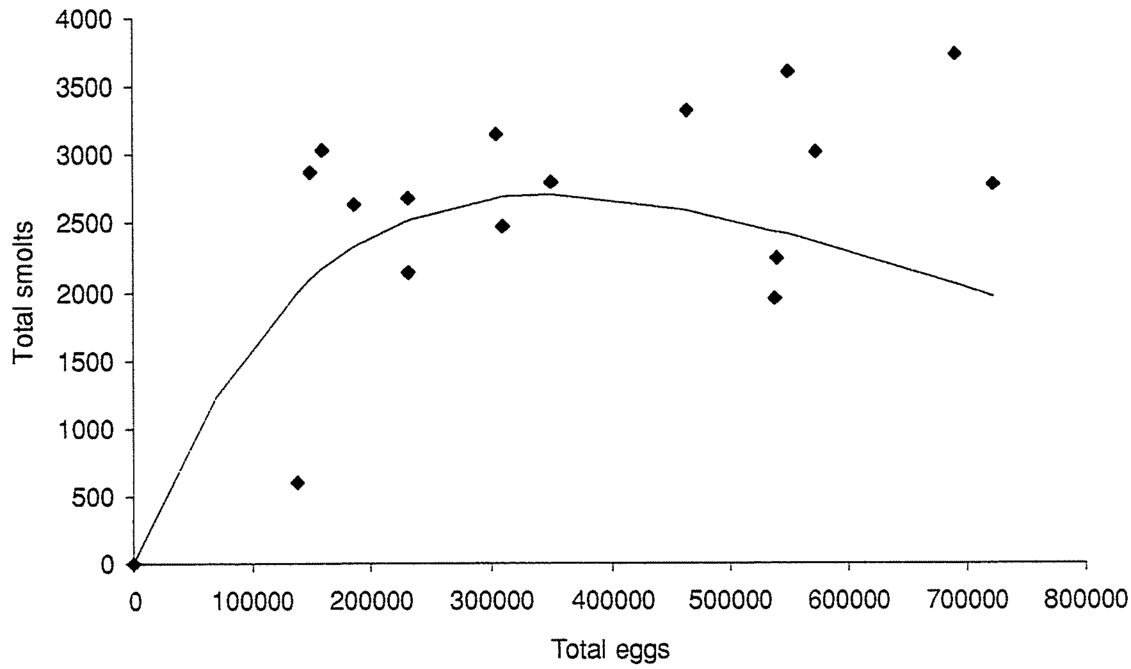

Figure 7.1 Stock recruitment model transported from the River Bush. Data points are total egg and smolt data from the Girnock Burn

7.4 Discussion

The model calibrated on the River Bush gives reasonable predictions for the smolt output at different egg depositions on the Girnock Burn. Note that the stock-recruitment curve has been transported from the River Bush using GIS data, and is not derived from the Girnock stock-recruitment data. The pronounced dome-shape of the model is not readily apparent from the data. The apparent difference between the smolt output from the Bush and the North Esk cannot be explained by the current model; the reasons for this are unclear.

The GIS estimates are close to, but less than the actual estimates. Whilst this may be due to inaccuracies in the procedure, underestimation would be expected from 1:250,000 GIS since small first order streams (as seen at the 1:50,000 scale) will be excluded.

8. APPLICATION OF MODEL TO AGENCY RIVERS

8.1 Methods

The smolt production model was applied to salmon rivers in England and Wales. River lengths for each river type were obtained from GIS, and the width estimates obtained in Section 6 were used to estimate the relative proportions of stream area (τ_{ij}). National average parr densities (η_{jk}) were assumed to prevail in each catchment, and estimates of survival (α_k) and smolt production rates (θ_k) from the River Bush were applied. The target egg deposition for maximum smolt production (x_{ms}) was estimated using Equation 6, and the maximum smolt production by substituting the target egg deposition into Equation 5. This work fulfils specific objective 4.

8.2 Results

River lengths from GIS for each river are given in Appendix C. The estimated stock-recruitment curves for Environment Agency rivers are summarised in Table 8.1. On some systems, the existence of 5th order rivers (1:250,000), or high altitude streams meant that some river sections were not included in the estimate of smolt producing stream area. The percentage of river (by length) that was included in the GIS estimate is also shown in Table 8.1. The maximum smolt target (i.e. the egg deposition required to produce the highest smolt production) is expressed in terms of the total stream area estimated from GIS ("GIS area"), and also the commonly quoted baseline area termed "nursery area" on the Bush (around half of the total area), assuming that this proportion is the same in Agency rivers ("Bush area").

Table 8.1 Estimated stock-recruitment curves for Environment Agency rivers and the River Bush

River & region		% of total length used in model	Maximum smolt target		Maximum smolt output	
			Eggs.100m^{-2} (GIS area)	Eggs.100m^{-2} (Bush area)	Smolts.100m^{-2} (GIS area)	Smolts.100m^{-2} (Bush area)
River Lyn	SW	93.4	667	1266	5.13	9.73
River Mawddach	W	86.2	698	1324	4.69	8.89
River Dwyryd	W	85.1	656	1244	4.47	8.47
River Ogwen	W	64.1	555	1053	4.24	8.05
River Eden	NW	90.3	587	1114	4.06	7.71
River Esk - Yorkshire	NE	99.3	589	1118	4.03	7.65
River Wye	W	83.9	586	1112	4.00	7.60
River Taff	W	92.8	560	1062	3.98	7.56
River Llyfni	W	98.1	589	1117	3.94	7.47
River Afan	W	94.2	568	1078	3.94	7.47
River Conwy	W	90.0	600	1139	3.81	7.24
River Ribble	NW	86.6	532	1010	3.76	7.13
River Rheidol	W	79.6	533	1012	3.76	7.13
River Kent	NW	95.4	515	978	3.76	7.13
River Fowey	SW	100.0	549	1041	3.74	7.10
River Lune	NW	90.4	558	1059	3.71	7.04
River Esk - Border	NW	99.0	559	1061	3.70	7.01
River Dyfi	W	86.4	544	1032	3.69	7.00
River Usk	W	93.3	579	1098	3.69	7.00
River Aeron	W	100.0	524	994	3.69	7.00
River Clwyd	W	98.3	550	1044	3.67	6.96
River Artro	W	99.1	532	1009	3.66	6.94
River Neath	W	92.7	554	1051	3.62	6.88
River Plym	SW	96.8	567	1076	3.60	6.83
River Teifi	W	97.7	537	1019	3.58	6.79
River Tyne	NE	95.3	549	1043	3.50	6.65
River Dwyfawr & Dwyfach	W	96.6	478	908	3.48	6.61
River Esk - Lakes	NW	90.7	533	1012	3.48	6.60
River Dart	SW	87.0	519	985	3.45	6.55
River Ystwyth	W	87.1	513	973	3.44	6.53
River Duddon	NW	97.9	519	984	3.42	6.49
River Severn	M	90.6	500	949	3.39	6.43
River Tawe	W	85.2	477	905	3.38	6.42
River Coquet	NE	97.4	478	907	3.37	6.39
River Derwent	NW	88.6	457	868	3.35	6.36
River Teign	SW	94.5	504	957	3.30	6.27
River Lynher	SW	100.0	495	939	3.29	6.24
River Tywi	W	96.7	499	947	3.28	6.23

Table 8.1. Continued

River & region		% of total length used in model	Maximum smolt target		Maximum smolt output	
			Eggs.100m^{-2} (GIS area)	Eggs.100m^{-2} (Bush area)	Smolts.100m^{-2} (GIS area)	Smolts.100m^{-2} (Bush area)
River Wear	NE	93.6	463	878	3.23	6.12
River Gwyrfai	W	99.2	460	873	3.22	6.11
River Dee	W	94.8	507	962	3.19	6.06
River Seiont	W	94.8	491	932	3.16	6.00
River Exe	SW	99.2	477	905	3.13	5.95
River Leven	NW	95.4	435	825	3.00	5.69
River Nevern	NW	100.0	433	821	2.96	5.62
River Ehen	NW	98.9	420	796	2.95	5.60
River Ellen	NW	98.7	400	758	2.89	5.48
River Glaslyn	W	89.1	442	838	2.87	5.44
River Taw	SW	98.9	429	815	2.85	5.40
River Tavy	SW	84.8	398	756	2.73	5.17
River Camel	SW	100.0	502	952	2.72	5.15
River Irt	NW	91.5	401	761	2.68	5.09
River Tamar	SW	99.4	385	731	2.66	5.05
River Bush	N.I.	100.0	369	701	2.62	4.97
River Torridge	SW	97.0	376	713	2.59	4.91
River Tees	NE	83.4	391	741	2.58	4.90
River Yealm	SW	97.8	369	700	2.58	4.89
River Avon - Avon & Somerset	SW	94.5	373	708	2.56	4.86
River Loughor	W	97.7	373	708	2.55	4.83
River Cleddau - Eastern	W	100.0	395	749	2.52	4.78
River Taf	W	100.0	355	674	2.49	4.72
River Dysinni	W	93.9	375	712	2.49	4.72
River Thames	T	94.3	336	638	2.44	4.62
River Erme	SW	93.9	464	880	2.35	4.47
River Wyre	NW	99.0	353	669	2.34	4.44
River Frome	SW	100.0	322	610	2.29	4.35
River Ogmore	W	98.9	330	627	2.26	4.29
River Axe	SW	100.0	313	593	2.26	4.29
River Avon - Hampshire	SW	100.0	306	580	2.20	4.17
River Stour	SW	100.0	266	505	1.97	3.73
River Cleddau - Western	W	100.0	266	504	1.95	3.71
River Gwendraeth - Fach & Fawr	W	100.0	266	505	1.94	3.68
River Looe	SW	100.0	250	474	1.91	3.63
River Piddle	SW	100.0	235	445	1.77	3.36
River Test	S	100.0	230	437	1.75	3.32
River Itchen	S	100.0	224	425	1.72	3.27

The maximum smolt output (i.e. the height of the stock-recruitment curve) predicted by the GIS model is correlated with the mean catchment altitude (Figure 8.1). Thus the procedure will tend to predict a greater smolt production in rivers with a high proportion of "upland" streams. Rivers such as the Wye and the Conwy are predicted to have a high smolt production, whereas rivers that drain more predominantly "lowland" areas, such as the Bush, the Eastern and Western Cleddau and the Torridge are predicted to have a relatively lower smolt production. Predicted smolt production is not a function of catchment size, as measured by total river length (Figure 8.2).

The position of the maximum points on the river-specific stock-recruitment curves are shown in Figure 8.3. The survival (egg to smolt) at the point of maximum smolt production (i.e. the gradient of the line connecting the maximum of the stock-recruitment curve to the origin) for each river is independent of both mean altitude (Figure 8.4) and river length (Figure 8.5).

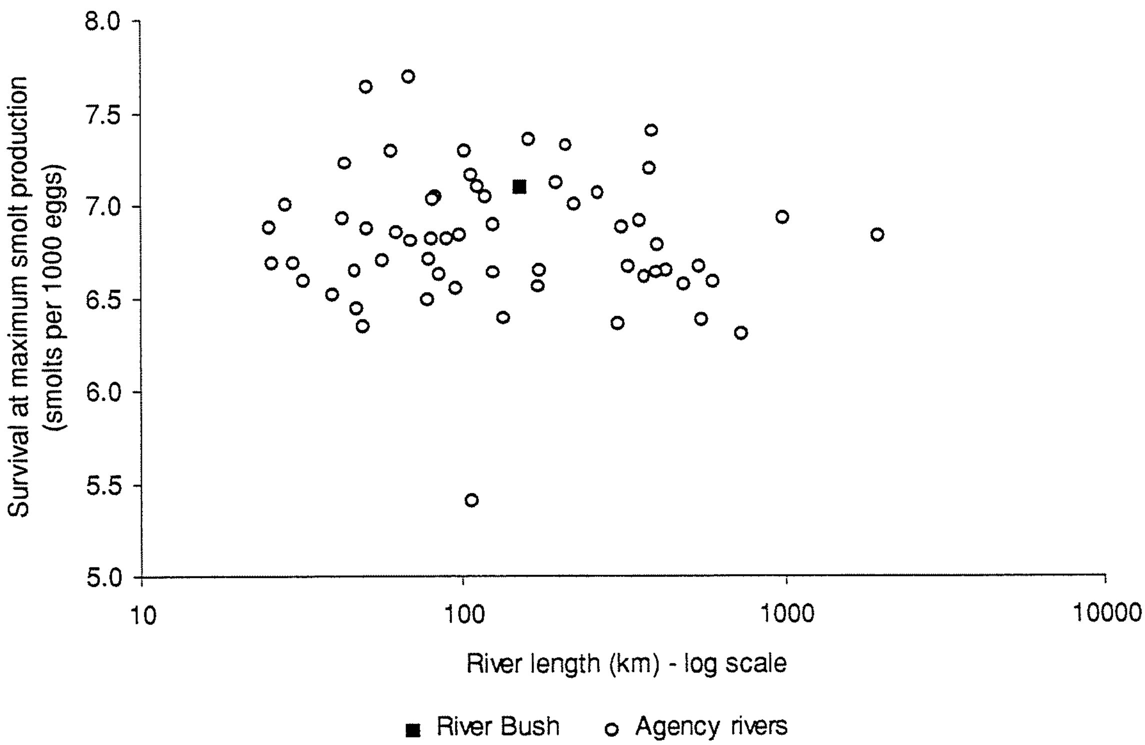

Figure 8.1 Predicted maximum smolt output per unit area against mean altitude for Agency rivers and the River Bush

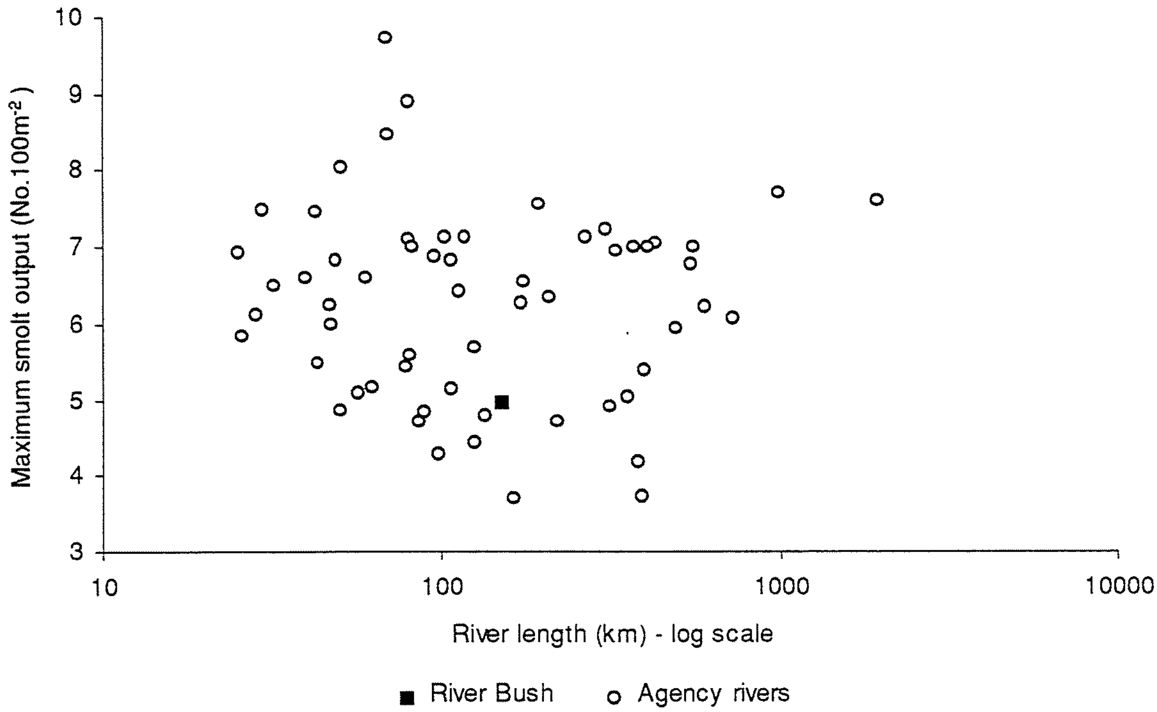

Figure 8.2 **Predicted maximum smolt output per unit area against total river length for Agency rivers and the River Bush**

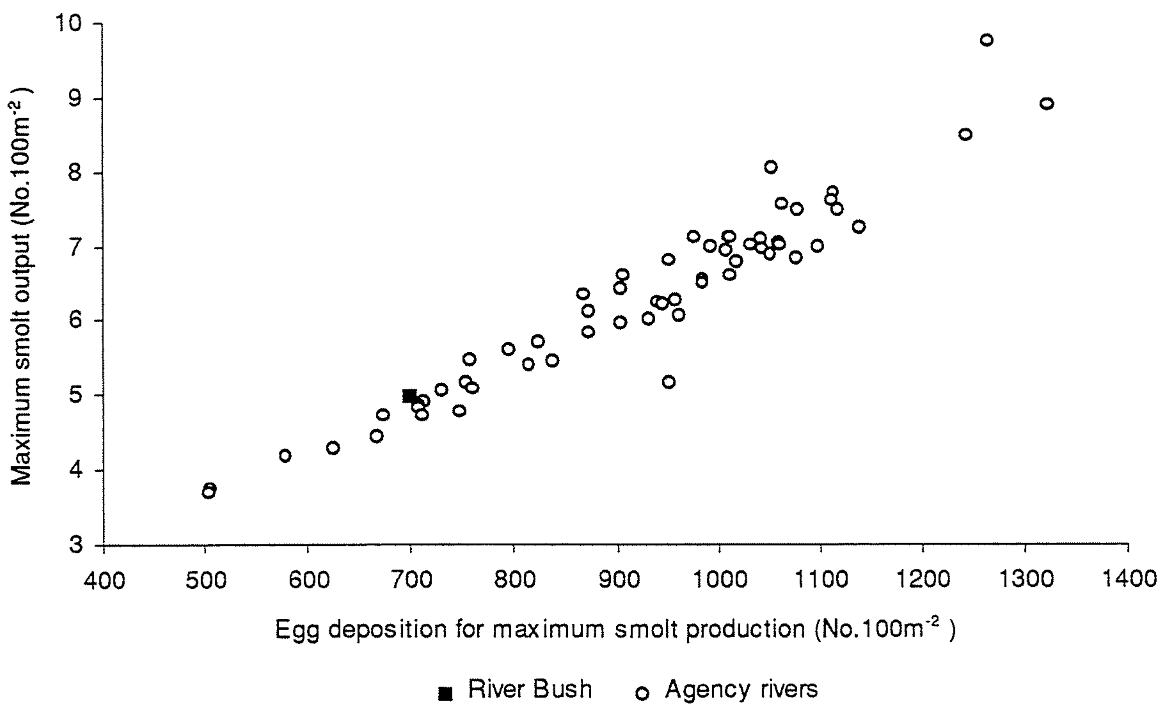

Figure 8.3 **Predicted maximum smolt output per unit area against the egg deposition required to produce the maximum smolt production for Agency rivers and the River Bush - each point represents the peak of a dome-shaped stock-recruitment curve**

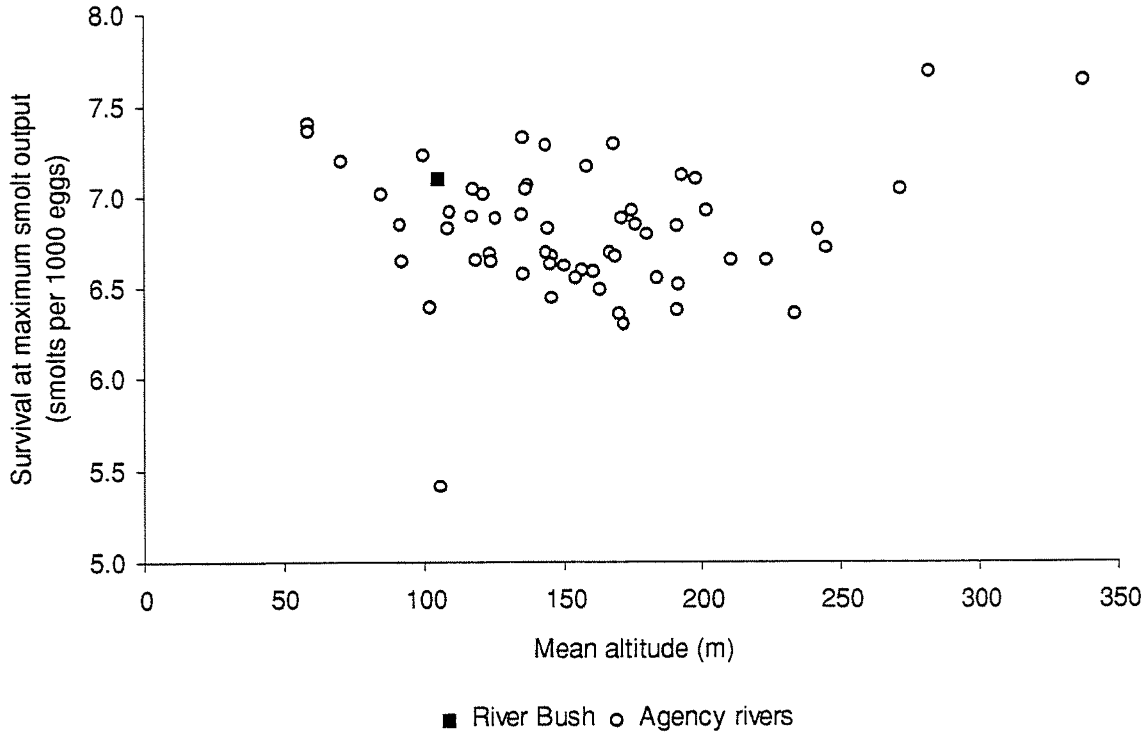

Figure 8.4 Predicted survival at maximum smolt output against mean altitude for Agency rivers and the River Bush

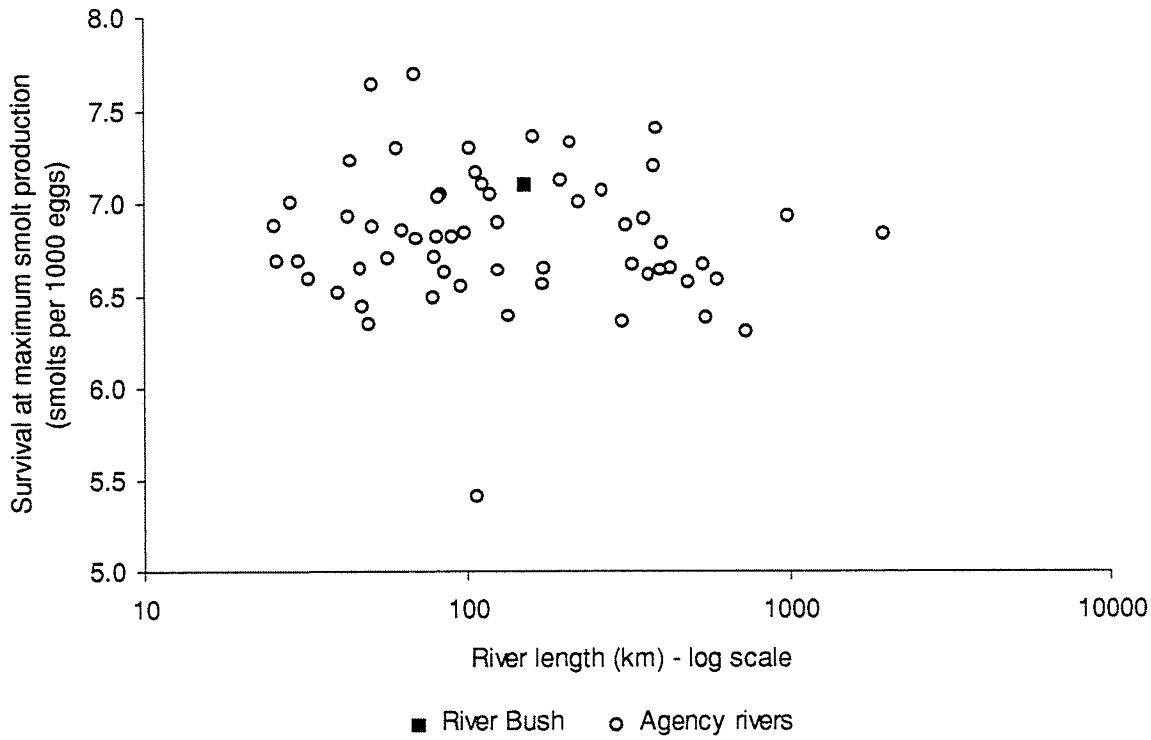

Figure 8.5 Predicted survival at maximum smolt output against total river length for Agency rivers and the River Bush

8.3 Discussion

An important issue that arises at this point in the methodology is the definition of stream area. The GIS procedure includes all stream area, but classifies it on a 22-point scale from poor (maximum 1 smolt/100m^2 assuming spawning not limiting) to good (maximum 8 smolts/100m^2 assuming spawning not limiting) (see Figure 6.1). Targets for the Bush however, have been traditionally expressed in terms of eggs per unit area of "salmonid nursery" habitat. This represents about half of the total stream area, and excludes unsuitable habitat (bedrock, sand etc.) from site inspections throughout the river system. Whatever system of habitat assessment is employed, it is essential that it is applied in a consistent manner to both the "donor" river and "recipient" rivers for target setting, and that the same procedure is used for both target setting and compliance assessment in the "recipient" rivers.

With targets expressed in terms of eggs per "GIS area", the estimate of stream area used to estimate the requirement for total eggs should be made on the same basis (i.e. area of river below 400m, stream orders 1 to 4, excluding classes F3 and F4, see Section 4). This is equivalent to assuming that spawning and smolt production does not occur in higher altitude or higher order sections. If it is believed that such sections are important as spawning and rearing areas, then additional habitat definitions will need to be introduced, and targets reassessed. The same is true for lakes connected to the river network which contribute to the smolt output from the system.

9. TRANSPORTATION OF MAXIMUM GAIN TARGETS TO AGENCY RIVERS

9.1 Methods

Data was provided by the Environment Agency on the proportion of females (υ), average fecundity (ω), and the proportion of grilse (γ) for each river. The survival rate for grilse (π_1) was assumed to be 25%, and for multi-sea winter fish (π_2), 15%. The replacement value (eggs/smolt) was estimated from Equation 13, and the maximum gain target from Equation 14. This work fulfils specific objectives 5 and 6.

9.2 Results

Estimates of maximum gain targets are given in Table 9.1. As in Table 8.1, two measures of area have been used. The use of the "Bush area" gives a maximum gain target of 549 eggs/100m^2 for the River Bush, which is very similar to the published value of 563 obtained from the Ricker model.

Rivers are categorised according to their productivity (smolt production) and replacement value (eggs per smolt) in Table 9.2. Freshwater productivity has been divided into three classes, and the replacement value into two classes.

Table 9.1 Maximum gain targets for Environment Agency rivers

River & region		% grilse	% marine survival	Sex ratio, % female	Average fecundity	Replacement value	Maximum gain target Eggs.100m^{-2} (GIS)	Eggs.100m^{-2} (Bush)
River Lyn	SW	100.0	25.0	60.1	4812	723	556	1055
River Mawddach	W	76.3	21.6	59.5	5536	711	545	1034
River Dwyryd	W	86.3	22.9	62.7	5209	748	520	987
River Llyfni	W	90.7	23.5	65.4	5071	781	469	889
River Esk - Yorkshire	NE	61.2	19.9	59.0	6087	714	468	887
River Ogwen	W	89.1	23.3	62.1	5131	742	465	882
River Eden	NW	76.3	21.6	48.0	6601	685	464	880
River Wye	W	51.3	18.9	53.4	6467	652	456	866
River Conwy	W	77.5	21.7	55.4	5549	668	452	857
River Afan	W	100.0	25.0	60.9	4812	732	450	854
River Esk - Border	NW	66.1	20.4	64.7	5764	761	440	836
River Taff	W	91.4	23.6	51.2	5117	620	436	828
River Plym	SW	38.4	17.7	64.7	6542	750	436	827
River Fowey	SW	79.5	22.0	58.9	5445	705	430	815
River Rheidol	W	89.2	23.3	57.4	5155	689	426	809
River Artro	W	100.0	25.0	61.7	4812	742	423	803
River Usk	W	79.2	22.0	49.5	5575	606	423	802
River Lune	NW	75.4	21.5	51.6	5596	620	420	797
River Neath	W	92.2	23.8	55.2	5069	664	419	794
River Dyfi	W	82.3	22.4	53.4	5414	646	419	794
River Tyne	NE	27.2	16.8	61.4	6966	720	418	794
River Clwyd	W	89.8	23.4	52.4	5165	634	417	792
River Aeron	W	87.7	23.1	58.3	5195	700	417	791
River Ribble	NW	73.2	21.2	51.5	5631	615	413	784
River Teifi	W	61.9	19.9	54.8	6076	664	413	784
River Duddon	NW	95.5	24.3	61.5	4946	738	402	763
River Dart	SW	77.8	21.8	56.6	5524	681	401	761
River Esk - Lakes	NW	56.2	19.3	56.4	6222	679	401	761
River Kent	NW	80.9	22.2	57.7	4541	581	399	758
River Ystwyth	W	94.0	24.0	56.4	5004	678	397	754
River Dwyfawr & Dwyfach	W	83.1	22.5	61.2	5313	731	390	739
River Severn	M	41.2	18.0	54.8	6760	665	389	737
River Teign	SW	77.1	21.7	55.2	5566	666	383	727
River Seiont	W	72.3	21.1	63.6	5602	752	380	721
River Tawe	W	81.1	22.2	57.2	5413	688	379	719
River Lynher	SW	92.4	23.8	58.1	5049	698	378	718
River Tywi	W	65.5	20.3	53.4	5985	650	377	716
River Coquet	NE	72.8	21.2	54.3	5723	658	377	715
River Gwyrfai	W	30.1	17.1	66.7	6715	764	372	706
River Derwent	NW	61.4	19.9	56.1	6063	676	369	700
River Dee	W	64.8	20.2	55.8	5384	608	367	697
River Wear	NE	57.2	19.5	55.6	6210	672	364	690
River Nevern	W	75.6	21.5	61.8	5528	735	344	652
River Exe	SW	100.0	25.0	45.0	4812	541	343	651
River Leven	NW	88.7	23.2	55.6	5181	670	338	642
River Camel	SW	60.4	19.8	60.4	6003	717	338	641

Table 9.1 Continued

River & region		% grilse	% marine survival	Sex ratio, % female	Average fecundity	Replacement value	Maximum gain target Eggs.100m^{-2} (GIS)	Eggs.100m^{-2} (Bush)
River Glaslyn	W	82.9	22.4	60.2	5327	720	337	640
River Ehen	NW	95.7	24.3	58.8	4946	707	335	636
River Taw	SW	76.8	21.7	51.6	5630	629	323	612
River Ellen	NW	100.0	25.0	60.0	4812	722	322	611
River Irt	NW	94.5	24.1	66.3	4961	793	317	601
River Tavy	SW	81.5	22.3	57.4	5396	690	312	593
River Tees	NE	27.2	16.8	62.2	6940	726	302	573
River Erme	SW	100.0	25.0	63.3	4812	761	300	569
River Yealm	SW	69.3	20.8	65.8	5659	773	297	563
River Cleddau - Eastern	W	69.8	20.8	59.4	5737	709	296	561
River Avon - Avon & Somerset	SW	78.8	21.9	61.5	5438	732	294	559
River Tamar	SW	86.1	22.9	49.4	5322	602	293	555
River Torridge	SW	67.1	20.5	54.6	5905	661	291	553
River Loughor	W	100.0	25.0	56.3	4812	678	289	549
River Bush	N.I.	100.0	31.6	60.0	3400	645	289	549
River Dysinni	W	95.0	24.2	60.3	4964	724	287	545
River Taf	W	74.3	21.3	57.9	5168	638	276	523
River Thames	T	42.6	18.1	54.4	6730	661	269	510
River Wyre	NW	97.9	24.7	53.7	4883	646	264	502
River Frome	SW	56.3	19.4	58.3	6174	696	257	488
River Ogmore	W	94.5	24.1	54.3	4994	653	253	481
River Axe	SW	100.0	25.0	52.8	4812	635	247	469
River Avon - Hampshire	SW	67.3	20.5	51.5	5966	630	240	454
River Stour	SW	36.5	17.6	63.9	6616	743	218	414
River Gwendraeth - Fach & Fawr	W	100.0	25.0	57.0	4812	686	214	405
River Cleddau - Western	W	100.0	25.0	55.0	4812	661	213	404
River Looe	SW	63.9	20.2	66.9	5292	713	207	393
River Piddle	SW	36.5	17.6	63.9	6616	742	194	369
River Test	S	52.6	19.0	56.1	6346	676	188	357
River Itchen	S	64.7	20.2	56.3	5949	678	184	349

Table 9.2 Average target values (eggs.100m^{-2} of total 'GIS area' / eggs.100m^{-2} 'Bush area') for six river classes - see text for details

Smolt output (smolts.100m^{-2} total GIS area)	Replacement value (eggs.smolt^{-1}) High (728 eggs.smolt^{-1})	Replacement value (eggs.smolt^{-1}) Low (647 eggs.smolt^{-1})
High smolt output Mean = 3.92 smolts.100m^{-2}	465 / 822 River Aeron River Afan River Artro River Dwyryd River Esk - Border River Esk - Yorkshire River Fowey River Llyfni River Lyn River Mawddach River Ogwen River Plym River Rheidol	428 / 811 River Clwyd River Conwy River Dyfi River Eden River Kent River Lune River Neath River Ribble River Taff River Teifi River Usk River Wye
Medium smolt output Mean = 3.21 smolts.100m^{-2}	463 / 691 River Duddon River Dwyfawr & Dwyfach River Ehen River Ellen River Glaslyn River Gwyrfai River Lynher River Nevern River Seiont River Tavy River Tawe River Tyne	372 / 705 River Coquet River Dart River Dee River Derwent River Esk - Lakes River Exe River Leven River Severn River Taw River Teign River Tywi River Wear River Ystwyth
Low smolt output Mean = 2.32 smolts.100m^{-2}	271 / 514 River Avon - Avon & Somerset River Camel River Cleddau - Eastern River Dysinni River Erme River Frome River Gwendraeth - Fach & Fawr River Irt River Looe River Piddle River Stour River Tees River Yealm	254 / 481 River Avon - Hampshire River Axe **River Bush** River Cleddau - Western River Itchen River Loughor River Ogmore River Taf River Tamar River Test River Thames River Torridge River Wyre

10. DISCUSSION

The procedure used in this report (using GIS to aggregate reach-specific stock-recruitment curves) provides a framework for transporting targets to rivers where egg deposition and smolt output data are not available. A large number of assumptions are required to transport the target to the river Bush to rivers in England and Wales, and a number of these assumptions require further investigation and refinement. Some areas for improvement include:

River reach classification (these may be developed as part of the river reach inventory project).

- The inclusion of more explanatory variables in the river-type/parr model, such as conductivity, other variables available in GIS format, and field measurements.
- The development of a more sophisticated method for defining river types, based on these variables, that maximally discriminated between habitat types with different carrying capacities.
- The inclusion of river specific juvenile abundance data, rather than reliance on national average data.
- The consideration of using 1:50,000 GIS so that headwater streams are included.
- The inclusion lakes as additional habitat types.
- The use of more robust width (and therefore area) estimation procedures, and preferably the use of river-specific width measurements and the exclusion of inaccessible reaches

Stock-recruitment model (these may be developed as part of the salmon lifecycle model project).

- Further analysis of the Bush data, with particular reference to changes in productivity, and the associated correction of targets.
- The use of a more sophisticated stock-recruitment model that does not rely on some of the existing assumptions (such as the constant proportion of parr that produce smolts in each river reach).
- The use of better parameter estimates reflecting the different dynamics of salmon populations in different river types.
- The inclusion of river-specific information on spawning distribution (built into existing model but not utilised).
- More intensive validation of the procedure on a river-by-river basis using available river specific data (e.g. rod and net catches, counter and trap data).

- The inclusion of better river-specific information on marine survival as estimates become available.
- The integration of sea trout into the target setting and compliance assessment procedure.
- The setting of sea-age-specific targets.
- The work reported here gives a deterministic framework for transporting targets. The use of a stochastic lifecycle model for target setting and compliance assessment is recommended.

APPENDIX A RELATIONSHIP BETWEEN STREAM ORDER AT SCALES 1:250,000 AND 1:50,000

INTRODUCTION

The GIS database used in this study was 1:250,000, whereas the data available from juvenile salmonid monitoring programmes (as used in the HABSCORE database) was from 1:50,000 maps. It was therefore necessary to convert stream orders from one map scale to the other.

METHODS

To convert stream orders at 1:250,000, to equivalent values at 1:50,000, data for stream orders and wetted widths were compared between the HABSCORE (with additional large river sites from Northumbrian) database (1:50,000) and the NRA River Habitat Survey (RHS) database (1:625:000). A model was produced relating wetted width (logged) to stream order and map scale. The model was used to convert from map scale 1:250,000 to 1:50,000 by assuming that the stream order for a site decreased linearly with a reduction in the (logged) map scale, and that as the map scale reduces, second-order streams become first-order streams, as third-order streams become second-order, and so on.

RESULTS

The results of the analysis are given in Tables A.1 to A.4. The percentage variance accounted for was 45.0, and the standard error of observations was estimated to be 0.671.

Table A.1 Summary of analysis

	d.f.	s.s.	m.s.	v.r.	Fpr.
Regression	2	668.6	334.2906	742.48	<.001
Residual	1810	814.9	0.4502		
Total	1812	1483.5	0.8187		

Table A.2 Estimates of regression coefficients

	estimate	s.e.	t(1810)	tpr.
Constant	-0.5162	0.0599	-8.62	<.001
order	0.6355	0.0167	37.98	<.001
scale 625	1.2160	0.0419	28.99	<.001

Table A.3 Correlations between parameter estimates

	Constant	order	scale 625
Constant	1.000		
order	-0.903	1.000	
scale 625	-0.833	0.630	1.000

Table A.4 Accumulated analysis of variance

Change	d.f.	s.s.	m.s.	v.r.	Fpr.
+ order	1	290.1178	290.1178	644.37	<.001
+ scale	1	378.4634	378.4634	840.59	<.001
Residual	1810	814.9214	0.4502		
Total	1812	1483.5026	0.8187		

The resulting conversion from stream orders at 1:250,000 to stream orders at 1:50,000 is given in Table A.5.

Table A.5 Conversion from stream orders at 1:250,000 to 1:50,000

Stream order (1:250,000)	Stream order (1:50,000)
1	2.219
2	3.219
3	4.219
4	5.219
5	6.219

DISCUSSION

The conversion of stream orders between map scales by equating sites of the same width is indirect, and must be regarded as an interim procedure. More direct methods would include an analysis of stream orders measured for the same sites using different map scales, thus by-passing the need for width measurements. It is recommended, however, that target setting and assessment procedures are developed based on 1:50,000 GIS, removing the problem of scale conversions altogether.

APPENDIX B INTERACTION BETWEEN JUVENILE SALMON AND TROUT POPULATIONS

INTRODUCTION

The potential interaction between salmon and migratory trout populations has implications for setting spawning targets for both species. Should the salmon spawning target for rivers with a large sea trout run be lower than for a salmon only river? This component of the work looks for evidence for an interaction between juvenile salmon and sea trout within the national data set used to estimate average carrying capacities for different river types (Section 4). This work addresses specific objective 7.

METHODS

The HABSCORE models were re-fitted to the raw data using iterative weighted least squares and Genstat 5.3 (see HABSCORE reports). The Genstat program created an output file for each model containing the observed and expected (HQS) values, and the standardised residuals (HUI). Minitab was used to undertake simple linear regression of the salmon densities, HQS and HUI values on the trout densities, HQS and HUI values.

RESULTS

0+ salmon and sea trout

Densities

There is no clear relationship between 0+ salmon densities and 0+ trout densities (Figure B.1). Whilst a linear regression model has a negative gradient (Table B.1), the 0+ trout densities explained virtually none of the variation in 0+ salmon densities ($R^2 = 0.2\%$, $R^2_{adj} = 0.0\%$), and the relationship was not significant (Table B.2).

Table B.1 Regression model predicting 0+ salmon densities from 0+ trout densities

Predictor	Coef	Stdev	t-ratio	p
Constant	3.8267	0.4402	8.69	0.000
t0o	-0.0729	0.1116	-0.65	0.515

Table B.2 Analysis of variance for model predicting 0+ salmon densities from 0+ trout densities

Source	DF	SS	MS	F	p
Regression	1	1.169	1.169	0.43	0.515
Error	173	474.414	2.742		
Total	174	475.582			

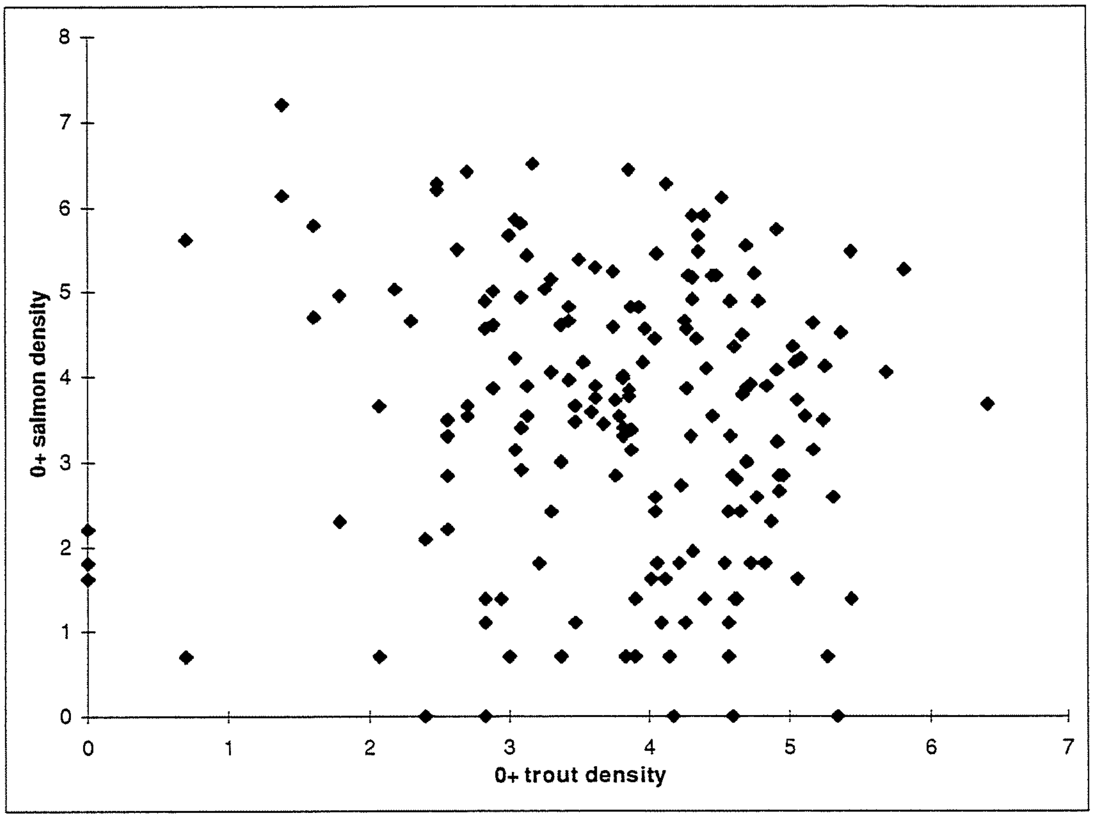

Figure B.1 Plot of 0+ salmon densities against 0+ trout densities

Habitat Quality Score (HQS)

There is no clear relationship between 0+ salmon HQS and 0+ trout HQS (Figure B.2). Whilst a linear regression model has a negative gradient (Table B.3), the 0+ trout HQSs explained none of the variation in 0+ salmon HQSs (R^2 = 0.0%, R^2_{adj} = 0.0%), and the relationship was not significant (Table B.4).

Table B.3 Regression model predicting 0+ salmon HQS from 0+ trout HQS

Predictor	Coef	Stdev	t-ratio	p
Constant	3.6652	0.6286	5.83	0.000
t0e	-0.0366	0.1639	-0.22	0.824

Table B.4 Analysis of Variance for model predicting 0+ salmon HQS from 0+ trout HQS

Source	DF	SS	MS	F	p
Regression	1	0.076	0.076	0.05	0.824
Error	173	262.654	1.518		
Total	174	262.730			

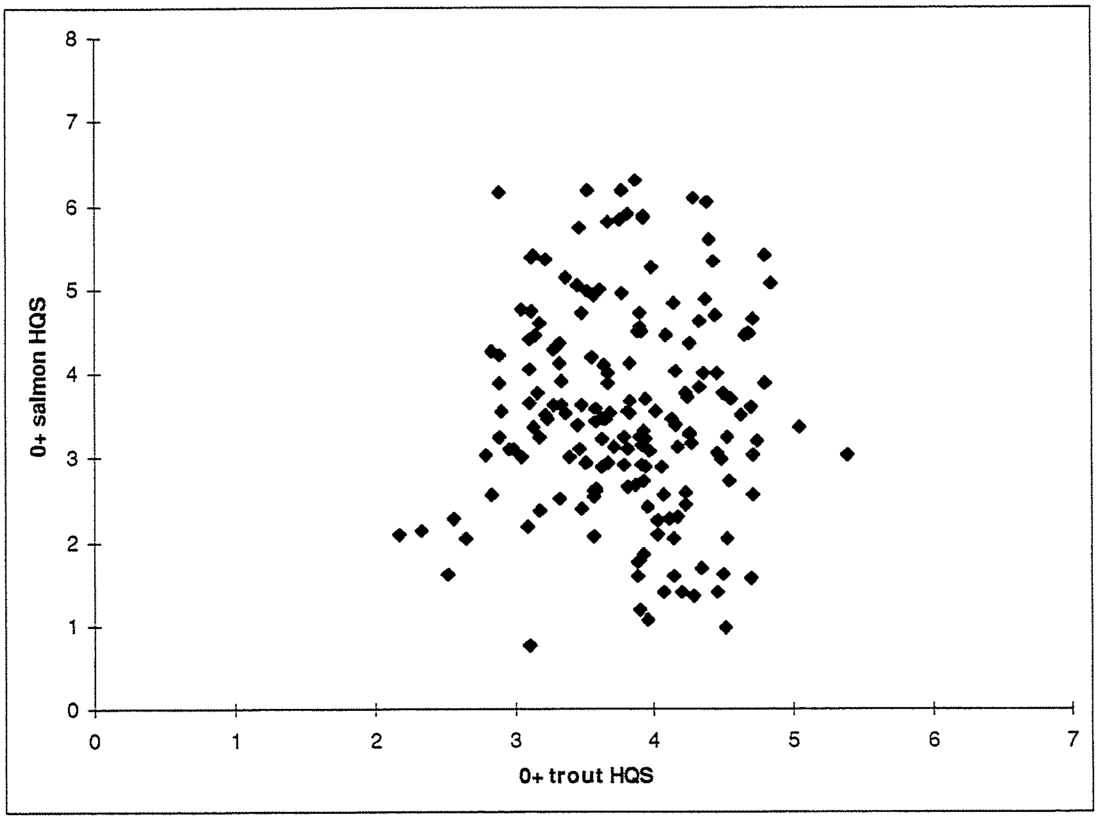

Figure B.2 Plot of 0+ salmon HQS against 0+ trout HQS

Habitat Utilisation Index (HUI)

There is no clear relationship between 0+ salmon HUI and 0+ trout HUI (Figure B.3). Whilst a linear regression model has a positive gradient (Table B.5), the 0+ trout HUIs explained virtually none of the variation in 0+ salmon HUIs (R^2 = 0.2%, R^2_{adj} = 0.0%), and the relationship was not significant (Table B.6).

Table B.5 Regression model predicting 0+ salmon HUI from 0+ trout HUI

Predictor	Coef	Stdev	t-ratio	p
Constant	0.02382	0.07423	0.32	0.749
t0r	0.04959	0.08312	0.60	0.552

Table B.6 Analysis of variance for model predicting 0+ salmon HUI from 0+ trout HUI

Source	DF	SS	MS	F	p
Regression	1	0.3431	0.3431	0.36	0.552
Error	173	166.7885	0.9641		
Total	174	167.1316			

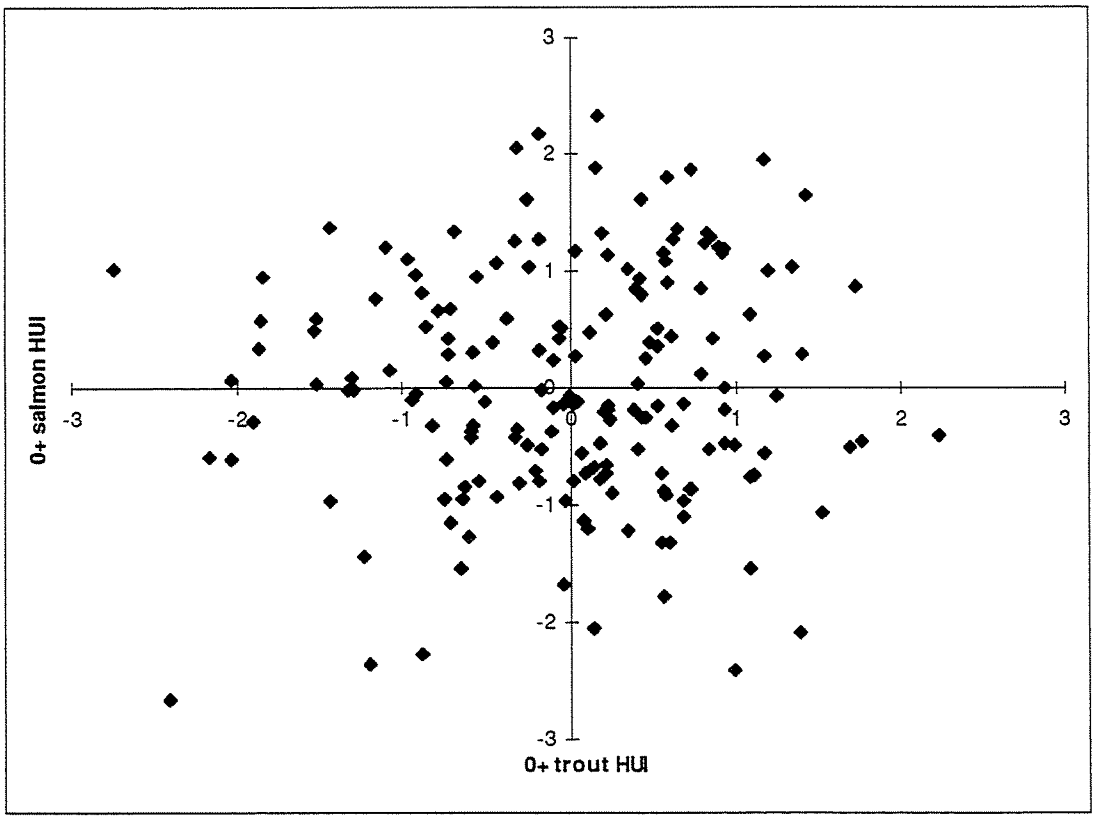

Figure B.3 Plot of 0+ salmon HUI against 0+ trout HUI

>0+ salmon and sea trout

Densities

There is slight positive relationship between >0+ salmon densities and >0+ trout densities (Figure B.4, Table B.7). The linear regression model explains a small proportion of the variation (R^2 = 3.9%, R^2_{adj} = 3.4%), which was significant (p=0.005) (Table B.8).

Table B.7 Regression model predicting >0+ salmon densities from >0+ trout densities

Predictor	Coef	Stdev	t-ratio	p
Constant	1.7652	0.2845	6.21	0.000
tlo	0.25600	0.09089	2.82	0.005

Table B.8 Analysis of variance for model predicting >0+ salmon densities from >0+ trout densities

Source	DF	SS	MS	F	p
Regression	1	16.185	16.185	7.93	0.005
Error	194	395.787	2.040		
Total	195	411.972			

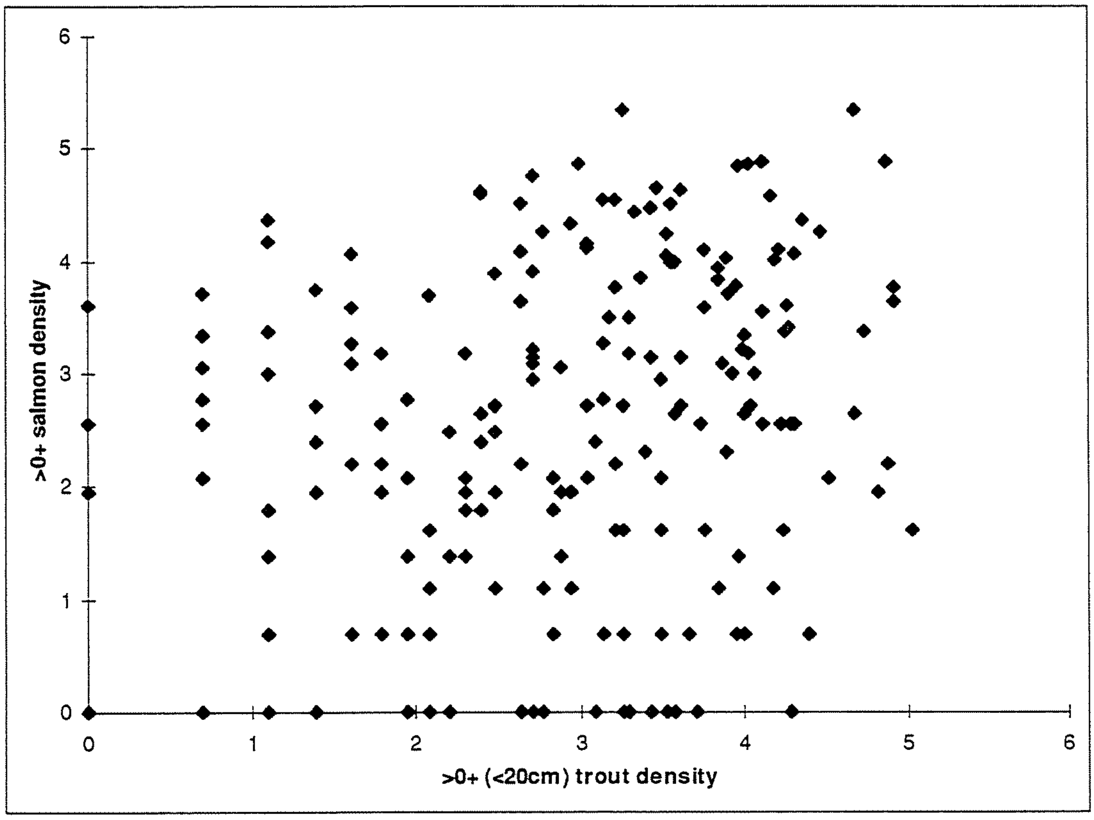

Figure B.4 Plot of >0+ salmon densities against >0+ trout densities

Habitat Quality Score (HQS)

There is slight positive relationship between >0+ salmon HQSs and >0+ trout HQSs (Figure B.9). The linear regression model explains a small proportion of the variation (R^2 = 13.8%, R^2_{adj} = 13.3%), which was significant (p=0.000) (Table B.10).

Table B.9 Regression model predicting >0+ salmon HQS from >0+ trout HQS

Predictor	Coef	Stdev	t-ratio	p
Constant	1.0223	0.2736	3.74	0.000
t1e	0.52931	0.09502	5.57	0.000

Table B.10 Analysis of Variance for model predicting >0+ salmon HQS from >0+ trout HQS

Source	DF	SS	MS	F	p
Regression	1	23.989	23.989	31.03	0.000
Error	194	149.980	0.773		
Total	195	173.969			

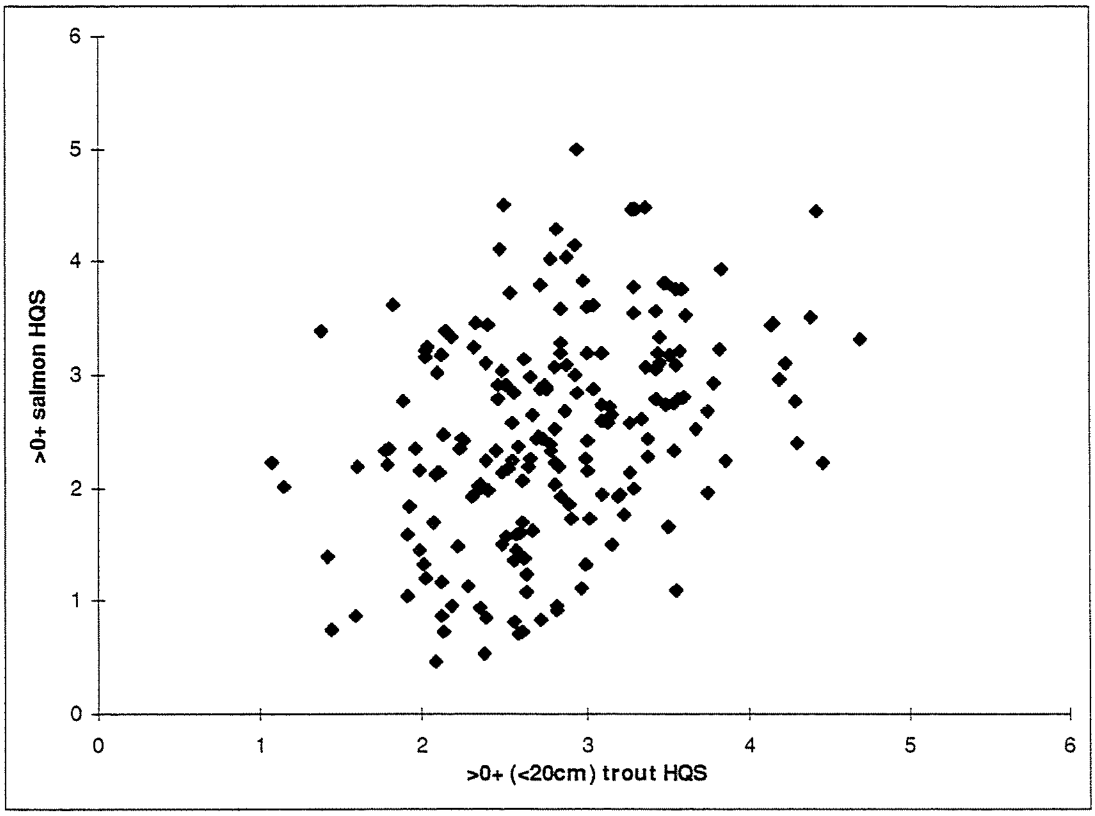

Figure B.5 Plot of >0+ salmon HQS against >0+ trout HQS

Habitat Utilisation Index (HUI)

There is no clear relationship between> 0+ salmon HUI and >0+ trout HUI (Figure B.6). Whilst a linear regression model has a positive gradient (Table B.11), the 0+ trout HUIs explained virtually none of the variation in 0+ salmon HUIs ($R^2 = 0.6\%$, $R^2_{adj} = 0.1\%$), and the relationship was not significant (Table B.12).

Table B.11 Regression model predicting >0+ salmon HUI from >0+ trout HUI

Predictor	Coef	Stdev	t-ratio	p
Constant	-0.00259	0.07232	-0.04	0.971
t1r	0.08205	0.07594	1.08	0.281

Table B.12 Analysis of Variance for model predicting >0+ salmon HUI from >0+ trout HUI

Source	DF	SS	MS	F	p
Regression	1	1.179	1.179	1.17	0.281
Error	194	196.031	1.010		
Total	195	197.211			

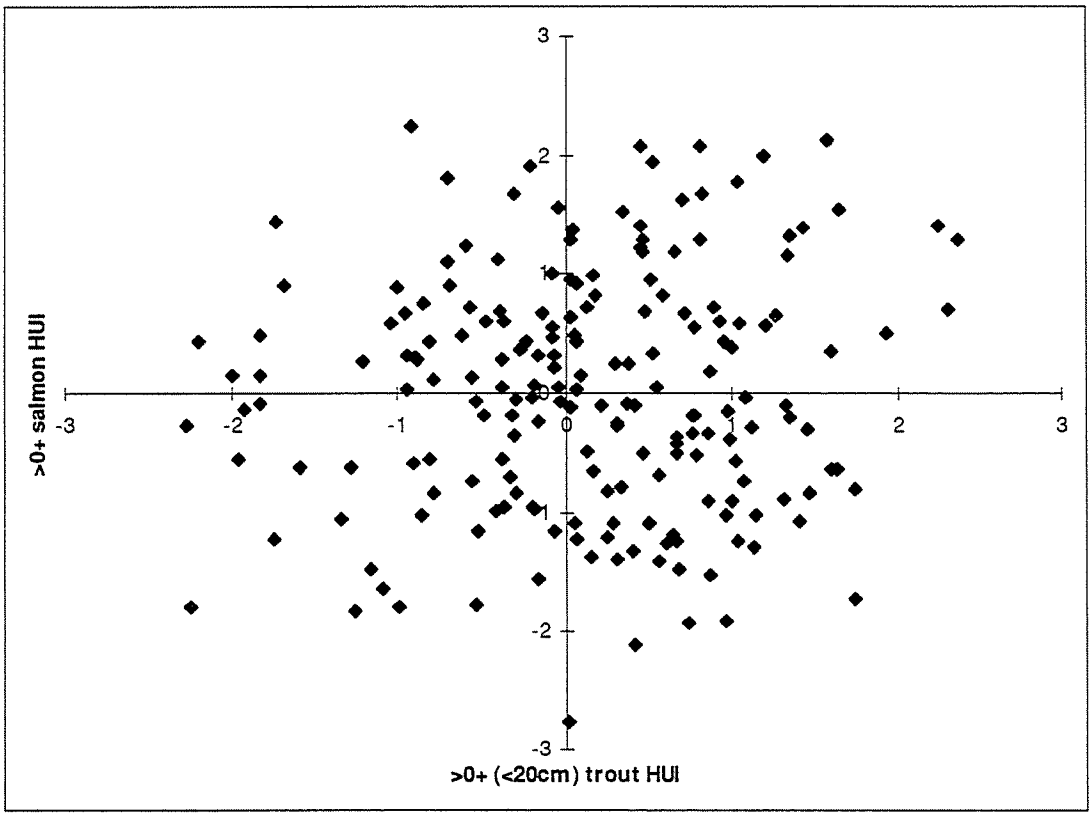

Figure B.6 Plot of >0+ salmon HUI against >0+ trout HUI

CONCLUSIONS

The following conclusions are drawn from this analysis.

- There is no evidence for any correlation between 0+ salmon and sea trout densities in the national database.

- Densities of >0+ salmon and sea trout are positively related, and this can be explained by common broad habitat requirements at a national scale.

There is therefore insufficient evidence from this analysis to adjust salmon spawning targets from an assessment of juvenile trout densities.

APPENDIX C RIVER LENGTHS FROM GIS

Length of river (metres) within each combination of altitude range and stream order

River	Alt. range (m)	Stream order (after Strahler)					
		1	2	3	4	5	6
River Aeron	0-49	0	1246	5975	0	0	0
River Aeron	50-99	8289	6005	12448	0	0	0
River Aeron	100-149	11332	7270	0	0	0	0
River Aeron	150-199	8713	2518	0	0	0	0
River Aeron	200-299	16437	1248	0	0	0	0
River Aeron	300-399	1175	0	0	0	0	0
River Afan	0-49	0	0	5633	0	0	0
River Afan	50-99	0	6031	1245	0	0	0
River Afan	100-149	3192	3594	0	0	0	0
River Afan	150-199	6983	1156	0	0	0	0
River Afan	200-299	10228	0	0	0	0	0
River Afan	300-399	2350	0	0	0	0	0
River Afan	400-499	2098	0	0	0	0	0
River Afan	500-599	399	0	0	0	0	0
River Artro	0-49	189	3511	0	0	0	0
River Artro	50-99	999	3047	0	0	0	0
River Artro	100-149	2879	2375	0	0	0	0
River Artro	150-199	3660	505	0	0	0	0
River Artro	200-299	2873	505	0	0	0	0
River Artro	300-399	4573	0	0	0	0	0
River Artro	400-499	225	0	0	0	0	0
River Avon - Avon & Somerset	0-49	5422	12622	0	0	0	0
River Avon - Avon & Somerset	50-99	5475	7376	0	0	0	0
River Avon - Avon & Somerset	100-149	5797	0	0	0	0	0
River Avon - Avon & Somerset	150-199	2808	0	0	0	0	0
River Avon - Avon & Somerset	200-299	4073	0	0	0	0	0
River Avon - Avon & Somerset	300-399	4199	0	0	0	0	0
River Avon - Avon & Somerset	400-499	2799	0	0	0	0	0
River Avon - Hampshire	0-49	54769	7445	4812	51723	0	0
River Avon - Hampshire	50-99	78897	56024	39800	0	0	0
River Avon - Hampshire	100-149	68919	14598	0	0	0	0
River Avon - Hampshire	150-199	1713	0	0	0	0	0
River Axe	0-49	10853	24005	10182	0	0	0
River Axe	50-99	38724	19128	0	0	0	0
River Axe	100-149	39263	0	0	0	0	0
River Axe	150-199	10156	0	0	0	0	0
River Axe	200-299	67	0	0	0	0	0
River Bush	0-49	11503	5234	16061	13763	0	0
River Bush	50-99	36331	13208	11992	0	0	0
River Bush	100-149	17252	1100	1478	0	0	0
River Bush	150-199	8902	0	1131	0	0	0
River Bush	200-299	5591	570	225	0	0	0
River Bush	300-399	5259	0	0	0	0	0

Length of river (metres) within each combination of altitude range and stream order

River	Alt. range (m)	Stream order (after Strahler)					
		1	2	3	4	5	6
River Calder	0-49	0	0	0	5951	0	0
River Calder	50-99	7307	0	6329	13162	0	0
River Calder	100-149	9645	11905	2968	0	0	0
River Calder	150-199	12803	9001	0	0	0	0
River Calder	200-299	18042	1529	0	0	0	0
River Calder	300-399	4816	0	0	0	0	0
River Calder	400-499	2851	0	0	0	0	0
River Camel	0-49	25764	15919	0	0	0	0
River Camel	50-99	14477	7544	0	0	0	0
River Camel	100-149	7760	3033	0	0	0	0
River Camel	150-199	11261	0	0	0	0	0
River Camel	200-299	21368	0	0	0	0	0
River Cleddau - Eastern	0-49	23382	9338	11496	7457	0	0
River Cleddau - Eastern	50-99	18253	7699	0	0	0	0
River Cleddau - Eastern	100-149	16118	3442	0	0	0	0
River Cleddau - Eastern	150-199	15274	2334	0	0	0	0
River Cleddau - Eastern	200-299	17999	0	0	0	0	0
River Cleddau - Eastern	300-399	1430	0	0	0	0	0
River Cleddau - Western	0-49	41495	21029	21205	0	0	0
River Cleddau - Western	50-99	47499	11055	0	0	0	0
River Cleddau - Western	100-149	11482	131	0	0	0	0
River Cleddau - Western	150-199	5611	0	0	0	0	0
River Cleddau - Western	200-299	2025	0	0	0	0	0
River Cleddau - Western	300-399	374	0	0	0	0	0
River Clwyd	0-49	11894	10198	22447	10092	0	0
River Clwyd	50-99	14381	13631	14551	0	0	0
River Clwyd	100-149	30145	21686	9085	0	0	0
River Clwyd	150-199	33284	16528	2525	0	0	0
River Clwyd	200-299	55871	18451	0	0	0	0
River Clwyd	300-399	32691	3723	0	0	0	0
River Clwyd	400-499	5562	0	0	0	0	0
River Conwy	0-49	14142	5692	3999	21512	0	0
River Conwy	50-99	8864	1779	4577	569	0	0
River Conwy	100-149	8497	6328	5538	2079	0	0
River Conwy	150-199	20203	11094	7087	3901	0	0
River Conwy	200-299	50778	27890	4296	123	0	0
River Conwy	300-399	61476	3914	0	0	0	0
River Conwy	400-499	20256	2117	0	0	0	0
River Conwy	500-599	6063	0	0	0	0	0
River Conwy	600-699	1477	0	0	0	0	0
River Conwy	700-799	723	0	0	0	0	0

Length of river (metres) within each combination of altitude range and stream order

River	Alt. range (m)	Stream order (after Strahler)					
		1	2	3	4	5	6
River Coquet	0-49	11687	0	24255	0	0	0
River Coquet	50-99	18246	4019	21376	0	0	0
River Coquet	100-149	24516	6339	8838	0	0	0
River Coquet	150-199	12078	7911	0	0	0	0
River Coquet	200-299	14700	10717	0	0	0	0
River Coquet	300-399	11621	0	0	0	0	0
River Coquet	400-499	4474	0	0	0	0	0
River Coquet	500-599	226	0	0	0	0	0
River Dart	0-49	16360	4500	18189	0	0	0
River Dart	50-99	13175	272	5688	0	0	0
River Dart	100-149	6305	1763	3297	0	0	0
River Dart	150-199	4446	238	2451	0	0	0
River Dart	200-299	19418	5907	5878	0	0	0
River Dart	300-399	37809	6274	0	0	0	0
River Dart	400-499	18151	0	0	0	0	0
River Dart	500-599	4628	0	0	0	0	0
River Dee	0-49	74994	39997	12961	70670	0	0
River Dee	50-99	53962	22274	3085	10397	0	0
River Dee	100-149	25855	15133	3226	36260	0	0
River Dee	150-199	35460	22337	13124	5603	0	0
River Dee	200-299	93172	43337	4067	0	0	0
River Dee	300-399	86479	19669	0	0	0	0
River Dee	400-499	29484	373	0	0	0	0
River Dee	500-599	7280	0	0	0	0	0
River Dee	600-699	559	0	0	0	0	0
River Derwent	0-49	1289	3844	1691	1759	16424	0
River Derwent	50-99	29136	20947	3386	30305	0	0
River Derwent	100-149	27735	8646	757	0	0	0
River Derwent	150-199	14965	1741	0	0	0	0
River Derwent	200-299	28004	2064	0	0	0	0
River Derwent	300-399	8392	0	0	0	0	0
River Derwent	400-499	6228	0	0	0	0	0
River Derwent	500-599	810	0	0	0	0	0
River Derwent	600-699	260	0	0	0	0	0
River Duddon	0-49	249	6171	0	0	0	0
River Duddon	50-99	1311	4943	0	0	0	0
River Duddon	100-149	4845	0	0	0	0	0
River Duddon	150-199	5259	0	0	0	0	0
River Duddon	200-299	4839	0	0	0	0	0
River Duddon	300-399	3988	0	0	0	0	0
River Duddon	400-499	665	0	0	0	0	0

Length of river (metres) within each combination of altitude range and stream order

		Stream order (after Strahler)					
River	Alt. range (m)	1	2	3	4	5	6
River Dwyfawr & Dwyfach	0-49	0	4216	4992	0	0	0
River Dwyfawr & Dwyfach	50-99	0	7428	5706	0	0	0
River Dwyfawr & Dwyfach	100-149	10070	7481	0	0	0	0
River Dwyfawr & Dwyfach	150-199	7713	0	0	0	0	0
River Dwyfawr & Dwyfach	200-299	7136	0	0	0	0	0
River Dwyfawr & Dwyfach	300-399	3237	0	0	0	0	0
River Dwyfawr & Dwyfach	400-499	1508	0	0	0	0	0
River Dwyfawr & Dwyfach	500-599	476	0	0	0	0	0
River Dwyfawr & Dwyfach	600-699	58	0	0	0	0	0
River Dwyryd	0-49	721	2786	4652	0	0	0
River Dwyryd	50-99	522	3079	0	0	0	0
River Dwyryd	100-149	2932	1883	0	0	0	0
River Dwyryd	150-199	6305	6491	0	0	0	0
River Dwyryd	200-299	15935	2153	0	0	0	0
River Dwyryd	300-399	11700	313	0	0	0	0
River Dwyryd	400-499	8900	0	0	0	0	0
River Dwyryd	500-599	1553	0	0	0	0	0
River Dyfi	0-49	8875	17739	6352	10074	20485	0
River Dyfi	50-99	15191	22584	9439	10996	0	0
River Dyfi	100-149	35787	33103	11243	0	0	0
River Dyfi	150-199	53898	13804	1274	0	0	0
River Dyfi	200-299	60251	6635	0	0	0	0
River Dyfi	300-399	29202	2881	0	0	0	0
River Dyfi	400-499	23434	383	0	0	0	0
River Dyfi	500-599	6791	0	0	0	0	0
River Dyfi	600-699	2341	0	0	0	0	0
River Dyfi	700-799	1417	0	0	0	0	0
River Dysinni	0-49	10287	10927	2931	12100	0	0
River Dysinni	50-99	3155	5575	0	0	0	0
River Dysinni	100-149	5354	1999	0	0	0	0
River Dysinni	150-199	5115	1253	0	0	0	0
River Dysinni	200-299	11271	1073	0	0	0	0
River Dysinni	300-399	8919	0	0	0	0	0
River Dysinni	400-499	3179	0	0	0	0	0
River Dysinni	500-599	1769	0	0	0	0	0
River Dysinni	600-699	238	0	0	0	0	0
River Eden	0-49	23585	17835	13831	18955	0	0
River Eden	50-99	36267	28575	31225	35348	0	0
River Eden	100-149	87839	51681	57803	5583	0	0
River Eden	150-199	127979	45727	14633	0	0	0
River Eden	200-299	181115	43939	428	0	0	0
River Eden	300-399	61701	8569	429	0	0	0
River Eden	400-499	54851	1104	0	0	0	0
River Eden	500-599	27608	1095	0	0	0	0
River Eden	600-699	8592	0	0	0	0	0
River Eden	700-799	2313	0	0	0	0	0

Length of river (metres) within each combination of altitude range and stream order

River	Alt. range (m)	Stream order (after Strahler)					
		1	2	3	4	5	6
River Ehen	0-49	3440	0	11537	0	0	0
River Ehen	50-99	8493	11669	654	0	0	0
River Ehen	100-149	19676	8051	0	0	0	0
River Ehen	150-199	8476	327	0	0	0	0
River Ehen	200-299	5868	0	0	0	0	0
River Ehen	300-399	2206	0	0	0	0	0
River Ehen	400-499	605	0	0	0	0	0
River Ehen	500-599	250	0	0	0	0	0
River Ellen	0-49	1742	16106	0	0	0	0
River Ellen	50-99	2674	6005	0	0	0	0
River Ellen	100-149	0	6604	0	0	0	0
River Ellen	150-199	1944	2710	0	0	0	0
River Ellen	200-299	4107	0	0	0	0	0
River Ellen	300-399	861	0	0	0	0	0
River Ellen	400-499	386	0	0	0	0	0
River Ellen	500-599	184	0	0	0	0	0
River Erme	0-49	12185	1966	0	0	0	0
River Erme	50-99	3376	0	0	0	0	0
River Erme	100-149	2519	0	0	0	0	0
River Erme	150-199	2017	0	0	0	0	0
River Erme	200-299	3544	0	0	0	0	0
River Erme	300-399	4757	0	0	0	0	0
River Erme	400-499	1986	0	0	0	0	0
River Esk - Border	0-49	15363	0	32435	1315	0	0
River Esk - Border	50-99	25302	22420	19514	0	0	0
River Esk - Border	100-149	60674	22706	6173	0	0	0
River Esk - Border	150-199	53057	11320	0	0	0	0
River Esk - Border	200-299	75044	1128	0	0	0	0
River Esk - Border	300-399	15959	0	0	0	0	0
River Esk - Border	400-499	2840	0	0	0	0	0
River Esk - Border	500-599	776	0	0	0	0	0
River Esk - Lakes	0-49	1661	9065	0	0	0	0
River Esk - Lakes	50-99	957	4538	0	0	0	0
River Esk - Lakes	100-149	1387	1510	0	0	0	0
River Esk - Lakes	150-199	2907	773	0	0	0	0
River Esk - Lakes	200-299	7413	0	0	0	0	0
River Esk - Lakes	300-399	6006	0	0	0	0	0
River Esk - Lakes	400-499	1830	0	0	0	0	0
River Esk - Lakes	500-599	776	0	0	0	0	0
River Esk - Lakes	600-699	774	0	0	0	0	0
River Esk - Lakes	700-799	334	0	0	0	0	0

Length of river (metres) within each combination of altitude range and stream order

		Stream order (after Strahler)					
River	Alt. range (m)	1	2	3	4	5	6
River Esk - Yorkshire	0-49	0	3194	0	0	0	0
River Esk - Yorkshire	50-99	2570	7219	0	0	0	0
River Esk - Yorkshire	100-149	16404	11959	0	0	0	0
River Esk - Yorkshire	150-199	16743	4434	0	0	0	0
River Esk - Yorkshire	200-299	11906	372	0	0	0	0
River Esk - Yorkshire	300-399	3843	0	0	0	0	0
River Esk - Yorkshire	400-499	576	0	0	0	0	0
River Exe	0-49	26543	8628	44187	12605	0	0
River Exe	50-99	81083	30017	19866	0	0	0
River Exe	100-149	54785	24519	10006	0	0	0
River Exe	150-199	43869	14924	2579	0	0	0
River Exe	200-299	64982	13798	0	0	0	0
River Exe	300-399	30397	0	0	0	0	0
River Exe	400-499	4095	0	0	0	0	0
River Fowey	0-49	2967	0	13411	0	0	0
River Fowey	50-99	6192	6611	2909	0	0	0
River Fowey	100-149	4217	4394	0	0	0	0
River Fowey	150-199	4704	7616	0	0	0	0
River Fowey	200-299	17831	9236	0	0	0	0
River Frome	0-49	33945	5572	25575	0	0	0
River Frome	50-99	28842	2695	15902	0	0	0
River Frome	100-149	30275	2062	0	0	0	0
River Frome	150-199	5117	0	0	0	0	0
River Glaslyn	0-49	12910	2223	10328	0	0	0
River Glaslyn	50-99	4208	9625	0	0	0	0
River Glaslyn	100-149	5250	1100	0	0	0	0
River Glaslyn	150-199	8832	148	0	0	0	0
River Glaslyn	200-299	9369	0	0	0	0	0
River Glaslyn	300-399	6092	0	0	0	0	0
River Glaslyn	400-499	4699	0	0	0	0	0
River Glaslyn	500-599	3204	0	0	0	0	0
River Glaslyn	600-699	647	0	0	0	0	0
River Gwendraeth - Fach & Fawr	0-49	18169	23989	0	0	0	0
River Gwendraeth - Fach & Fawr	50-99	15885	3441	0	0	0	0
River Gwendraeth - Fach & Fawr	100-149	9008	74	0	0	0	0
River Gwendraeth - Fach & Fawr	150-199	3790	0	0	0	0	0
River Gwendraeth - Fach & Fawr	200-299	1331	0	0	0	0	0

Length of river (metres) within each combination of altitude range and stream order

River	Alt. range (m)	Stream order (after Strahler)					
		1	2	3	4	5	6
River Gwyrfai	0-49	1763	4000	0	0	0	0
River Gwyrfai	50-99	2416	2234	0	0	0	0
River Gwyrfai	100-149	2013	9868	0	0	0	0
River Gwyrfai	150-199	2811	0	0	0	0	0
River Gwyrfai	200-299	2298	0	0	0	0	0
River Gwyrfai	300-399	899	0	0	0	0	0
River Gwyrfai	400-499	227	0	0	0	0	0
River Irt	0-49	3387	13904	0	0	0	0
River Irt	50-99	9000	7342	0	0	0	0
River Irt	100-149	4922	0	0	0	0	0
River Irt	150-199	3312	0	0	0	0	0
River Irt	200-299	7365	0	0	0	0	0
River Irt	300-399	2788	0	0	0	0	0
River Irt	400-499	2854	0	0	0	0	0
River Irt	500-599	905	0	0	0	0	0
River Irt	600-699	589	0	0	0	0	0
River Irt	700-799	483	0	0	0	0	0
River Itchen	0-49	34392	33127	3463	0	0	0
River Itchen	50-99	18976	3632	0	0	0	0
River Kent	0-49	0	404	14173	0	0	0
River Kent	50-99	960	13887	2555	0	0	0
River Kent	100-149	7486	14826	0	0	0	0
River Kent	150-199	6458	8707	0	0	0	0
River Kent	200-299	16126	4071	0	0	0	0
River Kent	300-399	7661	0	0	0	0	0
River Kent	400-499	2940	0	0	0	0	0
River Kent	500-599	1616	0	0	0	0	0
River Kent	600-699	164	0	0	0	0	0
River Leven	0-49	7559	8675	18537	0	0	0
River Leven	50-99	15751	14401	721	0	0	0
River Leven	100-149	12603	4328	1253	0	0	0
River Leven	150-199	8094	1031	2502	0	0	0
River Leven	200-299	14501	1252	2346	0	0	0
River Leven	300-399	6136	0	0	0	0	0
River Leven	400-499	3597	0	0	0	0	0
River Leven	500-599	1701	0	0	0	0	0
River Leven	600-699	416	0	0	0	0	0
River Llyfni	0-49	0	1992	0	0	0	0
River Llyfni	50-99	1529	3486	0	0	0	0
River Llyfni	100-149	5821	4684	0	0	0	0
River Llyfni	150-199	2501	0	0	0	0	0
River Llyfni	200-299	7076	0	0	0	0	0
River Llyfni	300-399	2160	0	0	0	0	0
River Llyfni	400-499	420	0	0	0	0	0
River Llyfni	500-599	132	0	0	0	0	0

Length of river (metres) within each combination of altitude range and stream order

		Stream order (after Strahler)					
River	Alt. range (m)	1	2	3	4	5	6
River Looe	0-49	4653	14841	0	0	0	0
River Looe	50-99	11183	2179	0	0	0	0
River Looe	100-149	3364	0	0	0	0	0
River Loughor	0-49	11059	6208	14676	0	0	0
River Loughor	50-99	14364	4876	0	0	0	0
River Loughor	100-149	16219	334	0	0	0	0
River Loughor	150-199	11158	0	0	0	0	0
River Loughor	200-299	5858	0	0	0	0	0
River Loughor	300-399	3009	0	0	0	0	0
River Loughor	400-499	1541	0	0	0	0	0
River Loughor	500-599	520	0	0	0	0	0
River Lune	0-49	3906	15196	2359	29014	0	0
River Lune	50-99	1450	25741	4767	12491	0	0
River Lune	100-149	26708	32005	9571	0	0	0
River Lune	150-199	31434	20595	11432	0	0	0
River Lune	200-299	84796	18772	0	0	0	0
River Lune	300-399	51166	4416	0	0	0	0
River Lune	400-499	28356	0	0	0	0	0
River Lune	500-599	8786	0	0	0	0	0
River Lune	600-699	3925	0	0	0	0	0
River Lyn	0-49	0	0	379	136	0	0
River Lyn	50-99	0	0	1358	0	0	0
River Lyn	100-149	0	701	3742	0	0	0
River Lyn	150-199	0	637	3427	0	0	0
River Lyn	200-299	12056	14073	2788	0	0	0
River Lyn	300-399	21526	3341	0	0	0	0
River Lyn	400-499	4546	0	0	0	0	0
River Lynher	0-49	571	12141	0	0	0	0
River Lynher	50-99	2710	8274	0	0	0	0
River Lynher	100-149	4573	4066	0	0	0	0
River Lynher	150-199	3781	0	0	0	0	0
River Lynher	200-299	10805	0	0	0	0	0
River Mawddach	0-49	1025	219	5588	0	0	0
River Mawddach	50-99	1481	4412	0	0	0	0
River Mawddach	100-149	2292	3385	0	0	0	0
River Mawddach	150-199	9664	2425	0	0	0	0
River Mawddach	200-299	21494	5017	0	0	0	0
River Mawddach	300-399	11580	0	0	0	0	0
River Mawddach	400-499	8214	0	0	0	0	0
River Mawddach	500-599	1854	0	0	0	0	0
River Mawddach	600-699	693	0	0	0	0	0
River Mawddach	700-799	237	0	0	0	0	0

Length of river (metres) within each combination of altitude range and stream order

		Stream order (after Strahler)					
River	Alt. range (m)	1	2	3	4	5	6
River Neath	0-49	4137	0	14457	0	0	0
River Neath	50-99	6650	1828	4659	0	0	0
River Neath	100-149	11016	3517	0	0	0	0
River Neath	150-199	8163	0	0	0	0	0
River Neath	200-299	22577	0	0	0	0	0
River Neath	300-399	11183	0	0	0	0	0
River Neath	400-499	5640	0	0	0	0	0
River Neath	500-599	1324	0	0	0	0	0
River Nevern	0-49	2603	3543	6884	0	0	0
River Nevern	50-99	12399	3841	4139	0	0	0
River Nevern	100-149	16615	5525	0	0	0	0
River Nevern	150-199	8382	0	0	0	0	0
River Nevern	200-299	6221	0	0	0	0	0
River Nevern	300-399	2041	0	0	0	0	0
River Ogmore	0-49	14838	26659	1722	0	0	0
River Ogmore	50-99	18933	2403	0	0	0	0
River Ogmore	100-149	15697	0	0	0	0	0
River Ogmore	150-199	6841	0	0	0	0	0
River Ogmore	200-299	6620	0	0	0	0	0
River Ogmore	300-399	2797	0	0	0	0	0
River Ogmore	400-499	1045	0	0	0	0	0
River Ogwen	0-49	0	0	3726	0	0	0
River Ogwen	50-99	0	0	1417	0	0	0
River Ogwen	100-149	0	1253	2956	0	0	0
River Ogwen	150-199	0	3613	460	0	0	0
River Ogwen	200-299	227	8866	97	0	0	0
River Ogwen	300-399	7071	2998	0	0	0	0
River Ogwen	400-499	3957	3591	0	0	0	0
River Ogwen	500-599	6205	0	0	0	0	0
River Ogwen	600-699	2799	0	0	0	0	0
River Ogwen	700-799	1443	0	0	0	0	0
River Ogwen	800-899	322	0	0	0	0	0
River Piddle	0-49	17148	18910	0	0	0	0
River Piddle	50-99	25304	3761	0	0	0	0
River Piddle	100-149	6782	0	0	0	0	0

Length of river (metres) within each combination of altitude range and stream order

		Stream order (after Strahler)					
River	Alt. range (m)	1	2	3	4	5	6
River Plym	0-49	5013	7639	0	0	0	0
River Plym	50-99	2824	1906	0	0	0	0
River Plym	100-149	1620	6831	0	0	0	0
River Plym	150-199	1835	1243	0	0	0	0
River Plym	200-299	9255	2181	0	0	0	0
River Plym	300-399	7297	0	0	0	0	0
River Plym	400-499	1596	0	0	0	0	0
River Rheidol	0-49	2074	0	16476	0	0	0
River Rheidol	50-99	3398	0	2908	0	0	0
River Rheidol	100-149	1444	178	1169	0	0	0
River Rheidol	150-199	833	370	2327	0	0	0
River Rheidol	200-299	12486	8235	7900	0	0	0
River Rheidol	300-399	19742	14065	3184	0	0	0
River Rheidol	400-499	14994	549	0	0	0	0
River Rheidol	500-599	5329	0	0	0	0	0
River Ribble	0-49	408	9929	7247	1318	32165	0
River Ribble	50-99	17973	14165	26563	0	0	0
River Ribble	100-149	25524	31548	226	0	0	0
River Ribble	150-199	29862	5783	0	0	0	0
River Ribble	200-299	35109	8991	0	0	0	0
River Ribble	300-399	13516	0	0	0	0	0
River Ribble	400-499	2633	0	0	0	0	0
River Ribble	500-599	418	0	0	0	0	0
River Seiont	0-49	3947	6018	0	0	0	0
River Seiont	50-99	5441	2881	0	0	0	0
River Seiont	100-149	6882	8181	0	0	0	0
River Seiont	150-199	1741	415	0	0	0	0
River Seiont	200-299	7433	88	0	0	0	0
River Seiont	300-399	2068	0	0	0	0	0
River Seiont	400-499	1812	0	0	0	0	0
River Seiont	500-599	625	0	0	0	0	0
River Seiont	600-699	56	0	0	0	0	0
River Severn	0-49	221020	95021	81237	10229	148325	55222
River Severn	50-99	585979	236041	157949	98240	53302	0
River Severn	100-149	346627	134341	75016	66921	68	0
River Severn	150-199	270693	118041	34812	7929	0	0
River Severn	200-299	337169	104104	10494	0	0	0
River Severn	300-399	165290	6248	0	0	0	0
River Severn	400-499	60161	0	0	0	0	0
River Severn	500-599	10302	0	0	0	0	0
River Severn	600-699	969	0	0	0	0	0

Length of river (metres) within each combination of altitude range and stream order

		Stream order (after Strahler)					
River	Alt. range (m)	1	2	3	4	5	6
River Stour	0-49	55882	24852	2498	73939	0	0
River Stour	50-99	143013	27190	28480	0	0	0
River Stour	100-149	26513	3219	0	0	0	0
River Stour	150-199	1652	0	0	0	0	0
River Taf	0-49	29083	27306	23692	577	0	0
River Taf	50-99	33932	18817	4600	0	0	0
River Taf	100-149	38127	12419	0	0	0	0
River Taf	150-199	23603	955	0	0	0	0
River Taf	200-299	7394	0	0	0	0	0
River Taff	0-49	4420	0	18354	0	0	0
River Taff	50-99	3572	11096	6607	0	0	0
River Taff	100-149	12807	33103	0	0	0	0
River Taff	150-199	14621	11250	0	0	0	0
River Taff	200-299	34187	8759	0	0	0	0
River Taff	300-399	20239	1198	0	0	0	0
River Taff	400-499	10100	0	0	0	0	0
River Taff	500-599	2719	0	0	0	0	0
River Taff	600-699	910	0	0	0	0	0
River Taff	700-799	200	0	0	0	0	0
River Tamar	0-49	2687	0	6951	35552	0	0
River Tamar	50-99	50506	67527	12217	0	0	0
River Tamar	100-149	88006	24738	4155	0	0	0
River Tamar	150-199	25052	8425	0	0	0	0
River Tamar	200-299	18111	6166	0	0	0	0
River Tamar	300-399	556	0	0	0	0	0
River Tamar	400-499	1802	0	0	0	0	0
River Tamar	500-599	243	0	0	0	0	0
River Tavy	0-49	3085	11115	0	0	0	0
River Tavy	50-99	10998	6020	0	0	0	0
River Tavy	100-149	4254	3552	0	0	0	0
River Tavy	150-199	1859	1887	0	0	0	0
River Tavy	200-299	1881	3567	0	0	0	0
River Tavy	300-399	2598	2611	0	0	0	0
River Tavy	400-499	5090	1254	0	0	0	0
River Tavy	500-599	3251	0	0	0	0	0

Length of river (metres) within each combination of altitude range and stream order

		Stream order (after Strahler)					
River	Alt. range (m)	1	2	3	4	5	6
River Taw	0-49	12701	10493	10590	24810	0	0
River Taw	50-99	59395	39284	17559	0	0	0
River Taw	100-149	81061	29308	0	0	0	0
River Taw	150-199	49945	6170	0	0	0	0
River Taw	200-299	34663	5790	0	0	0	0
River Taw	300-399	9358	0	0	0	0	0
River Taw	400-499	2694	0	0	0	0	0
River Taw	500-599	1559	0	0	0	0	0
River Tawe	0-49	1424	551	19739	0	0	0
River Tawe	50-99	3585	7762	2214	0	0	0
River Tawe	100-149	13673	8191	0	0	0	0
River Tawe	150-199	9861	2880	0	0	0	0
River Tawe	200-299	12618	3087	0	0	0	0
River Tawe	300-399	8439	1316	0	0	0	0
River Tawe	400-499	9546	0	0	0	0	0
River Tawe	500-599	5691	0	0	0	0	0
River Tawe	600-699	1186	0	0	0	0	0
River Tawe	700-799	107	0	0	0	0	0
River Tees	0-49	69903	34205	26200	54313	0	0
River Tees	50-99	87479	24606	24948	0	0	0
River Tees	100-149	45573	3536	14122	0	0	0
River Tees	150-199	20629	8835	7998	0	0	0
River Tees	200-299	36413	23594	10673	0	0	0
River Tees	300-399	35758	18245	8116	0	0	0
River Tees	400-499	41867	12739	2038	0	0	0
River Tees	500-599	26203	4761	0	0	0	0
River Tees	600-699	11610	0	0	0	0	0
River Tees	700-799	1816	0	0	0	0	0
River Tees	800-899	36	0	0	0	0	0
River Teifi	0-49	22367	16217	22452	10762	0	0
River Teifi	50-99	43700	33449	24372	0	0	0
River Teifi	100-149	86495	34347	28416	0	0	0
River Teifi	150-199	75040	19733	18137	0	0	0
River Teifi	200-299	71739	5269	416	0	0	0
River Teifi	300-399	19580	0	0	0	0	0
River Teifi	400-499	12509	0	0	0	0	0
River Teifi	500-599	38	0	0	0	0	0
River Teign	0-49	16355	7782	18548	0	0	0
River Teign	50-99	18172	1760	11855	0	0	0
River Teign	100-149	17767	0	7777	0	0	0
River Teign	150-199	18551	1493	1753	0	0	0
River Teign	200-299	23107	1928	0	0	0	0
River Teign	300-399	14312	995	0	0	0	0
River Teign	400-499	7847	0	0	0	0	0
River Teign	500-599	1679	0	0	0	0	0

Length of river (metres) within each combination of altitude range and stream order

River	Alt. range (m)	Stream order (after Strahler)					
		1	2	3	4	5	6
River Test	0-49	79287	32756	34068	171	0	0
River Test	50-99	78466	2484	0	0	0	0
River Test	100-149	2547	0	0	0	0	0
River Thames	0-49	191326	97066	107142	7432	126916	0
River Thames	50-99	819217	400549	181598	62094	14894	0
River Thames	100-149	338185	82827	0	0	0	0
River Thames	150-199	73911	0	0	0	0	0
River Thames	200-299	5528	0	0	0	0	0
River Torridge	0-49	9360	10134	0	31068	0	0
River Torridge	50-99	52288	29135	20391	3936	0	0
River Torridge	100-149	70731	19187	0	0	0	0
River Torridge	150-199	33141	4933	0	0	0	0
River Torridge	200-299	8622	1013	0	0	0	0
River Torridge	300-399	7097	0	0	0	0	0
River Torridge	400-499	6696	0	0	0	0	0
River Torridge	500-599	2728	0	0	0	0	0
River Tyne	0-49	16373	29399	7654	45730	0	0
River Tyne	50-99	31803	22830	33080	0	0	0
River Tyne	100-149	52045	61881	7431	0	0	0
River Tyne	150-199	71932	31922	0	0	0	0
River Tyne	200-299	129672	26087	0	0	0	0
River Tyne	300-399	54232	0	0	0	0	0
River Tyne	400-499	19235	0	0	0	0	0
River Tyne	500-599	6908	0	0	0	0	0
River Tyne	600-699	2615	0	0	0	0	0
River Tyne	700-799	1463	0	0	0	0	0
River Tyne	800-899	346	0	0	0	0	0
River Tywi	0-49	11322	12198	16216	42591	0	0
River Tywi	50-99	43667	26120	46068	3725	0	0
River Tywi	100-149	75579	41576	11030	0	0	0
River Tywi	150-199	83282	14009	0	0	0	0
River Tywi	200-299	82794	18407	0	0	0	0
River Tywi	300-399	45542	5959	0	0	0	0
River Tywi	400-499	17234	0	0	0	0	0
River Tywi	500-599	2172	0	0	0	0	0
River Tywi	600-699	162	0	0	0	0	0
River Tywi	700-799	120	0	0	0	0	0

Length of river (metres) within each combination of altitude range and stream order

		Stream order (after Strahler)					
River	Alt. range (m)	1	2	3	4	5	6
River Usk	0-49	31096	24957	36622	22630	0	0
River Usk	50-99	27847	9764	17295	0	0	0
River Usk	100-149	21265	17027	22163	0	0	0
River Usk	150-199	31139	19547	9424	0	0	0
River Usk	200-299	121945	32551	3220	0	0	0
River Usk	300-399	62265	3209	0	0	0	0
River Usk	400-499	26539	0	0	0	0	0
River Usk	500-599	7823	0	0	0	0	0
River Usk	600-699	2547	0	0	0	0	0
River Wear	0-49	9757	7497	44268	0	0	0
River Wear	50-99	42315	24646	20973	0	0	0
River Wear	100-149	42373	19750	0	0	0	0
River Wear	150-199	29622	9935	0	0	0	0
River Wear	200-299	33993	12259	0	0	0	0
River Wear	300-399	23886	3923	0	0	0	0
River Wear	400-499	13127	3404	0	0	0	0
River Wear	500-599	4925	0	0	0	0	0
River Wear	600-699	609	0	0	0	0	0
River Wye	0-49	27345	28544	4004	30544	84587	0
River Wye	50-99	210785	57071	46954	43396	66758	0
River Wye	100-149	136114	70770	36236	13906	23228	0
River Wye	150-199	111756	71035	37876	28160	0	0
River Wye	200-299	274917	145314	41047	3753	0	0
River Wye	300-399	195539	34115	14895	0	0	0
River Wye	400-499	101866	2871	0	0	0	0
River Wye	500-599	20337	0	0	0	0	0
River Wye	600-699	1434	0	0	0	0	0
River Wyre	0-49	34987	26328	8155	0	0	0
River Wyre	50-99	7914	5521	0	0	0	0
River Wyre	100-149	11108	2791	0	0	0	0
River Wyre	150-199	9343	954	0	0	0	0
River Wyre	200-299	9981	754	0	0	0	0
River Wyre	300-399	5771	0	0	0	0	0
River Wyre	400-499	1212	0	0	0	0	0
River Yealm	0-49	0	7450	0	0	0	0
River Yealm	50-99	4891	1813	0	0	0	0
River Yealm	100-149	3960	0	0	0	0	0
River Yealm	150-199	2532	0	0	0	0	0
River Yealm	200-299	1601	0	0	0	0	0
River Yealm	300-399	1172	0	0	0	0	0
River Yealm	400-499	531	0	0	0	0	0

Length of river (metres) within each combination of altitude range and stream order

River	Alt. range (m)	Stream order (after Strahler)					
		1	2	3	4	5	6
River Ystwyth	0-49	6520	120	12796	0	0	0
River Ystwyth	50-99	8278	11127	1878	0	0	0
River Ystwyth	100-149	10731	7299	0	0	0	0
River Ystwyth	150-199	8134	3316	0	0	0	0
River Ystwyth	200-299	16700	5297	0	0	0	0
River Ystwyth	300-399	9080	3688	0	0	0	0
River Ystwyth	400-499	11265	1990	0	0	0	0
River Ystwyth	500-599	2350	0	0	0	0	0