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River fish habitat inventory phase 2: methodology development for juvenile salmonids

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This report represents a non-technical summary of the methodology development of the River Fish Habitat Inventory for juvenile salmonids. The technical side of things has previously been referred to in two papers already published by Canadian Journal of Fisheries and Aquatic Sciences (see References). It will be of interest to Agency Fisheries Scientist involved in the assessment of fish populations in relation to their habitat requirements.

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Steve Killeen
Head of Science

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Executive Summary

Salmonid management requires an understanding of the relationship between juvenile abundance and habitat, and fishery management tools, such as salmon conservation limits (CLs), require the enumeration of habitat quantity and quality throughout a catchment. The objectives of this project were to refine the current Agency habitat inventory for calculating salmon CLs, and to develop a modelling framework that would integrate a number of related techniques such as CLs, the Fish Classification Scheme (FCS) and HabScore.

The approach taken was to combine hydrological models of river networks based on geographical information systems (GIS) with statistical models of fish and habitat data. These models provide a quantitative inventory of the juvenile salmonid habitat and populations present within a catchment.

The models to quantify habitat were calibrated on reference sites throughout England and Wales that were not considered to be affected by factors such as limited access for migratory adults, poor water quality or sedimentation problems. The models operate at two levels – one is based on a very simple assessment of map-based variables from GIS, such as altitude and catchment area, and the other includes field-based variables from habitat surveys, such as substrate and flow types. The primary application for these models is to improve the current quantitative basis for salmon management, such as CLs.

The models to quantify juvenile populations are based on annual electrofishing data, and interpolate and/or extrapolate these data throughout a catchment using the habitat models described above. The method can be applied to sites that used either single- or multiple-pass removal sampling, by using the capture probabilities from multiple-pass sites to help interpret the catches at single-pass sites. The primary application for these models is the quantitative assessment of freshwater impacts on juvenile salmonids at a catchment scale.

This report provides a summary of the work undertaken and gives some example outputs from the method. Details of the modelling methods are provided in separate papers.

1 Introduction

1.1 Background

In recent years, the understanding of fish populations and their management has been enhanced through the development of new management tools and procedures, many of which require a quantitative river habitat assessment methodology and a complete river fish habitat inventory (RFHI). In particular, the move towards the use of conservation limits (CLs) to manage migratory salmonids requires estimates of juvenile salmonid habitat quality, accessibility and area for every relevant catchment. CLs currently use a juvenile salmon habitat inventory based on 1:250,000 scale river networks, and a simple classification of river type based on stream order and altitude. Wyatt and Barnard (1997a) recommended a number of improvements to the procedure, including:

- 'inclusion of more explanatory variables … and field measurements';
- 'development of a more sophisticated method for defining river types';
- 'inclusion of river-specific juvenile abundance data';
- 'consideration of using 1:50,000 GIS [geographical information systems] so that headwater streams are included';
- 'use of more robust width (and therefore area) estimation procedures, and preferably the use of river-specific width measurements'.

In addition to salmon CLs, the Salmon Lifecycle Model (Wyatt and Davidson, 2003) is entirely dependent on a quantitative RFHI. Numerous other aspects of freshwater fisheries management would also benefit from a habitat inventory, such as the design and analysis of fisheries monitoring programmes, and the assessment of the quantity and quality of habitat upstream of barriers to migration.

Furthermore, a number of other habitat assessment models are being used for salmonid management in the Environment Agency. These include the Fish Classification Scheme (FCS; Mainstone *et al*., 1994), HabScore (Wyatt *et al*., 1995) and methods to interpret semi-quantitative electrofishing data (Wyatt and Lacey, 1998). Rather than develop yet another set of habitat models, the Phase I report of the RFHI project (Wyatt and Barnard, 1997b) recommended the development of a single integrated framework to assess salmonid habitat on any geographical scale.

The RFHI project is therefore concerned with the integration and development of habitat modelling approaches, and is not primarily concerned with the development of new field-based habitat assessment methodologies.

1.2 Project objectives

The overall objective of the RFHI project (W2-040) Phase II was:

> *To develop a two-tier RFHI that will allow the classification of river habitat quality on a catchment scale for salmonids, based on (i) map features and (ii) map and field features combined. The final scheme will provide an integrated framework for the Agency Fish Classification Scheme (FCS), HabScore methodology, Salmon Lifecycle Model (SLM) and salmon Conservation Limit (CL) procedures.*

The specific objectives of this project were:

Map-based models

(1) To develop a map-based model for juvenile salmonid habitat quality based on national pristine reference sites.
(2) To apply the map-based model for habitat quality to selected case-study catchments using 1:50,000 scale digital datasets.
(3) To develop a methodology for estimating wetted stream widths, and areas for different habitat classes.
(4) To develop a catchment-scale, map-based model for juvenile salmonid abundance based on local electrofishing survey results.

Map- and field-based models

(5) To develop a two-tier (map and field) model for juvenile salmonid habitat quality, based on national pristine reference sites.
(6) To assess the variables, measurement precision and design required for catchment-scale, field-based salmonid habitat assessment, with reference to existing techniques (e.g. RHS [river habitat survey], HABSCORE). Recommend appropriate methodology.
(7) To apply the two-tier model for habitat quality to the selected case-study catchments using 1:50,000 scale digital datatsets.

Coarse fish

(8) To make recommendations for extending the RFHI to incorporate coarse fish.

1.3 Project reports

This report provides a non-technical summary of the main results of Phase II of the RFHI research and development (R&D) project. Particular emphasis is given to the way in which the RFHI model builds on existing Environment Agency fish-habitat models, and so the references are restricted to Environment Agency R&D reports. Full statistical details of the methods described in this report, together with reviews of the relevant scientific literature, are given in separate scientific papers. At the time of writing this report, two papers have been published (Wyatt, 2002, 2003), and others are in preparation.

Throughout the project, the modelling methodology was developed, tested and refined using data for salmon (0+ and >0+) and trout (0+ and >0+). In this report, a selection of results (mainly for salmon) is presented to illustrate the method.

The remainder of this report is structured around the eight project objectives.

2 Objective 1. To develop a map-based model for salmonid habitat quality

2.1 Introduction

The relationship between map-based variables and the expected abundance of juvenile salmonids is central to three methodologies used by the Fisheries Function – HabScore (Wyatt *et al*., 1995), the FCS (Mainstone *et al*., 1994) and salmon CLs (Wyatt and Barnard, 1997a).

The RFHI map-based models were calibrated on a database of pristine reference sites, including those originally used to calibrate the HabScore and salmon CL models. The sites included in the reference database were those with no known impacts on, or modifications to, the fish population, from factors such as sedimentation, acidification, low flows, water quality or stocking. This database has been extended to include some additional sites, and also additional years of fish survey data where available. The quantification of habitat quality from the RFHI models is therefore expressed in terms of the average density found at reference sites of a similar habitat. In this report, this quantity is termed the Reference Site Average Density (RSAD), and is conceptually equivalent to the Habitat Quality Score (HQS) of HabScore. A possible interpretation of the RSAD is that it represents the carrying capacity of the site, and this is being investigated as part of a separate R&D project ("Factors affecting carrying capacity of salmonids in rivers").

The RFHI map-based models for salmonid habitat quality comprise four components:

- non-linear map-based sub-model (Section 2.2);
- geographical sub-model (Section 2.3);
- temporal sub-model (Section 2.4);
- fish sampling sub-model (Section 2.5).

These components all operate together in a single model, but are described separately below. The model also produces probabilistic outputs, which are described in Section 2.6.

2.2 Non-linear map-based sub-model

This sub-model was concerned with the relationship between the densities of juvenile salmonids at the reference sites, and site-specific map-based variables such as altitude and gradient. The map-based variables available from the database were those collected from paper-based 1:50000 maps for HabScore surveys.

The HabScore models and salmon CL models are based on "linear" (e.g. exponential and quadratic) relationships between fish density and habitat variables. However, such models are very inflexible. For example, the data for fish densities at sites with poor habitat quality exert a strong influence on the model predictions for sites with good habitat quality, and *vice versa*. This inflexibility is particularly noticeable at the extremes of habitat quality, where an exponential or quadratic curve may very rapidly rise or fall, to give poor predictions and even poorer extrapolations.

The FCS avoided some of these problems by using a non-parametric approach, similar to a moving average. The RFHI models used a similar approach that fits a smoothing function through the data, which is not dependent on the assumption of linear relationships between fish density and habitat. The results of the simplest model developed for 0+ salmon, based on just a measure of river size (catchment area upstream of site) and river type (altitude), are given in *Figures 2.1* and *2.2*. This model is therefore of comparable complexity to the salmon CLs model (stream order and altitude) and the FCS model (width and gradient). For 0+ (*Figure 2.1*) and >0+ salmon, densities were highest in streams with an altitude of around 180m and a catchment area upstream of around 120km^2.

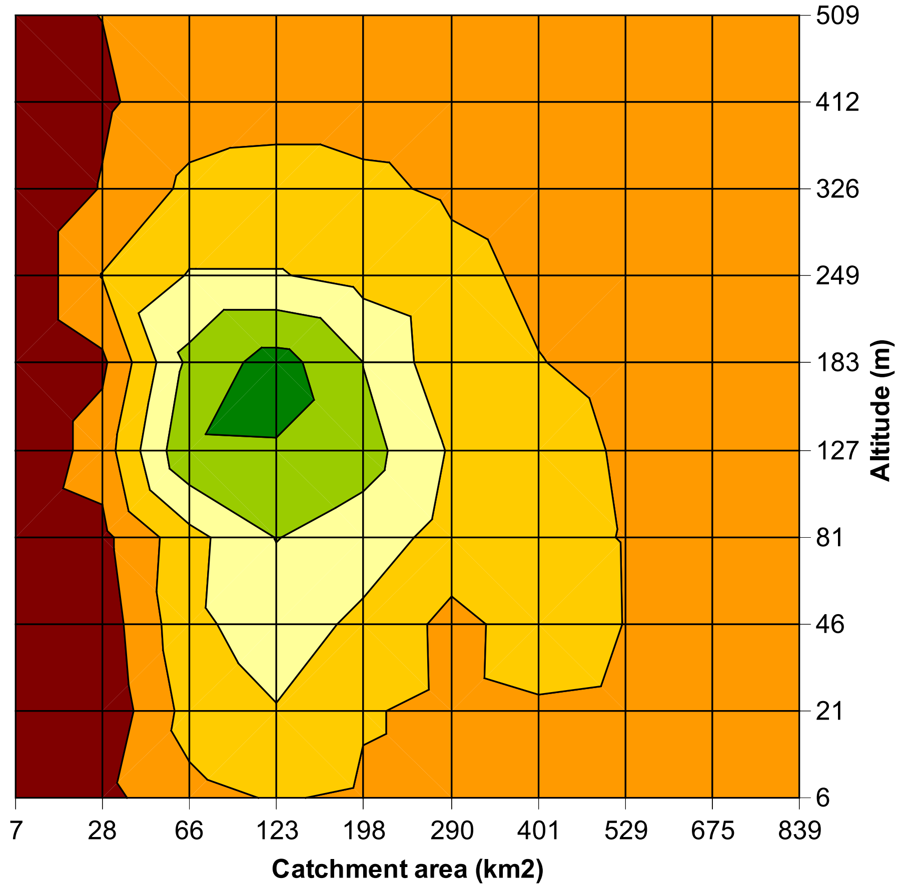


Figure 2.1 Relative abundance of 0+ salmon at the reference sites in relation to catchment area and altitude (green, high; red, low).

There are relatively few reference sites with catchment areas greater than 400km^2, and yet predictions of juvenile densities may be required for larger rivers. In these situations, the model is extrapolating and will give predictions that are close to average (Figure 2.1) but with very low precision (Figure 2.2). To improve the precision of these models will require better methods for evaluating populations in large rivers, and this is being addressed by the new R&D project “Evaluating Salmonid Abundance And Habitat In Large Rivers” (W2-071).

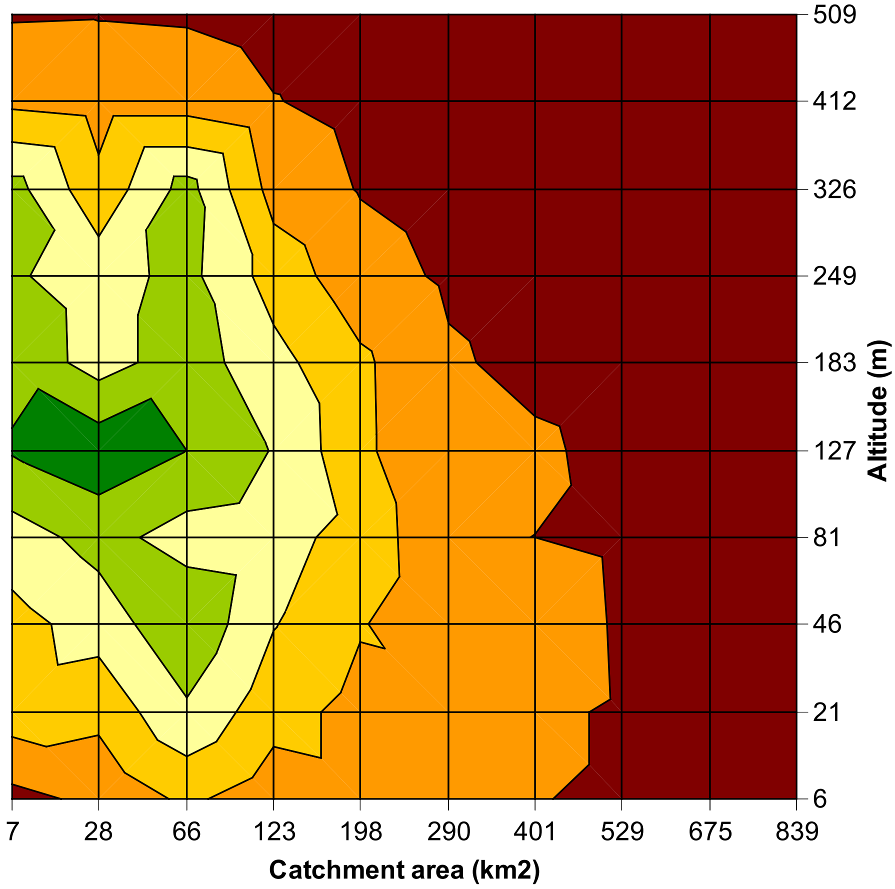


Figure 2.2 Precision of the map-based sub-model for 0+ salmon abundance (green, high; red, low).

The fit of the model was informally described by the proportion of the variance of (logged) densities explained by the model. This figure is not comparable to the r^2 values cited for HabScore models, and for 0+ salmon it was around 49%.

Other variables, such as the average altitude upstream and the distance to the river mouth, were also found to be important in determining the distribution of salmon. However, strong correlations among these variables (e.g., high altitudes tend to be further from the river mouth) make these models more difficult to interpret.

2.3 Geographical sub-model

All previous habitat models in the Environment Agency assumed that the same model holds true across all geographical regions of England and Wales. However, this assumption is unlikely to be true and so the RFHI models relax this assumption. The RFHI models assume that habitat quality varies from catchment to catchment, and that catchments that are geographically close to each other are more similar than those that are further apart. The result is that outputs from the RFHI model take account of where the model is being used, and are most influenced by pristine reference sites close by and less influenced by pristine reference sites further away.

The initial results for 0+ salmon are shown in *Figure 2.3*, and reveal that densities are relatively lower in north east England, and relatively higher in Wales and south west England. There are two possible reasons for this, which require further investigation. Firstly, there may be genuine regional differences in habitat quality, perhaps caused by environmental variables not currently included in the model, such as climate or geology. Secondly, further retrospective screening of the pristine reference sites may be required. This is particularly noticeable where individual catchments appear to have poor quality (orange and/or red), but are surrounded by good quality (green) catchments.

There are few data from the east of England in the database of pristine reference sites for salmonids. The prediction from the geographical sub-model for this area is therefore average (yellow, pale-green, *Figure 2.3*), but the uncertainty is very high (red, inset *Figure 2.3*). However, the overall prediction from the map-based sub-model for these rivers would be low because of their low altitudes (*Figure 2.1*). The inclusion of the geographical sub-model increased the fit of the model from 49% to 66%.

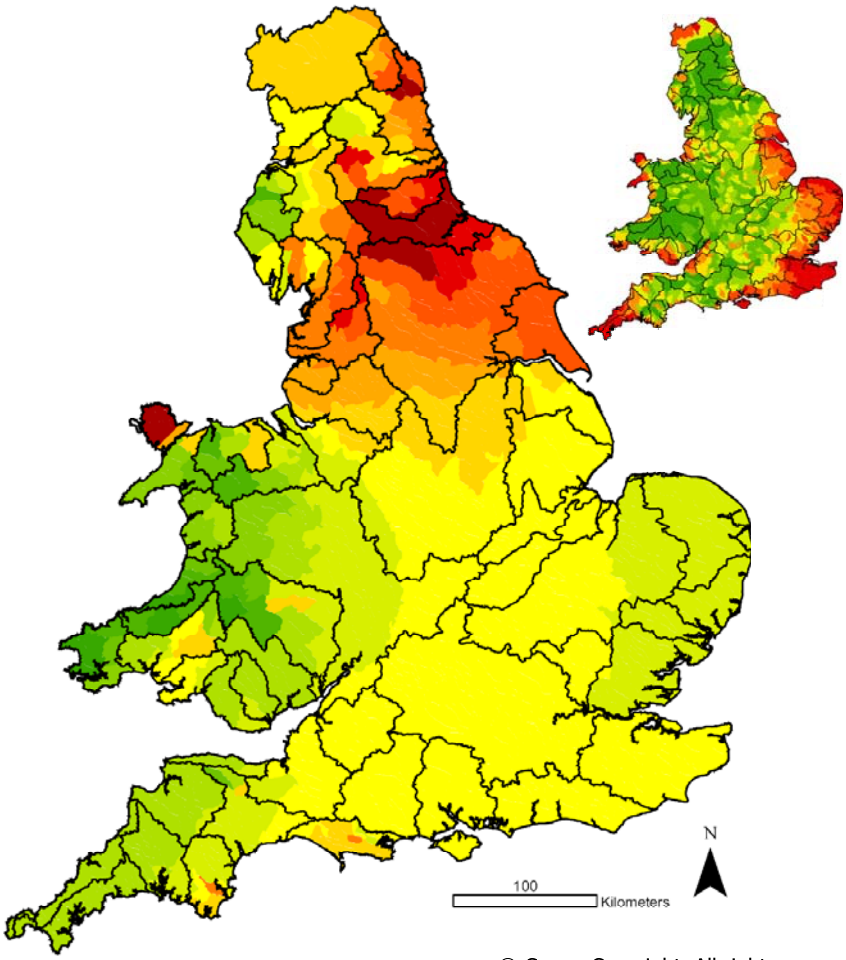


Figure 2.3 Geographical correction-factor for 0+ salmon model (red, lower than average; green, higher than average). Inset map shows estimation error (red, high; green, low).

2.4 Temporal sub-model

The development of all previous fish habitat models in the Environment Agency was based on electrofishing data obtained at each site on a single occasion. This creates a number of problems, in particular the inability to distinguish between temporal variation in fish numbers and spatial variation caused by differences in habitat quality.

Where possible, the RFHI model was calibrated on time series of fish population data from each site, and the habitat at a site was related to the long-term mean fish density (horizontal line, *Figure 2.4*) rather than to the density observed in a single year. The timing of a survey within a year is also important, particularly for 0+ fish. The RFHI models therefore include an exponential survival function that corrects for the higher densities observed earlier in the year (*Figure 2.4*). An understanding of the relative magnitudes of spatial and temporal variances is also important to both assess the performance of habitat models and to apply the models to impact assessments.

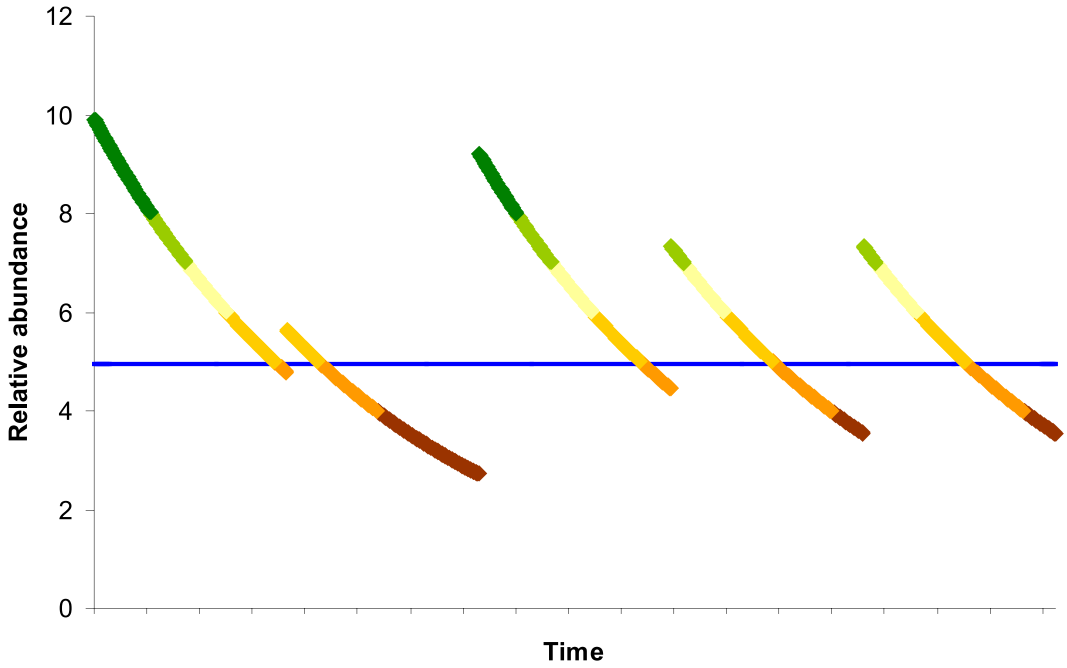


Figure 2.4 Illustration of temporal sub-model for five years, showing within- and between-year variations in abundance. Colour codes relate to abundance classification. Horizontal line represents the long-term average.

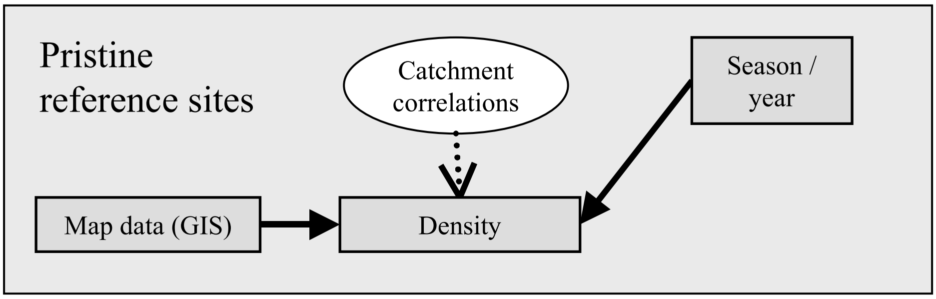
2.5 Fish sampling sub-model

The original HabScore models were based on a regression analysis of the estimated population density at a site (numbers/area), estimated from removal sampling (e.g., methods of Zippin or Carle and Strub), against habitat variables obtained from maps or field measurement. However, population estimates obtained from the removal method are unlikely to follow a normal distribution, and will contain a large proportion of zeros for many species and/or age groups. The assumption of regression analysis that the dependent data follow a normal distribution is therefore difficult to achieve, even after data transformation.

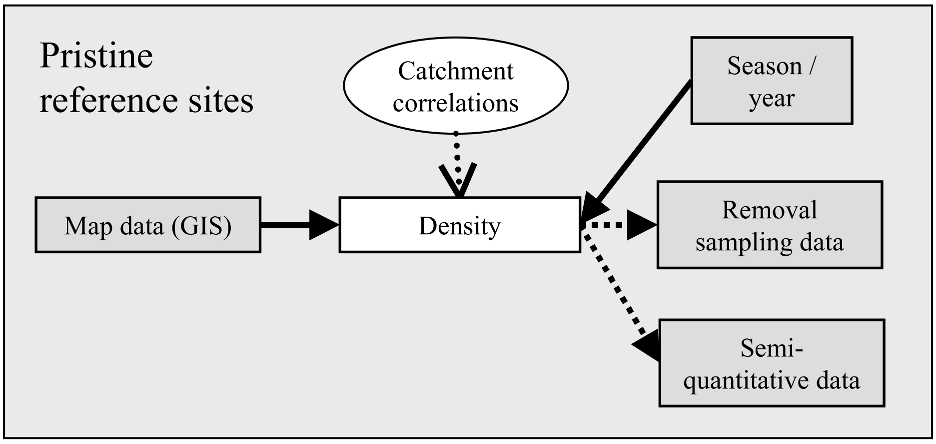
The salmon CL models were developed more recently, and overcame the problem of zeros by using a special type of regression called a generalised linear model (GLM). Ideally, this involves modelling the population size (numbers) rather than population densities (numbers/area), and using the site area as an explanatory variable (or 'offset') in the model. With a GLM, the population size at an electrofishing site is assumed to follow a Poisson distribution, which is more appropriate than the assumption of a normal distribution.

Fish population surveys in the Environment Agency now comprise occasional spatial surveys of single-pass 'semi-quantitative' sites, and annual temporal surveys of multiple-pass 'quantitative' sites. The RFHI methodology therefore needed to be able to include the raw catch data from an electrofishing survey, regardless of whether they were obtained from the sequence of catches from a quantitative survey or from a single catch from a semi-quantitative survey.

Statistical models can be depicted as flow diagrams in which data and unknown parameters are represented by shaded and unshaded nodes, respectively, and arrows show the dependencies between them (*Figure 2.5*). The RFHI model, which comprises the geographical sub-model (catchment correlations), temporal sub-model (season and/or year) and map-based sub-model (map data), was calibrated on density estimates (shaded node, *Figure 2.5a*). Alternatively, at sites where the raw catch data are available, the fish density was regarded as an unknown parameter (unshaded node, *Figure 2.5b*) and linked to the removal sampling data and semi-quantitative data using a fish-sampling sub-model. The statistical details of the fish-sampling sub-model are given in Wyatt (2002).



a)



b)

Figure 2.5 Flow diagram showing map-based model: a) using density estimates and b) integrating fish-sampling model.

2.6 Probabilistic output

The quantitative assessment of river habitat quality can be very imprecise, so habitat models must provide some measure of uncertainty. Outputs from the HabScore models are in the form of a single value for the Habitat Quality Score (HQS), together with upper and lower 95% confidence intervals. However, for many applications it is useful to present the outputs of a habitat model in probabilistic terms (Wyatt and Lacey, 1998). The RFHI habitat models therefore use Bayesian statistics to generate probability distributions for all unknown quantities (unshaded boxes, *Figure 2.5*), from which management questions can be answered in probabilistic terms. For example, the predicted population size (density × site area) at a site can be expressed as a probability distribution of possible values (*Figure 2.6*), from which a number of measures can be obtained, such as:

- probability that fish will be present or absent (height of zero bar, *Figure 2.6*);

- probability that the site falls within different FCS classes (colour codes, *Figure 2.6*);
- probability that the population is above some biological reference point (BRP);
- most likely population size (peak of histogram, *Figure 2.6*);
- standard deviation of possible population sizes;
- mean or median (50th percentile) of possible population sizes;
- 95% probability interval for population size (2.5th percentile and 97.5th percentiles).

Throughout the rest of this report, probabilistic outputs are tabulated and graphed as the median (50th percentile) with 95% probability intervals (2.5th percentile, 97.5th percentile). Maps show the median (50th percentile) with precision measured as the standard deviation.

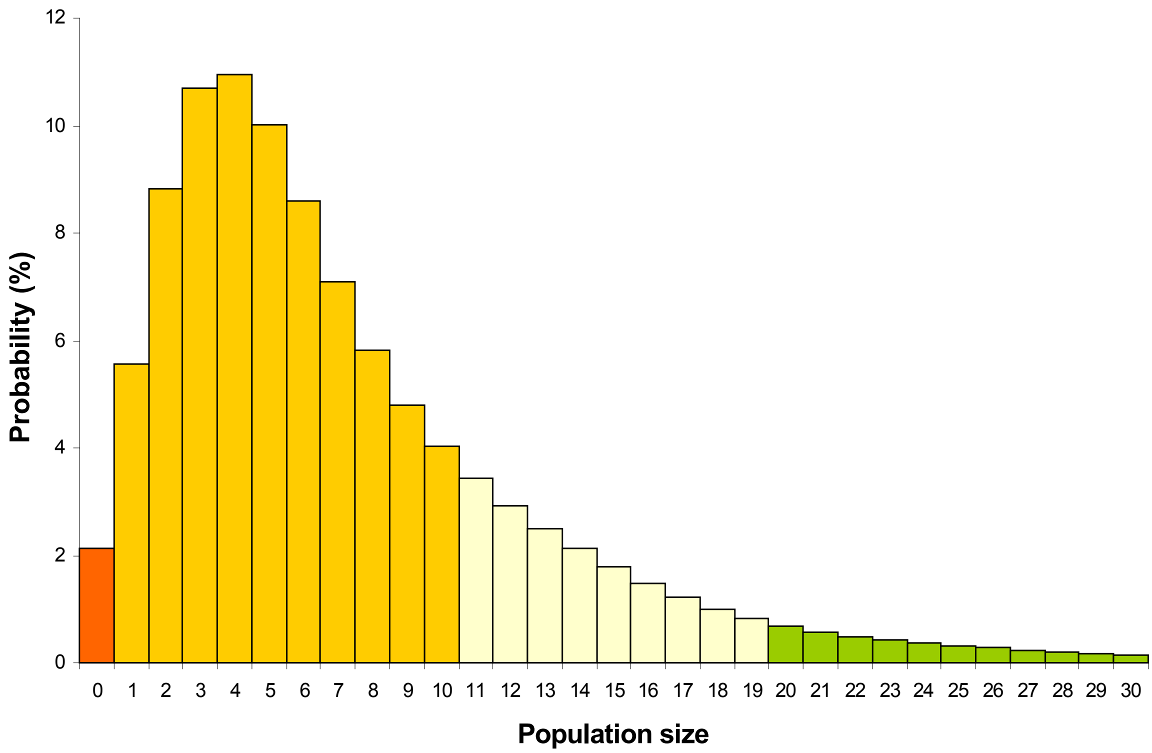


Figure 2.6 Example of probabilistic output from RFHI model showing probability that the population is within four abundance classes.

2.7 Conclusion

The RFHI map-based model for carrying capacity provides an improved basis for the Environment Agency's 'relative' FCS for the site-specific assessment of juvenile salmonids. This results from the use of more flexible modelling methods (Section 2.2), the allowance for geographical effects (Section 2.3), calibration on time-series data (Section 2.4) and the ability to calibrate the model on a larger sample of (semi-quantitative) sites (Section 2.5).

3 Objective 2. To apply the map-based model for salmonid habitat quality to test catchments

3.1 Introduction

To assess habitat quality on a tributary or catchment scale, the carrying capacity model (Section 2) must be applied to a river network.

3.2 Methods

Application of the models to test catchments was undertaken using ArcView 3.1, ArcView Spatial Analyst and ArcView Network Analyst.

The RFHI models were applied to the Conwy (North Wales), Avon (Hampshire), Stour (Hampshire), Tamar (South West) and Tavy (South West). In this report, the Tamar is used to illustrate model application at a catchment scale, and the Nant-y-Goron (Conwy) is used to illustrate application at a tributary scale. For each catchment, the following data were used:

- 50 m grid of elevation data from the Ordnance Survey LandForm Panorama Digital Terrain Model (DTM);
- river network, digitised by the Centre for Ecology and Hydrology (CEH) from Ordnance Survey 1:50,000 maps.

The surface and hydrological modelling functions in ArcView Spatial Analyst were used to convert the DTMs into data grids for:
.
- gradient;
- distance to source;
- distance to estuary;
- catchment area upstream (flow accumulation);
- average upstream characteristics (e.g., average upstream altitude);
- sub-catchment boundaries.

The river network was defined as cells for which the catchment area upstream exceeded some threshold value. This threshold was assessed on a sub-catchment basis to achieve the closest correspondence with the 1:50,000 river network. Where available, data on barriers to migration were included, and areas inaccessible to migratory salmonids excluded from the habitat assessment. Coley (2003) gives further details of modelling river networks using a GIS.

All data analysis and modelling were undertaken using statistical software packages, independently of the GIS. For tributary-scale models, data for each 50-m site were exported from the GIS, and for catchment-scale models, summary data for each reach were exported from the GIS. The average density found at reference sites of a similar habitat (RSAD) was then estimated for each site or reach from the model calibrated on the pristine reference sites (*Figure 3.1*).

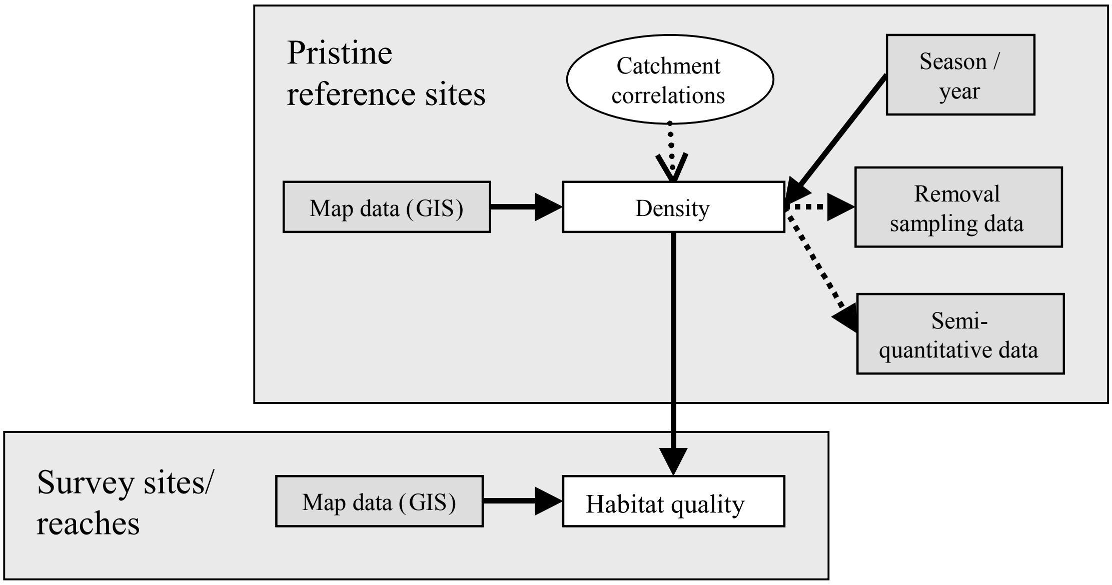


Figure 3.1 Application of map-based habitat quality model to survey sites.

3.3 Results

The elevation data for the Tamar and Tavy catchments, together with the application of the map-based model for habitat quality (Section 2) for 0+ salmon, is shown in *Figure 3.2*. The map displays what might be expected from Figure 2.1, with small streams, particularly those at low altitude, being less suitable for 0+ salmon. This, and all subsequent maps, assumes that all parts of the Tamar and Tavy catchments are accessible to migratory salmonids. Any final assessment of these catchments for management purposes would simply exclude areas known to be inaccessible.

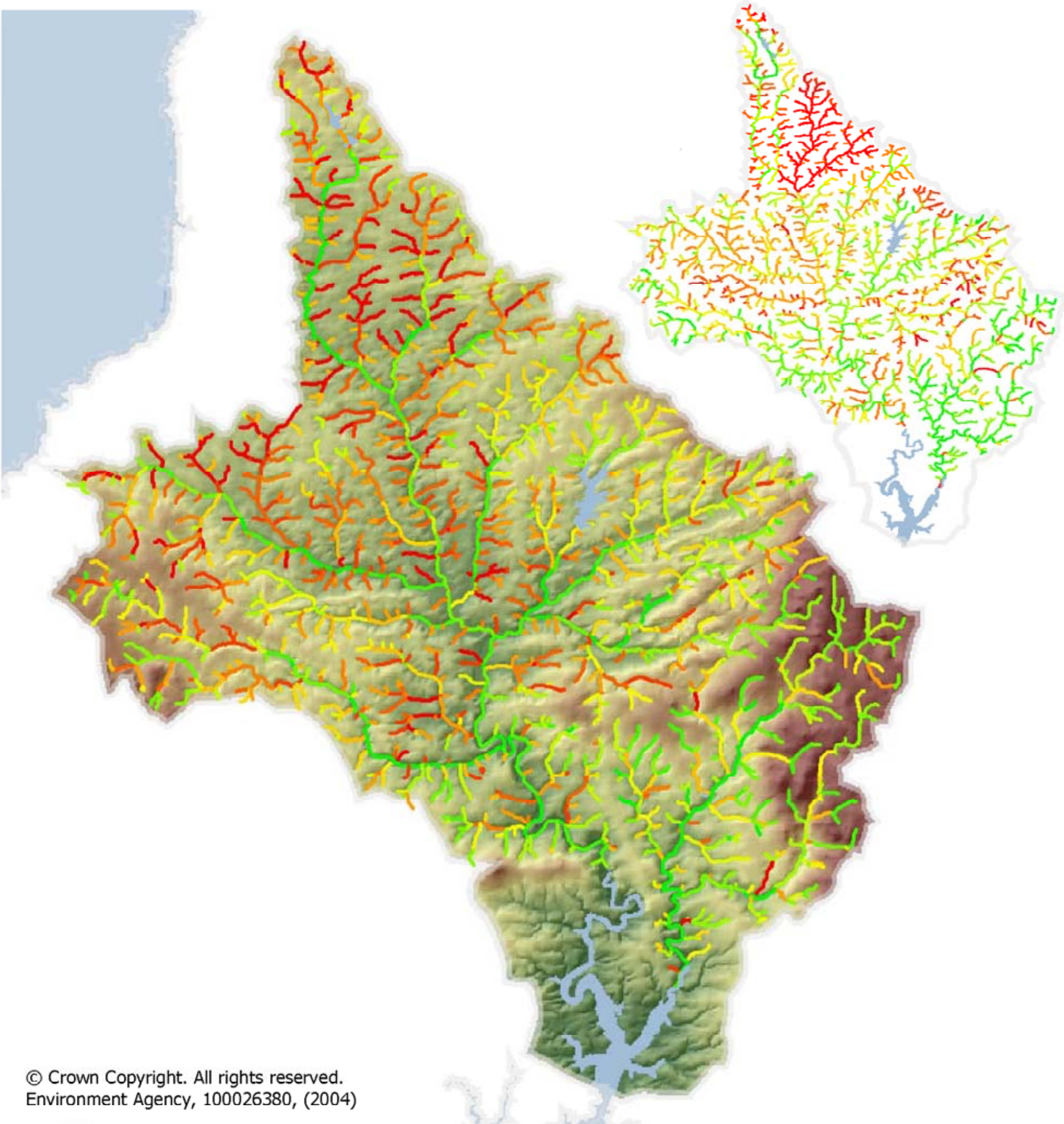


Figure 3.2 **Elevation (green area, low; brown area, high), and map-based habitat quality for 0+ salmon for the Rivers Tamar and Tavy. Green parts of the river denote high habitat quality (max. 59/100 m^2), and red parts of the river denote low habitat quality (min. 0.5/100 m^2). Inset map shows estimation error (red, high; green, low).**

4 Objective 3. To develop a methodology to estimate wetted stream width

4.1 Introduction

For some applications of map-based habitat models, such as calculating salmon CLs, it is necessary to estimate the areas of available habitat, or to express the model outputs in terms of the total numbers of fish, rather than the density of fish. To do this, it is necessary to estimate wetted river widths throughout a catchment.

4.2 Methods

Previous attempts to establish nationally applicable models that predict river width from variables such as upstream catchment area have demonstrated that they are subject to a high degree of uncertainty (Coley, 2003). The RFHI width model overcame this problem in two ways. Firstly, the model was calibrated on local width measurements taken at low summer flows. Sources included HabScore surveys, electrofishing and RHS surveys. Secondly, the model combines prediction based on map data, such as the catchment area upstream, with interpolation based on the estimated between-site or reach correlations (*Figure 4.1*). Two versions of the width model were developed for application at two different spatial scales – one operates at a 50 m resolution to be applied to small tributaries, and one operates at a river reach resolution (i.e. river lengths between confluences at a 1:50,000 scale) to be applied to entire river catchments. A probabilistic approach to data analysis was again used to allow probabilistic conclusions to be drawn about river widths and areas of habitat. Wyatt (2003) gives the statistical details of the width model.

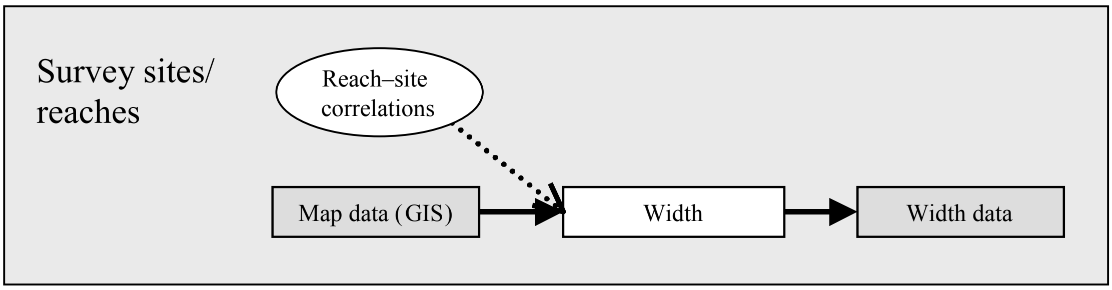


Figure 4.1 Simplified structure of RFHI model for wetted width. Shaded boxes indicate raw data.

4.3 Results

The catchment-scale width model is illustrated on the Rivers Tamar and Tavy. Width data were available from a combination of electrofishing surveys and RHS habitat surveys (*Figure 4.2*), and the probabilistic model generated widths for all reaches within the river system (*Figure 4.3*). The lowest uncertainty (error expressed as a percentage of width) occurred where the model interpolated between measurements, and the highest uncertainty occurred where the model extrapolated into headwater streams (*Figure 4.3*).

The width estimates and lengths for every reach (*Figure 4.3*) can be summed to provide estimates of wetted widths or wetted areas at any spatial scale (*Table 4.1*). Combining the estimates of width (*Figure 4.3*) with habitat quality (*Figure 3.2*) enables habitat quality to be expressed in many different ways, such as habitat quality averaged over all streams within a sub-catchment (*Table 4.2*).

The tributary-scale width model is illustrated on the Nant-y-Goron, a sub-catchment of the River Conwy. Width data were available at the nine 50 m electrofishing sites, and the probabilistic model generated estimates of the widths for all the remaining 50 m sites in the river (*Figure 4.4*). The model predicted a gradual increase in width with increasing upstream catchment area, and small step-increases where tributaries join the main river (vertical lines, *Figure 4.4*). It also reflected the between-site correlations, and so predicted a decline in width between sites 41 and 52, for example, despite the catchment area increasing down the reach. Uncertainty in the width estimates increased with increasing distance from the observed width measurements.

4.4 Conclusions

The combination of the width model with the carrying capacity model provides an improved basis from which to calculate salmon CLs. The use of interpolation, rather than prediction, delivers improved width estimates, and the use of the 1:50,000 river network delivers improved length estimates. The resulting area estimates, combined with the improved map-based habitat models (Section 2), will generate more reliable estimates of the salmon smolt production capacity used to calculate CLs. However, CLs cannot be simply recalculated by combining the average RSAD values (*Table 4.2*) based on a 1:50,000 scale river network, with the original smolt production estimates from the River Bush based on a 1:250,000 scale river network. To implement the RFHI for estimating CLs will therefore require either a remodelling of the River Bush using a 1:50,000 GIS, or the adoption of new approaches to setting Biological Reference Points (BRPs) and management targets for salmon that are not dependent on the stock-recruitment data from the River Bush.

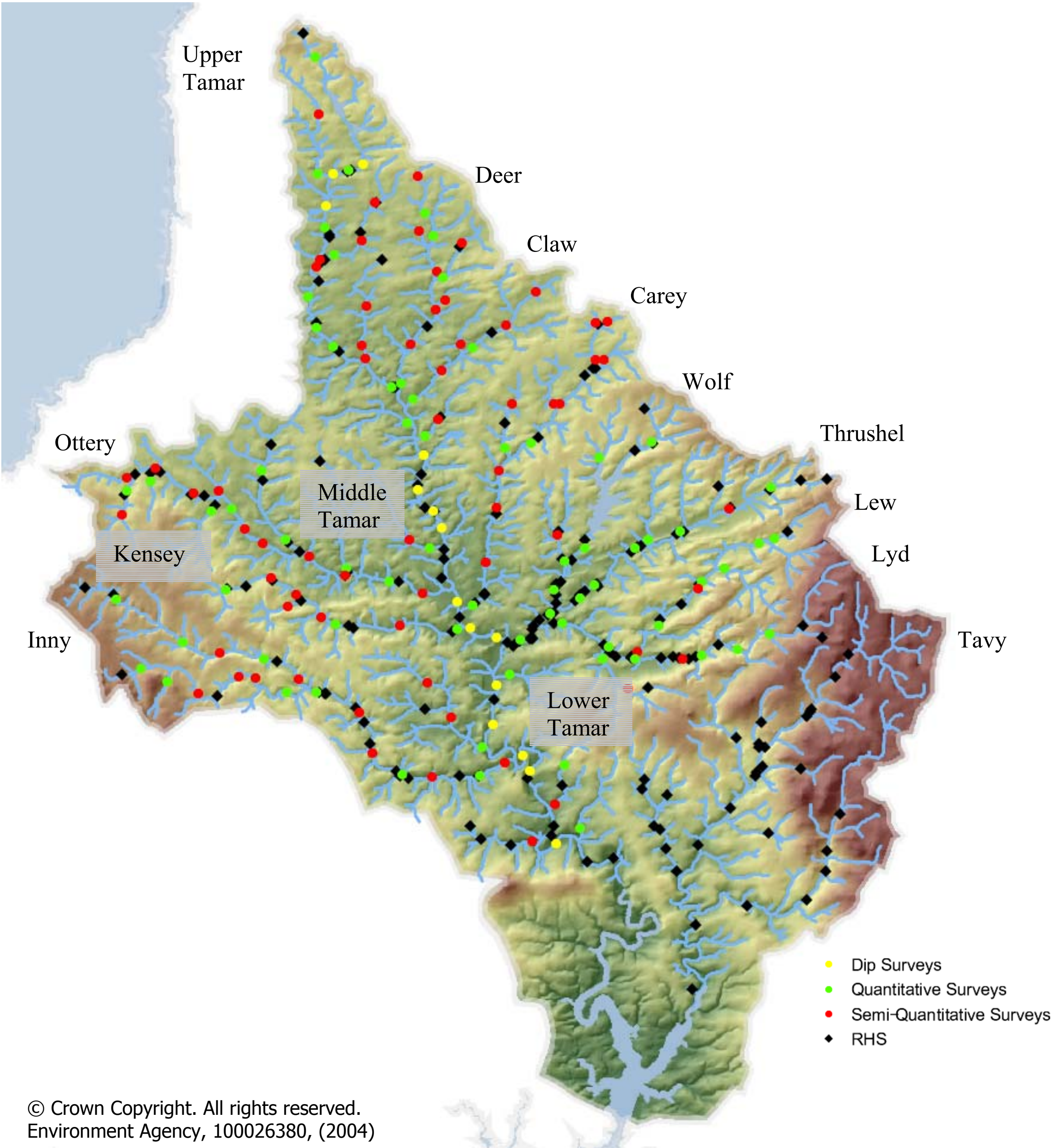


Figure 4.2 Location of sampling sites on the River Tamar (fish survey and RHS) and River Tavy (RHS only).

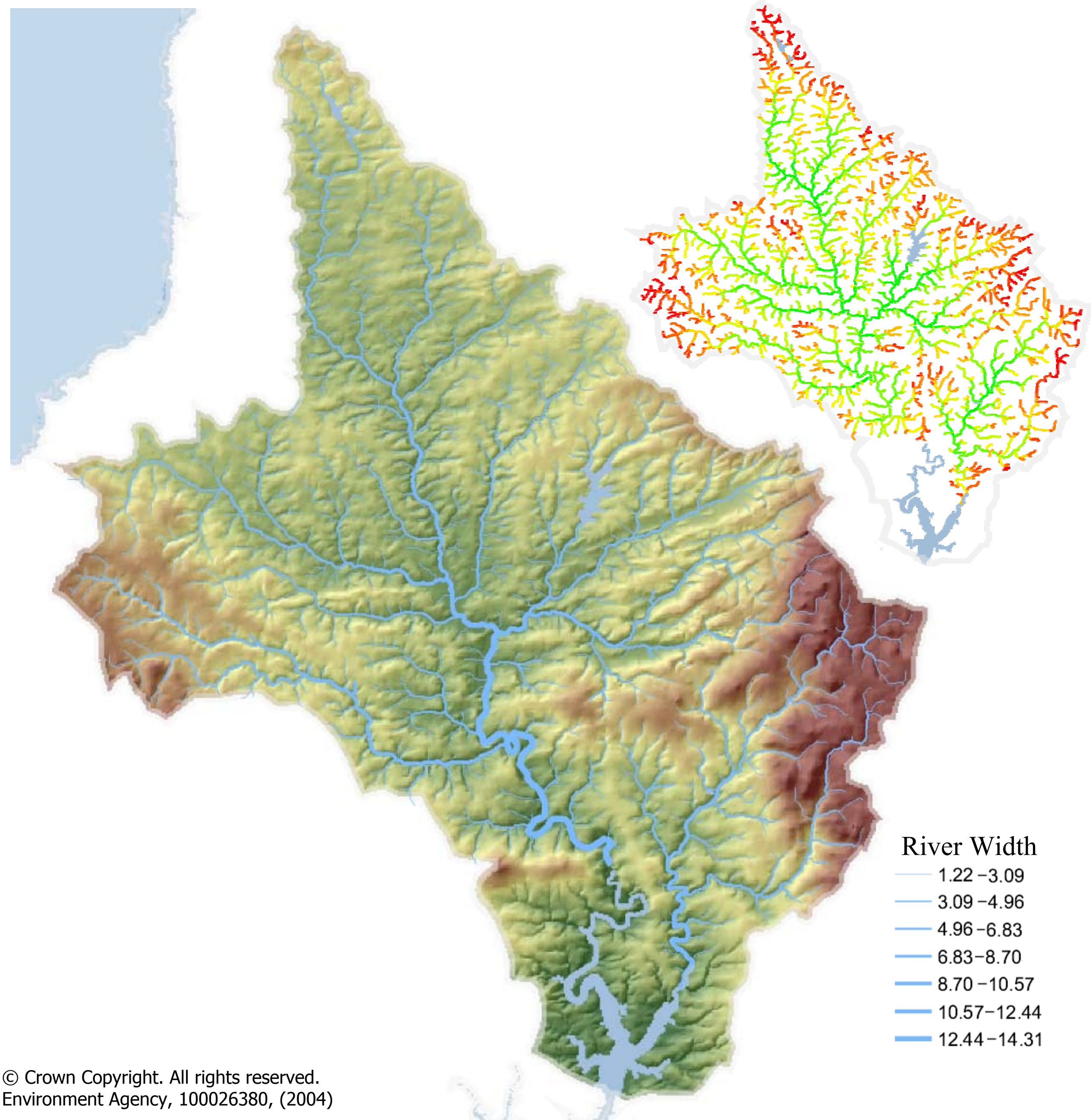


Figure 4.3 Estimated wetted widths from the RFHI model for the Rivers Tavy and Tamar. Inset map shows estimation error (red, high; green, low).

Table 4.1 Estimated length, width and area of the ten sub-catchments of the River Tamar.

Name	Length (km)	Average width (m)			Total area (m^2)		
		2.5	50.0	97.5	2.5	50.0	97.5
Carey	92.1	2.13	2.51	2.96	196,100	231,400	272,600
Deer and Claw	108.0	2.27	2.63	3.16	244,700	284,500	340,900
Inny	131.7	3.12	3.68	4.45	411,200	485,200	585,300
Kensey	45.8	2.31	2.82	3.37	105,500	129,100	154,200
Lew and Lyd	128.3	2.80	3.27	3.75	358,800	419,400	481,500
Ottery	151.2	2.30	2.72	3.19	347,300	410,500	482,200
Tamar (Lower)	143.0	4.05	4.60	5.40	578,700	657,500	771,600
Tamar (Middle)	80.2	3.02	3.39	4.04	242,000	271,600	324,200
Tamar (Upper)	121.3	2.04	2.39	2.89	247,600	290,300	350,300
Thrushel and Wolf	145.4	2.49	2.86	3.33	362,400	416,300	484,100

Table 4.2. Upstream catchment area and altitude of the ten sub catchments of the River Tamar, and estimated habitat quality (RSAD) for 0+ salmon.

Name	Catchment area (km^2)		Altitude (m)			Habitat quality (0+ salmon /100m^2)		
	mean	max	min	mean	max	2.5	50.0	97.5
Carey	9.7	67.2	54	122	435	3.6	7.6	16.4
Deer and Claw	10.2	145.3	79	115	162	4.1	9.0	21.4
Inny	16.2	107.3	5	167	539	4.3	9.1	20.8
Kensey	6.5	37.1	48	172	416	1.8	4.6	12.7
Lew and Lyd	15.0	221.1	8	156	550	4.1	9.3	22.7
Ottery	12.0	121.3	55	123	243	4.2	9.6	23.1
Tamar (Lower)	134.3	924.1	11	156	531	2.9	8.7	34.9
Tamar (Middle)	58.7	433.4	54	117	216	5.3	12.9	46.8
Tamar (Upper)	10.1	84.1	84	130	196	3.8	8.8	18.4
Thrushel and Wolf	8.6	113.9	51	119	255	2.9	6.9	15.7

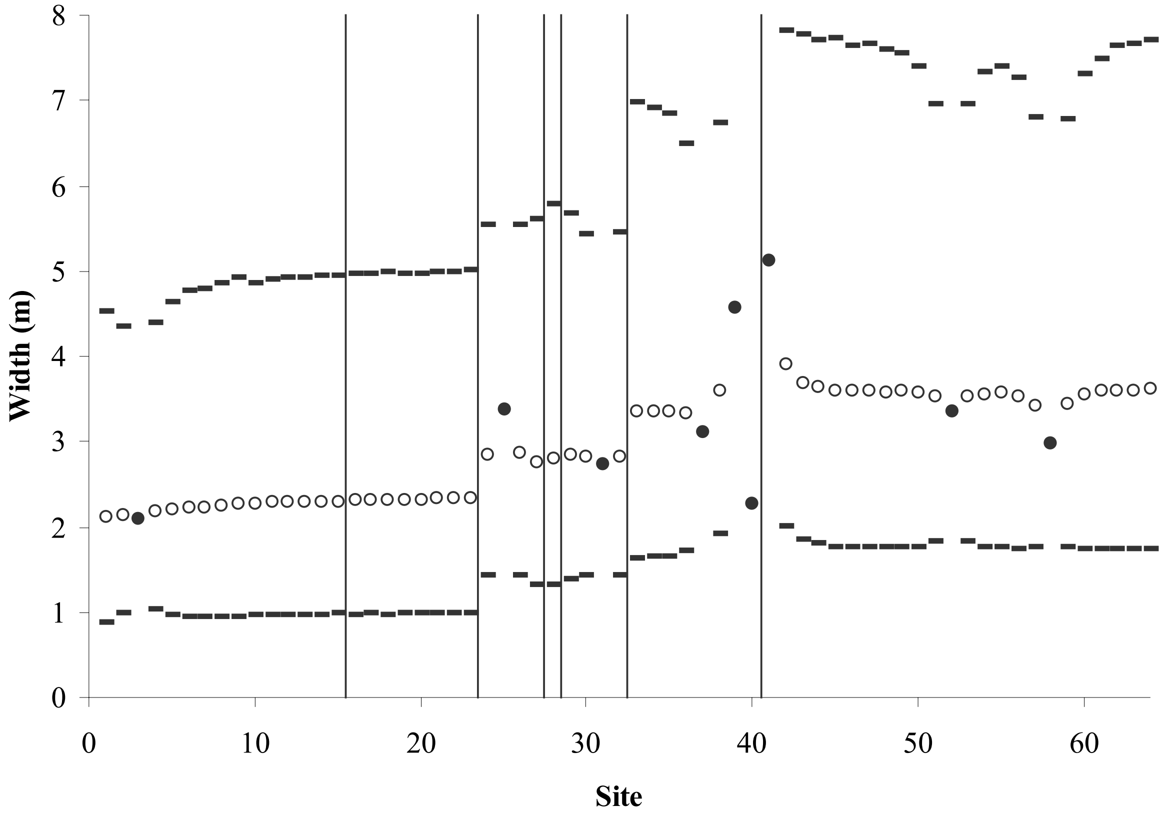


Figure 4.4 Estimated widths for Nant-y-Goron, River Conwy. Closed circles denote width measurements, and open circles denote width estimates. Horizontal lines give upper and lower 95% confidence intervals. Vertical lines denote confluences.

5 Objective 4. To develop a map-based model for fish abundance

5.1 Introduction

One of the uses of a habitat model is to enable the comparison between the spatial patterns in fish density and the spatial patterns in habitat quality at a catchment scale. It is therefore necessary to estimate and map the actual fish abundance in a particular year at a catchment scale.

5.2 Methods

The RFHI map-based models for fish abundance comprise four components, comparable to the four components used for the map-based habitat model:

- non-linear map-based sub-model (*cf* Section 2.2);
- geographical sub-model (*cf* Section 2.3);
- temporal sub-model (*cf* Section 2.4);
- fish sampling sub-model (*cf* Section 2.5).

The primary difference between the abundance and habitat models is that the habitat model was calibrated on a time series of data collected from a national network of pristine reference sites (*Figure 2.5b*), whereas the abundance model was calibrated on the survey data collected within a single catchment in a single year (*Figure 5.1*). There were also three major differences in the structure of the model. Firstly, because it is applied to a single year of data, the temporal component related only to within-year variation (not shown in *Figure 5.1*). Secondly, the map-based component of the abundance model directly utilises the outputs from the map-based component of the habitat model. Finally, the catchment-scale geographical sub-model of the carrying habitat model was replaced by a smaller scale geographical model that utilised either between-site correlations or between-reach correlations.

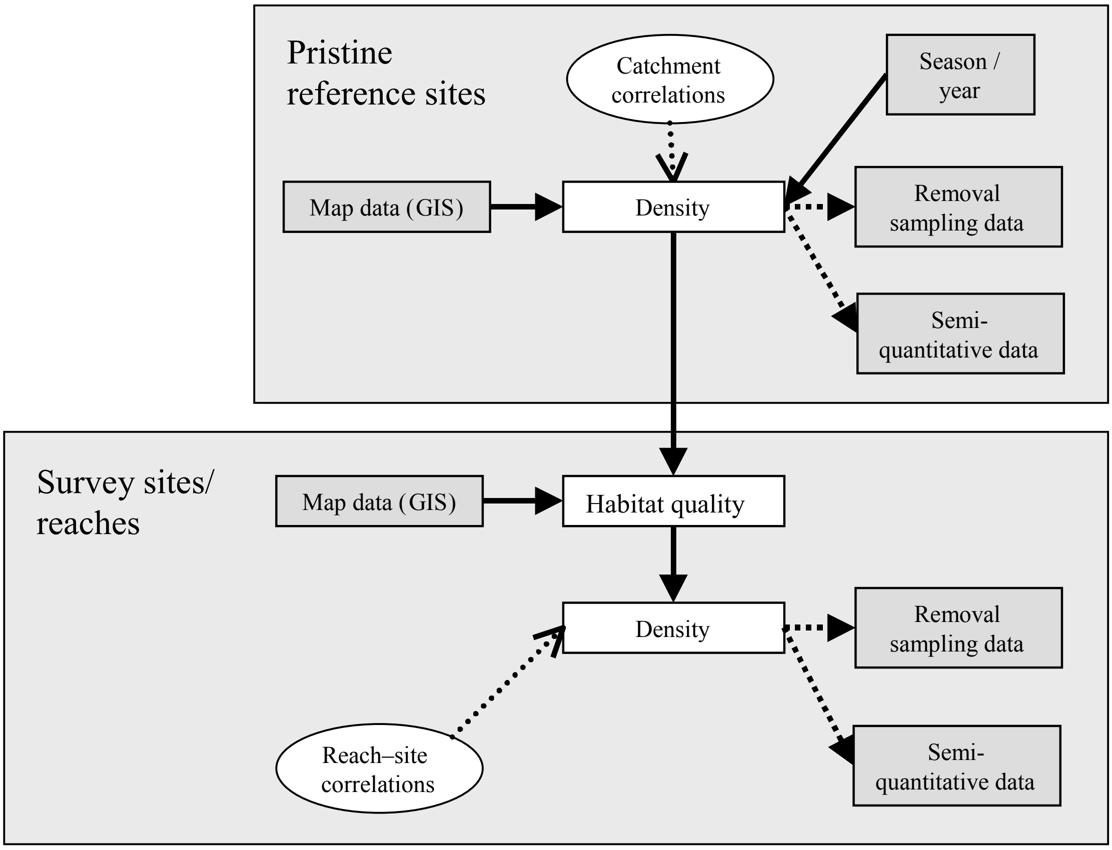


Figure 5.1 Structure of map-based model for salmonid density.

The combination of the density model (*Figure 5.1*) with the width model (*Figure 4.1*) and reach lengths enables the total fish population size to be estimated (*Figure 5.2*) for every individual site or reach. These components all operate together in a single model, and as with the map-based habitat model, the abundance model produces probabilistic outputs (*cf* Section 2.6). The statistical details of the fish abundance model are given in Wyatt (2003).

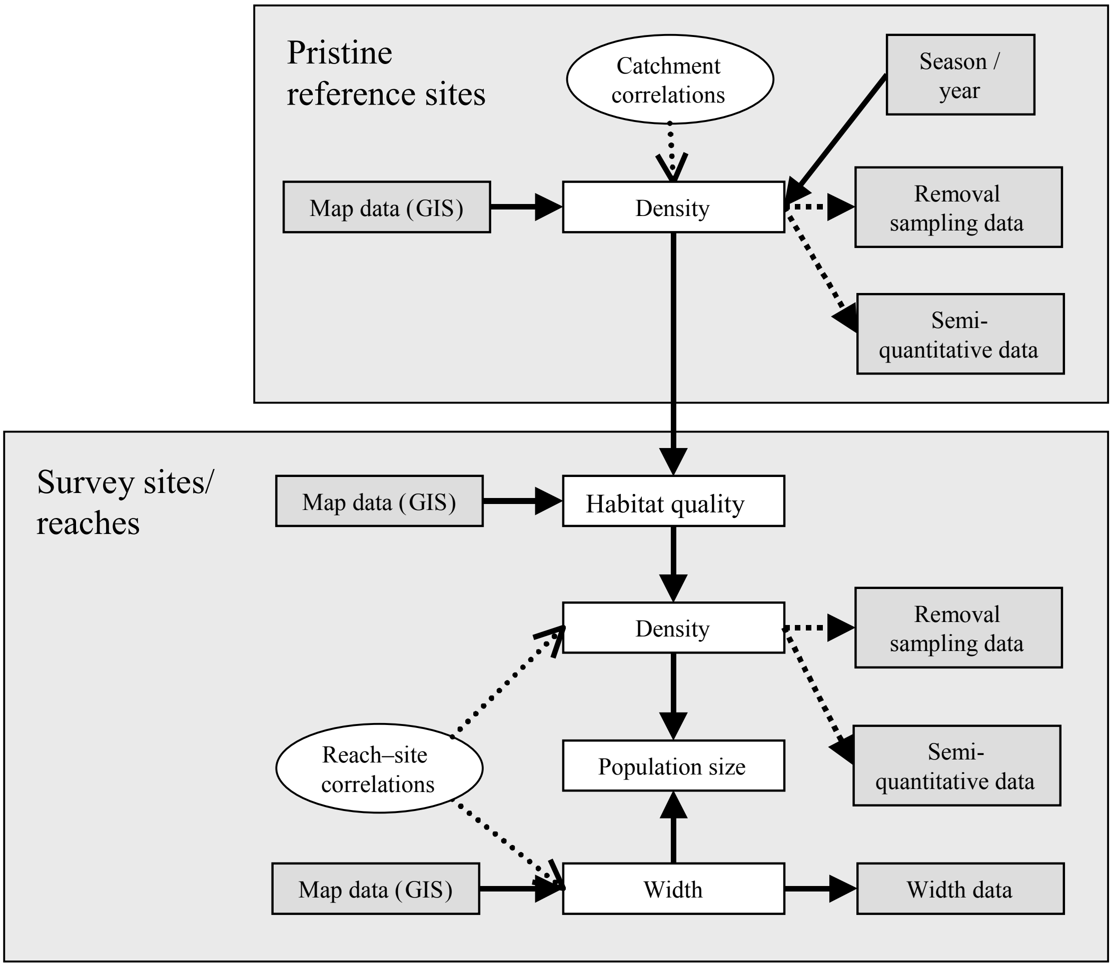


Figure 5.2 Combination of model for salmonid density with model for stream width to give population size.

5.3 Results

The estimated abundance of 0+ salmon on the Tamar in 1999 from the catchment-scale model is shown in *Figure 5.3*, and summarised at a sub-catchment level in *Table 5.1*. The results of the catchment-scale abundance model shows densities of 0+ salmon are relatively lower in the northern tributaries (e.g., Upper Tamar, Deer and Claw), and relatively higher in tributaries that drain Bodmin Moor (Inny) and Dartmoor (Lew and Lyd). The model also gives population estimates for the quantitative (multiple-pass) and semi-quantitative (single-pass) survey sites (*Table 5.2*). Population estimates from the semi-quantitative sites (e.g., Hicks Mill; estimate 37, interval (28, 52)) are not surprisingly less precise than those from quantitative sites (e.g., Trewinnow; estimate 37, interval (34, 42)).

The calibration of the Tamar model included sites from timed dip surveys. However, the model did not fully allow for the likely biased habitat selection undertaken in the main river, so the results for the main river are therefore tentative and will be improved following completion of the R&D project into estimating salmonid abundance in large rivers (R&D Project W2-071).

The estimated abundance from three different 50 m scale models for 1+ trout in the Nant-y-Goron is shown in *Figure 5.4*. The first graph (*Figure 5.4a*) includes just the fish-sampling sub-model (see Section 5.2), which generates density estimates for the sampled sites (closed circles), but the predictions for the unsampled sites correspond to the mean density for the reach (open circles). The second graph (*Figure 5.4b*) adds a map-based sub-model (based on site gradient), which gives higher density estimates for the high-gradient upper reaches and lower estimates for the low-gradient lower reaches. The third graph (*Figure 5.4c*) adds the geographical sub-model, which assumes that sites are more likely to be similar to those close-by than to those further away. This results in a smoother pattern of estimated densities and lower uncertainty in the immediate vicinity of surveyed sites.

5.4 Conclusions

The RFHI density model provides an integrated approach to estimate fish population size at a site, reach and catchment scale. It provides accurate site-specific population estimates, which replace the need for traditional removal methods (e.g., the Zippin method or the Carle & Strub method) or calibration of semi-quantitative methods (Wyatt, 2002). It also provides estimates of population size on any geographical scale (Wyatt, 2003), stratified by habitat quality, which replaces the need for traditional methods to average site-specific population estimates. The RFHI density model therefore provides a way to operate the ‘absolute’ FCS at a range of spatial scales (from 50 m site to catchment), using either quantitative or a mixture of quantitative and semi-quantitative sampling methods.

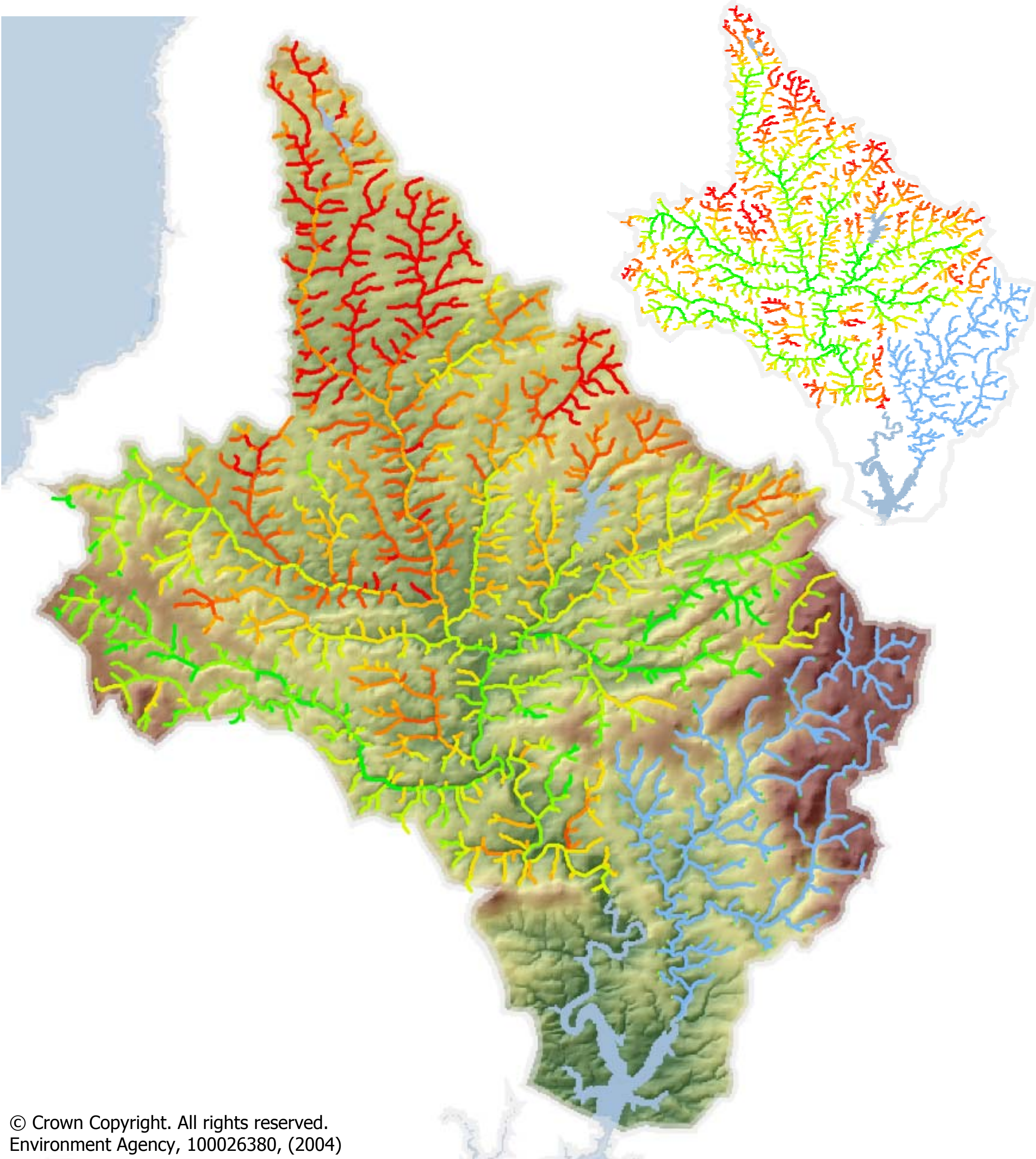


Figure 5.3 Estimated density of 0+ salmon on the River Tamar in 1999. Green denotes high densities (max. 76/100 m^2), and red denotes low densities (min. 0/100 m^2). Inset map shows estimation error (red is high, green is low).

Table 5.1 Density and population estimates for the ten sub-catchments of the Tamar.

Name	Density (/100m²)			Population (millions)		
	2.5	50.0	97.5	2.5	50.0	97.5
Carey	1.39	3.10	8.08	0.310	0.714	1.901
Deer and Claw	0.45	0.99	2.58	0.124	0.283	0.769
Inny	16.45	28.12	51.06	7.249	13.040	24.410
Kensey	1.60	3.67	9.34	0.185	0.439	1.107
Lew and Lyd	17.01	29.56	60.20	5.685	11.600	22.300
Ottery	3.01	5.59	12.61	1.193	2.258	4.769
Tamar (Lower)	6.00	11.57	24.15	3.870	7.700	15.700
Tamar (Middle)	0.77	1.64	3.52	0.217	0.433	0.914
Tamar (Upper)	0.24	0.49	1.23	0.065	0.140	0.296
Thrushel and Wolf	2.77	4.73	9.75	1.154	1.915	3.639

Table 5.2 Removal data and population estimates for the quantitative and semi-quantitative survey sites on the Inny sub-catchment.

Site name	Date	Removal data			Population estimate		
		c1	c2	c3	2.5	50.0	97.5
U/S Laneast Bridge	15-Aug-99	36	-	-	51	65	85
Kilabury	01-Sep-99	80	-	-	122	147	181
Trecarrell	20-Aug-99	154	52	39	259	271	287
Hicks Mill	13-Aug-99	20	-	-	28	37	52
Inny Foot	30-Jul-99	46	-	-	68	85	108
Trekenner Mill	30-Jul-99	50	-	-	74	92	117
Trewinnow	07-Aug-99	27	5	2	34	37	42
Knightsmill	22-Aug-99	63	-	-	95	116	145
St Clether	12-Aug-99	124	43	16	189	198	210
Treguddick	21-Aug-99	251	120	53	452	469	493
Trewen	16-Aug-99	64	22	6	94	100	108
Bealsmill	29-Jul-99	161	84	28	288	300	317
Tresmaine	19-Aug-99	15	-	-	19	27	40
Trekennick	13-Aug-99	21	-	-	28	38	52
Bowithick	10-Aug-99	17	1	2	20	22	26
Finches Bridge	14-Aug-99	132	50	22	213	222	236
Trerithick	15-Aug-99	31	-	-	44	57	75

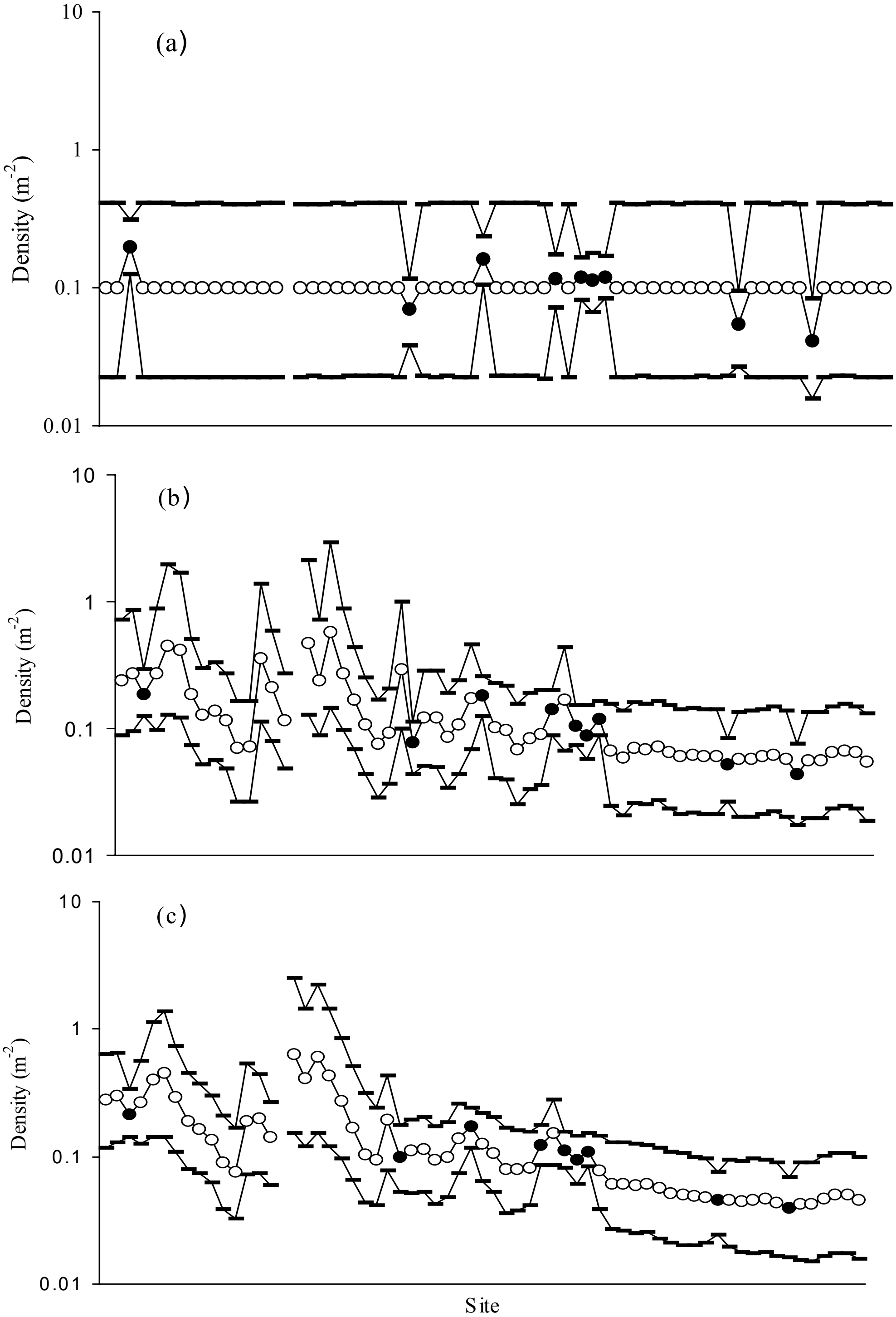


Figure 5.4 Estimated density of 1+ trout on the Nant-y-Goron using three models (see text for details). Closed circles denote surveyed sites, and open circles denote unsurveyed sites. Horizontal lines give upper and lower 95% confidence intervals.

6 Objective 5. To develop a map and field-based model for salmonid habitat quality

6.1 Introduction

The RFHI models include a field-based sub-model that will provide a more detailed picture of habitat quality in situations where appropriate field data are available (see also Section 7).

6.2 Methods

The RFHI field-based sub-model used the same non-linear modelling approach used for the map-based sub-model (Section 2.2), and was calibrated on the same national database of pristine reference sites. The addition of a field-based sub-model to the map-based carrying capacity model (*Figure 2.5b*) is shown in *Figure 6.1*. A number of different models were developed during the course of this project, and results are presented here for a simple model involving just wetted width and substrate type (percent cobbles).

6.3 Results

A simple field-based model for 0+ salmon based on wetted width and percent coverage of cobbles is shown in *Figure 6.2*. These variables need to be interpreted in relation to the map-based model described in Section 2.2, and so the influence of width is relative to a fixed catchment area upstream. The results show that 0+ salmon are most abundant in wide, riffle sites with a high percentage of cobbles, and less abundant in relatively narrow sites with few cobbles. Very similar results were obtained for >0+ salmon. For 0+ salmon, the addition of field-based variables does not improve the fit of the model by very much (from 66% to 68%).

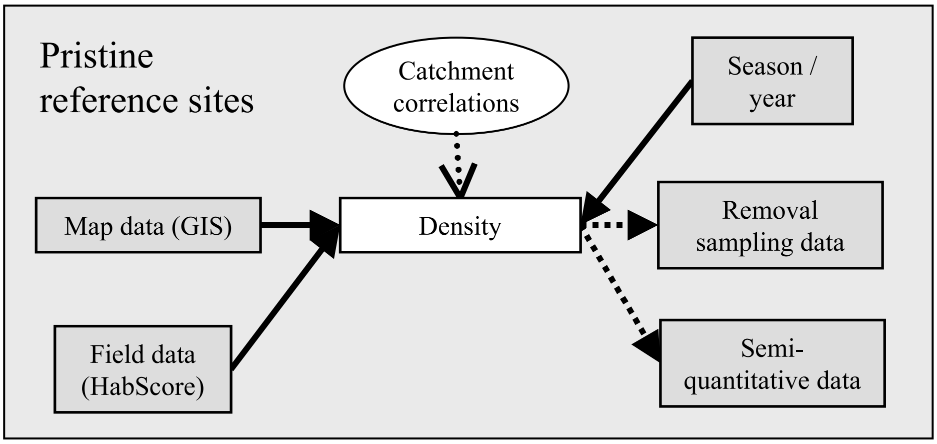


Figure 6.1 Structure of map- and field-based model for salmonid habitat quality.

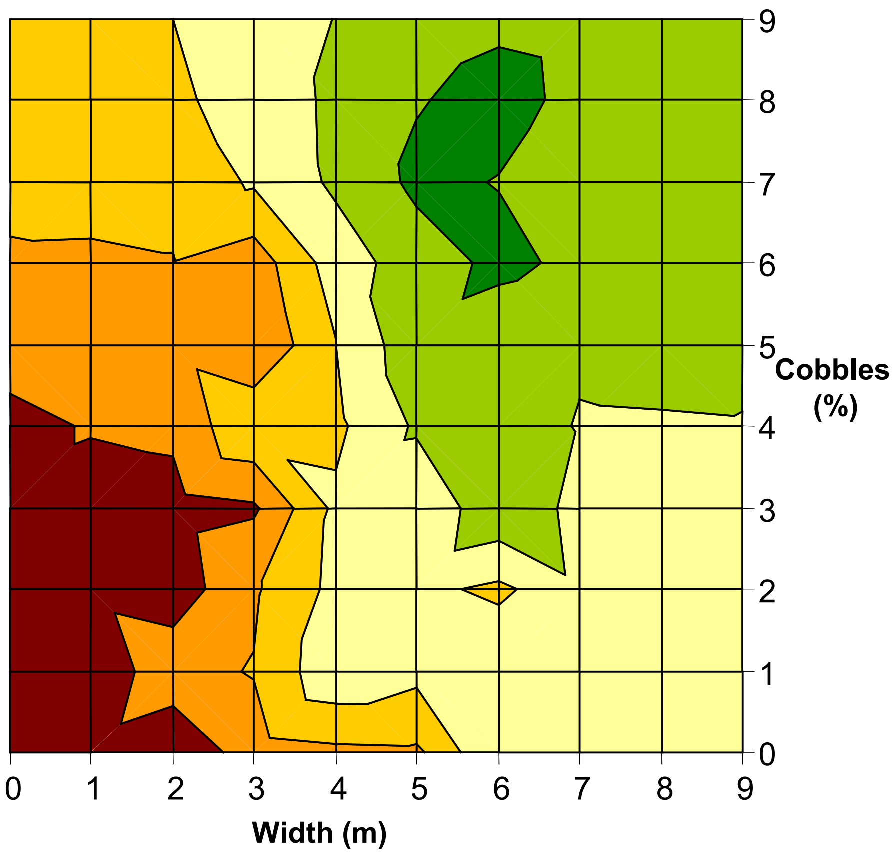


Figure 6.2 Relative abundance of 0+ salmon in relation to width and percent cobbles (green, high; red, low).

7 Objective 6. To Assess variables, precision and design of field-based surveys

7.1 Introduction

A number of techniques are used by the Environment Agency to collect basic habitat information at survey sites throughout a catchment, including HabScore, River Habitat Survey (Environment Agency, 1996) and RIVPACS (Wright *et al*., 1994). These techniques differ in terms of the location of sites and the precision with which habitat is measured. The original work plan for Objective 6 was to build on the Phase I work and undertake a comparative assessment of alternative field measurement systems, with a view to 'recommending [an] appropriate methodology'. However, a more powerful and flexible approach has been adopted, in which habitat models can be based on data collected from a diverse range of methodologies (Section 7.2) and extrapolated to sites that have not been surveyed (Section 7.3).

7.2 Habitat sampling model

Although habitat models relate fish populations to habitat, neither fish populations nor habitat can be sampled without measurement error. As described above, to overcome the problem of using different fish sampling techniques, a fish sampling model was developed to integrate data that are derived from different techniques characterised by different levels of sampling error (*Figure 2.5b*). The same approach was also adopted for habitat measurement, with the true but unknown field-based habitat being linked to field data from a range of techniques using a habitat-sampling model (*Figure 7.1*).

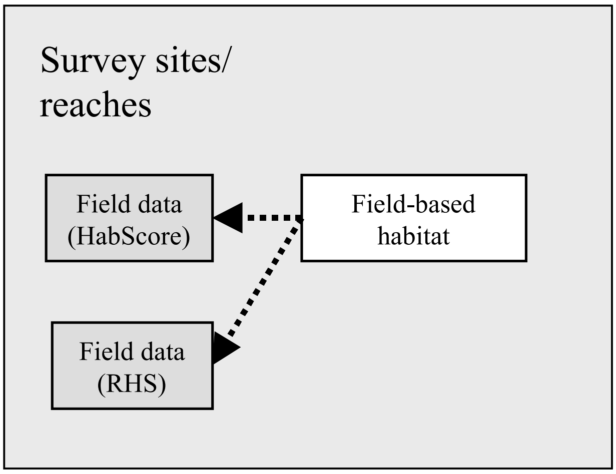


Figure 7.1 Habitat sampling model linking true (unknown) habitat to field data from different sources.

For example, RHS records the number of transects at which cobbles were dominant within a 500 m reach. A probabilistic model was constructed to relate the overall percentage of cobbles in the reach to the number of transects at which cobbles were recorded as 'dominant' (*Figure 7.2*). If the true percentage of cobbles is below 20%, some other substrate type is more likely to be dominant. Conversely, if the true percentage of cobbles is over 50%, cobbles are likely to be recorded as dominant. The RHS system is therefore particularly sensitive to changes in the percentage of cobbles in the range 20-50%.

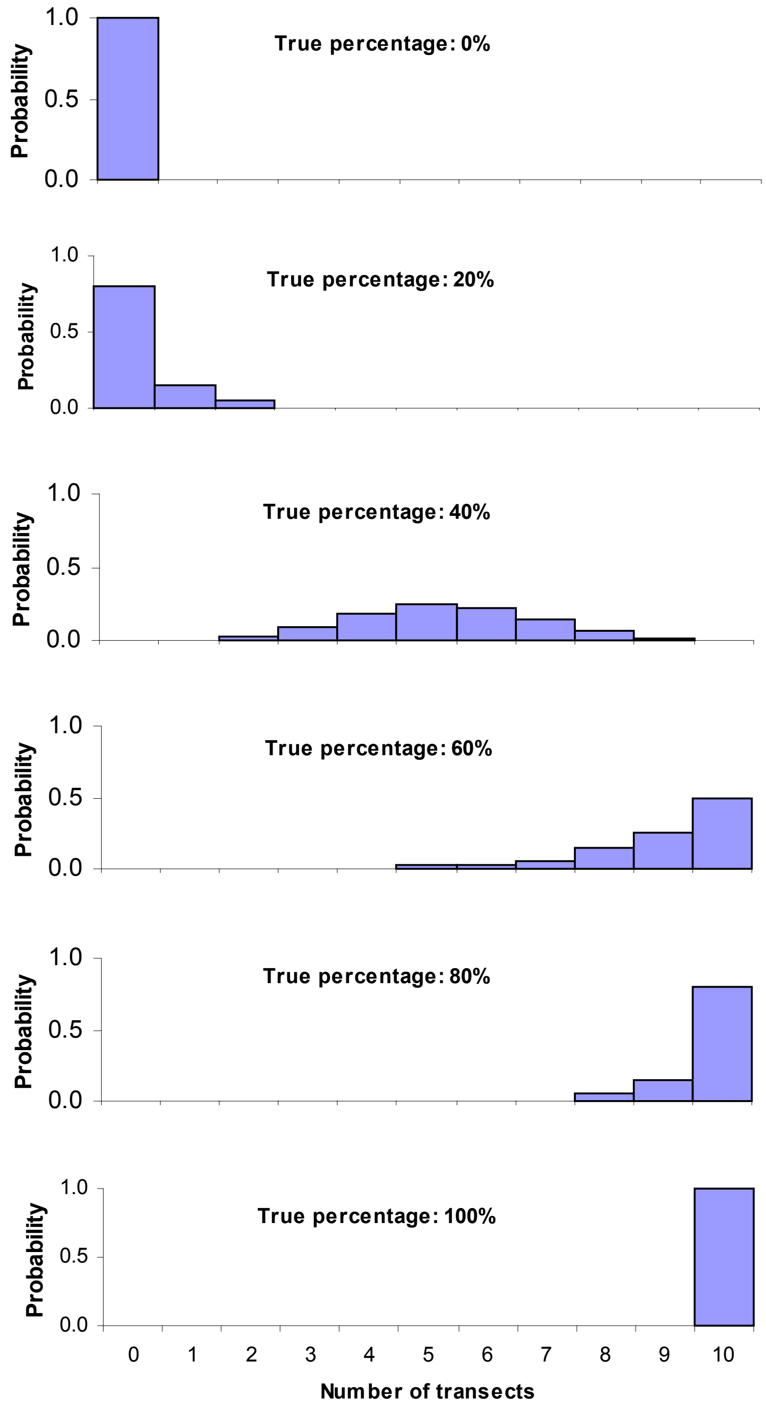


Figure 7.2 Probabilistic model that relates the true percentage of cobbles to the probability of recording cobbles as 'dominant' at an RHS transect.

7.3 Habitat extrapolation model

Map-based variables, such as altitude or upstream catchment area, can be derived for every point on the river network using a GIS (Section 3.2). However, field-based measurements obtained from habitat surveys are only available for a finite number of sites. For the construction of a habitat inventory, it is necessary to summarise field-based habitat data at a reach or catchment scale. At its simplest, this would involve averaging the habitat information measured at the sampling sites. However, a better option is to extrapolate the habitat data from the sampled sites to the unsampled sites. This was achieved by combining an extrapolation model similar to that used for widths (Section 4.2, *Figure 4.1*) with the habitat measurement error model (Section 7.2, *Figure 7.1*), and is shown in *Figure 7.3*. The underlying variation in the average abundance of cobbles on the Tamar and Tavy, estimated from the habitat extrapolation model, is shown in *Figure 7.4* and illustrates that cobble-dominated substrates are generally scarcer in the northern tributaries.

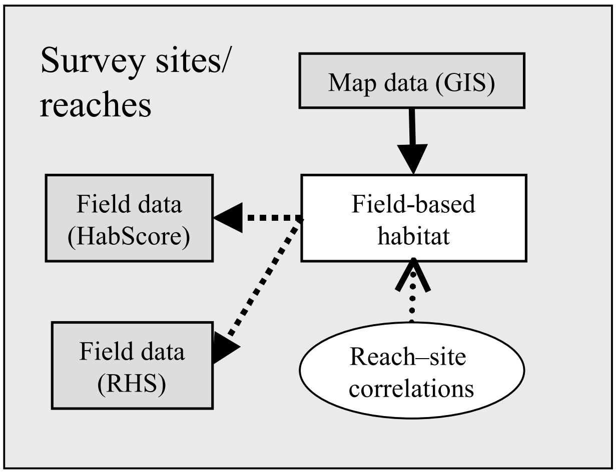


Figure 7.3 Combination of habitat sampling model with habitat extrapolation model.

7.4 Conclusion

The inclusion of a habitat-sampling sub-model in the RFHI allows the assessment of habitat on a catchment scale from a range of field methodologies, and takes into account the varying degrees of measurement error associated with habitat recording. Furthermore, the inclusion of a habitat extrapolation sub-model in the RFHI also allows habitat quality to be summarised at any spatial scale.

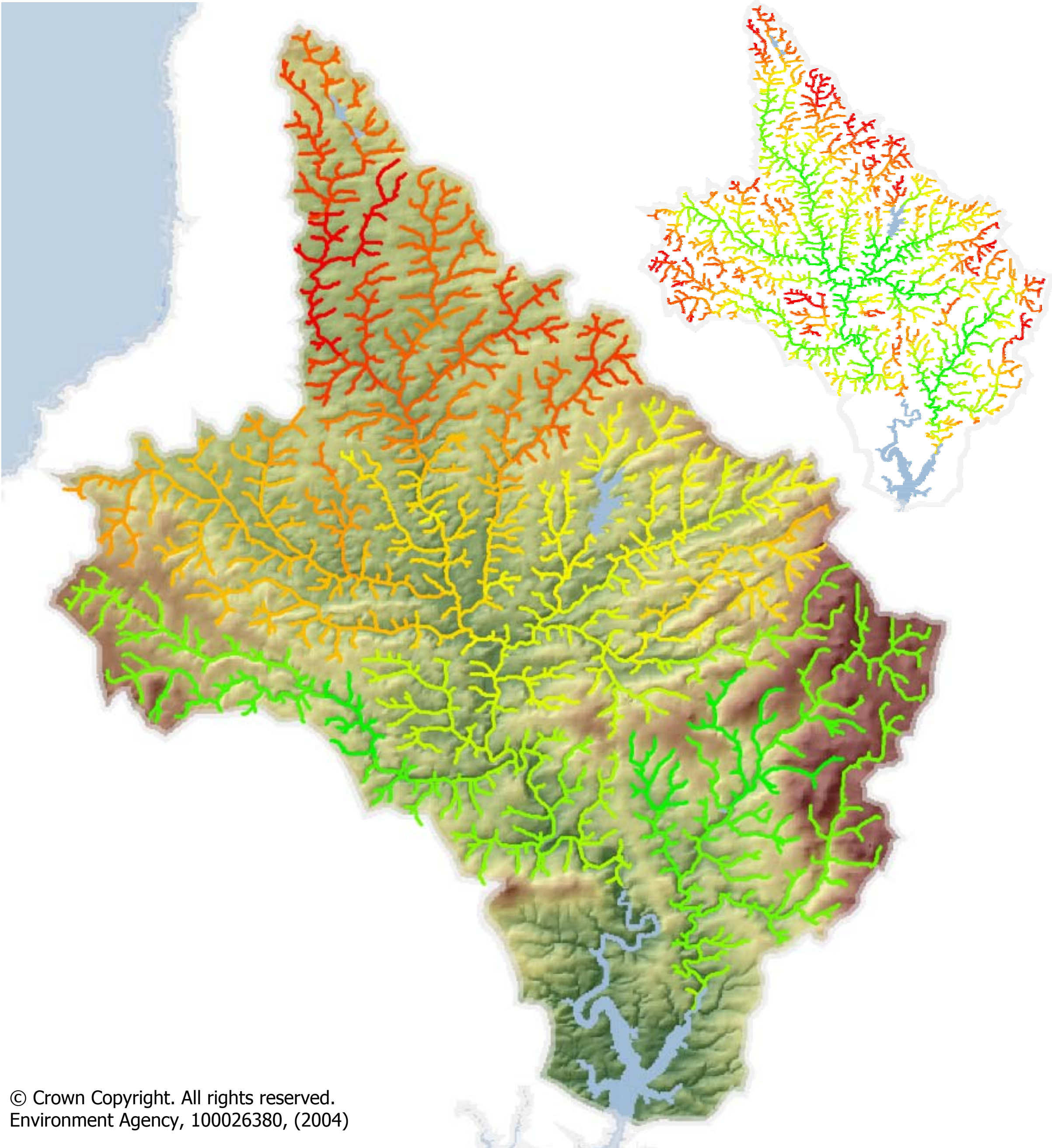


Figure 7.4 Variation in the average percentage of cobbles in the Tamar and Tavy catchments. Green denotes a high percentage (max. 40%), and red denotes a low percentage (min. 26%). Inset map shows estimation error (red is high, SD = 3.5%; green is low, SD = 1.5%).

8 Objective 7. To apply the map- and field-based model to test catchments

8.1 Methods

The map- and field-based models (Section 6, *Figure 6.1*) were applied to river networks using the extrapolated widths (Section 4, *Figure 4.1*) and other extrapolated field measurements (Section 7.3, *Figure 7.3*). The estimated habitat quality (RSAD) from this model (*Figure 8.1*) was combined with the estimated densities (Section 5, *Figure 5.1*) to estimate the degree of habitat utilisation (*Figure 8.2*).

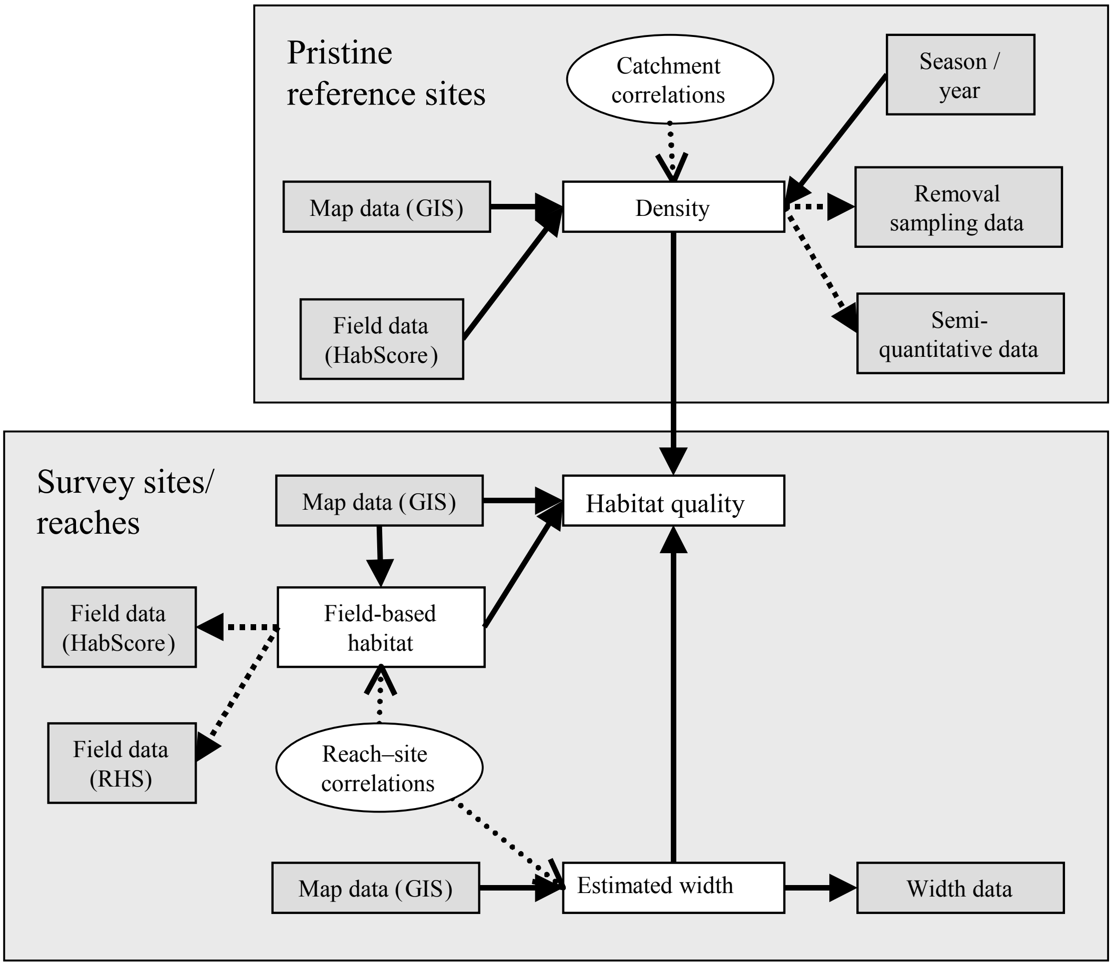


Figure 8.1 Application of map- and field-based habitat quality model.

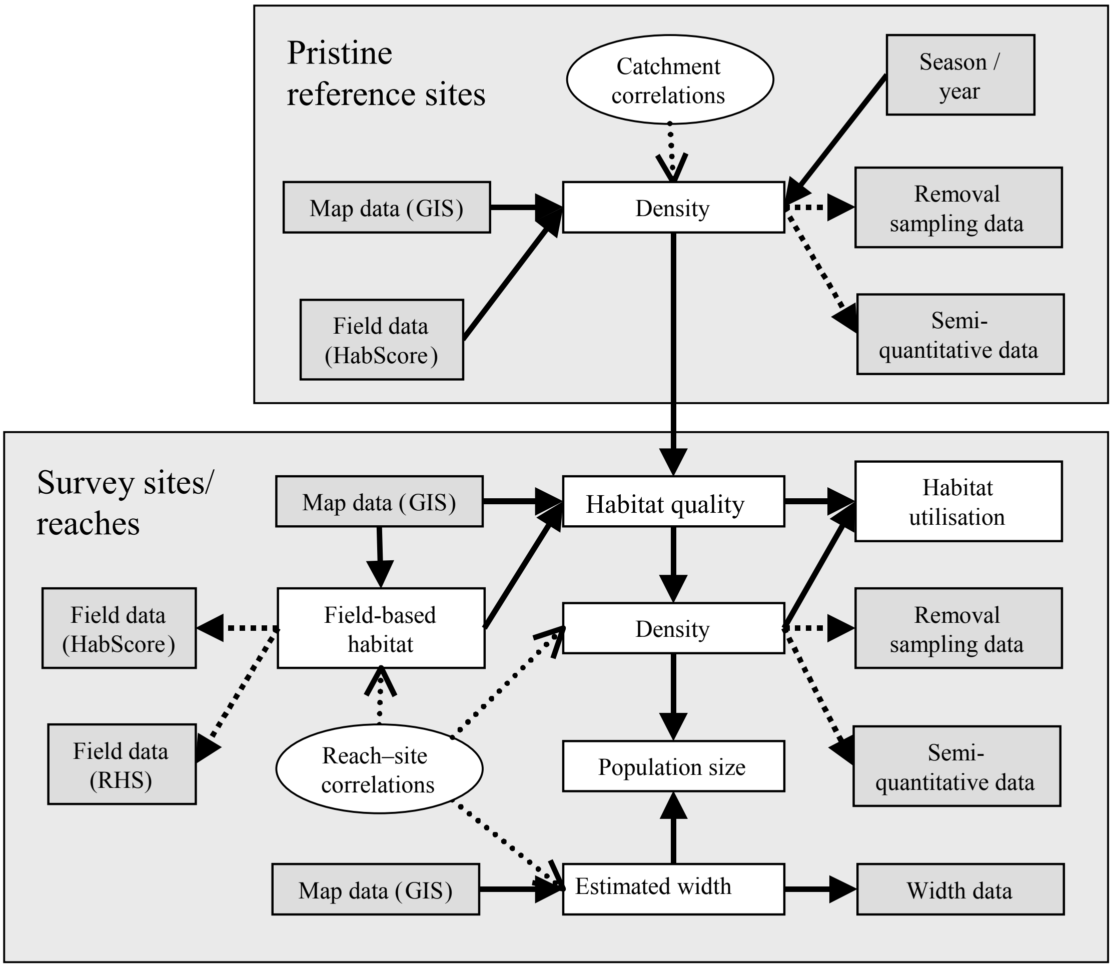


Figure 8.2 Calculation of habitat utilisation.

8.2 Results

The overall 0+ salmon habitat quality (map plus field) for the Rivers Tamar and Tavy, assessed from a combination of RHS and fish survey sites, is shown in *Figure 8.3*. This map- and field-based model gives a slightly modified picture of habitat quality, compared to the map-based model (*Figure 3.2*).

While the substrate (percent cobbles) is less suitable in the northern tributaries (*Figure 7.4*), this is not sufficient to explain the lower densities of 0+ salmon in these tributaries (*Figure 5.3*). The map of habitat utilisation (*Figure 8.4*) therefore shows that densities are lower than expected in the northern tributaries, particularly in the larger streams where densities are low (*Figure 5.3*), but habitat quality is good (*Figure 8.3*).

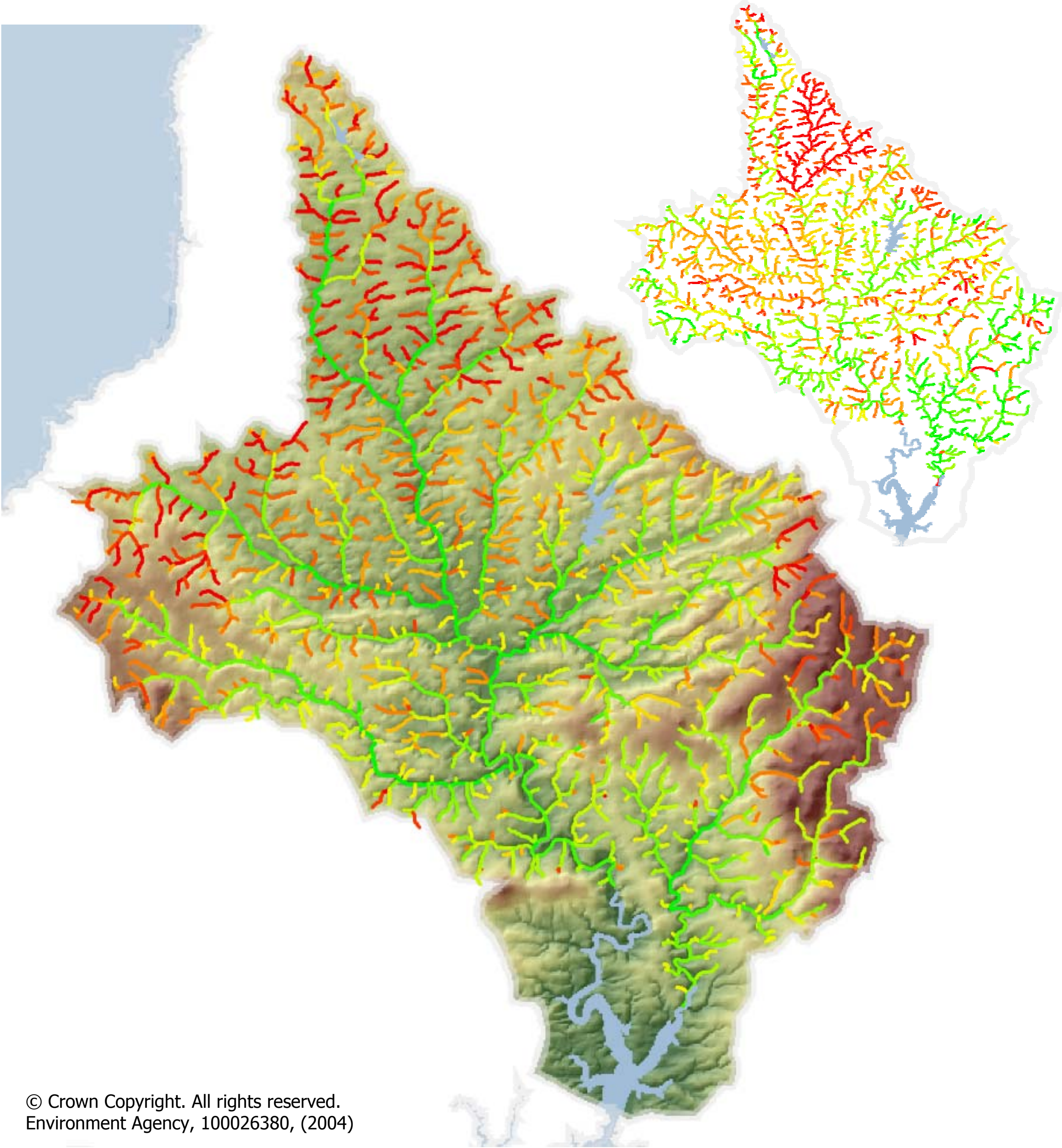


Figure 8.3 Map- and field-based habitat quality for 0+ salmon in the Rivers Tamar and Tavy. Green denotes high quality, and red denotes low quality. Inset map shows estimation error (red, high; green, low).

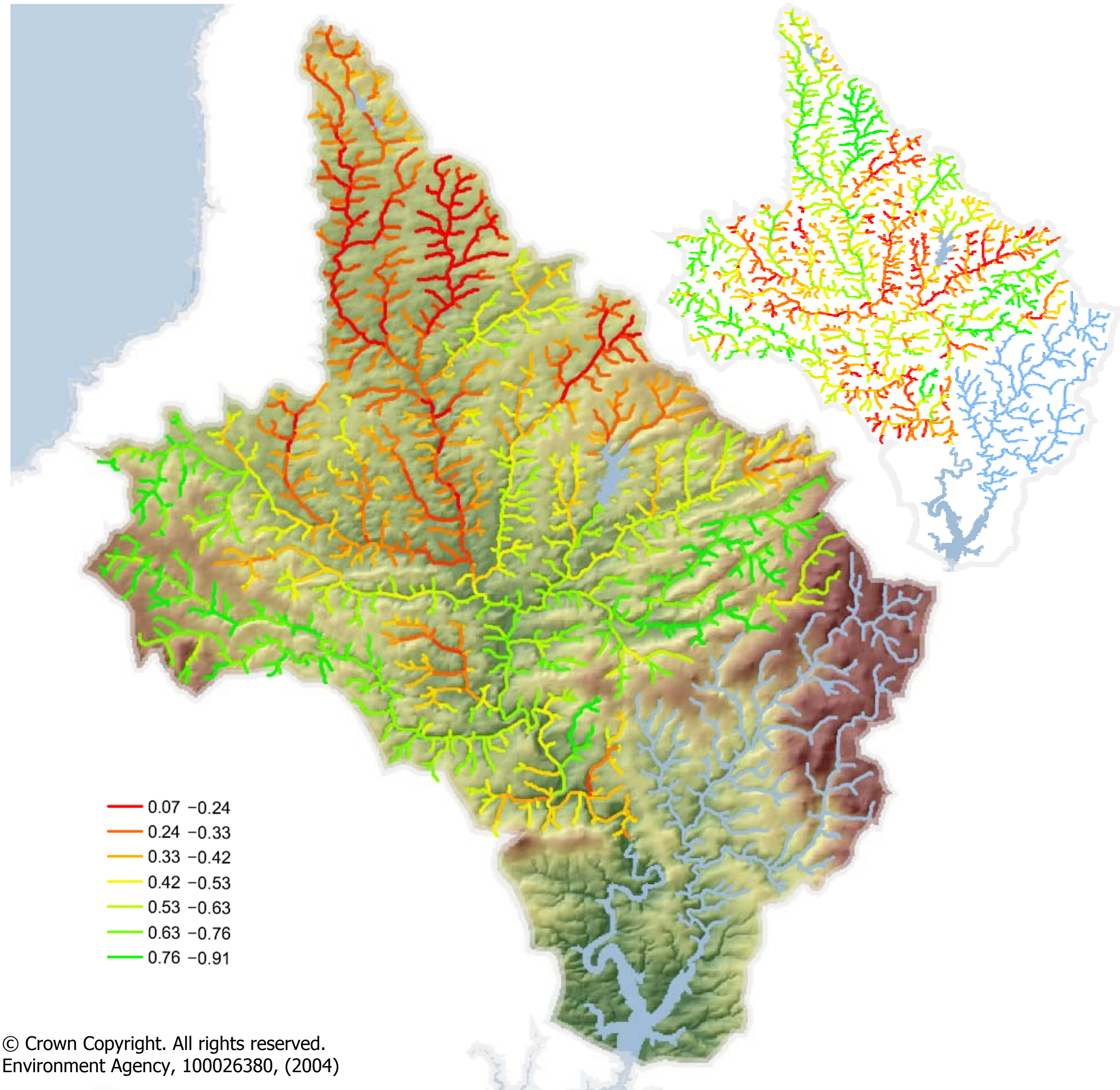


Figure 8.4 Probability that 0+ salmon densities were above the RSAD in 1999. Inset map shows estimation error (red, high; green, low).

8.3 Conclusions

The map- and field-based habitat model provides a technique that gives catchment-scale outputs comparable to the site-scale outputs of HabScore. Basic map- or field-based habitat information can be mapped, such as elevation (e.g., *Figure 3.2*) or the percentage of cobbles in the substrate (*Figure 7.4*). Habitat quality assessed from both map- and field-based data

(*Figure 8.3*) provides a catchment-scale equivalent to the HabScore HQS, and mapped fish densities (*Figure 5.3*) provide a catchment-scale equivalent to a site-specific population estimate. The comparison between observed fish densities and those expected from the habitat quality (*Figure 8.4*) provides a catchment-scale equivalent to the HabScore Habitat Utilisation Index (HUI).

The statistical modelling techniques used to develop the RFHI are more advanced than those used to develop the HabScore models ten years ago, which will be reflected in an improved performance and functionality of the models. However, the emphasis of the RFHI project has been on catchment-scale assessment, and therefore the field-based component of the models (Sections 6, 7 and 8) have been restricted to simple habitat variables (e.g., % cobbles) that can be interpolated from a range of habitat-recording methodologies on an extensive spatial scale. It would also be possible to utilise the RFHI modelling approach to develop site-specific models based on more detailed HabScore data (i.e., an updated HabScore model).

9 Objective 8. Recommendations for further work

9.1 Further reporting of the RFHI for salmonids

Before new methodologies are implemented and used to make management decisions, they need to be written up in detail and peer-reviewed. Some of the components of the RFHI for salmonids have already been reviewed such as the abundance model (Objective 4, Wyatt 2002; 2003) and the width model (Objective 3, Wyatt 2003). Priority should now be given to reporting the technical details of the habitat quality models (Objectives 1, 2, 5, 7).

9.2 Further development of the RFHI for salmonids

Phase II of the RFHI has succeeded in developing '*an integrated framework for the Agency Fish Classification Scheme (FCS), HabScore methodology, Salmon Lifecycle Model (SLM) and salmon Conservation Limit (CL) procedures*' (*Figure 8.2*). The abundance model (Objective 4) provides a habitat-stratified method to estimate abundance and operate the 'absolute' FCS at any spatial scale from quantitative or semi-quantitative surveys. The map-based habitat model (Objective 1) provides a more sophisticated basis for the 'relative' FCS, and in conjunction with the width model (Objective 3) enables the area and quality of habitat available to be estimated on a catchment scale, as required for salmon CLs and the SLM. The field-based habitat model (Objectives 5, 6 and 7) provides a catchment-scale equivalent to the HabScore HQS, and by comparison with density, provides a catchment-scale equivalent to the HabScore HUI.

While the overall structure and methods of the RFHI represent a substantial improvement compared to previous habitat methods, the models require further validation and re-calibration, in particular, initial model calibration has raised some issues over the choice of reference sites (*Section 2.3*). Furthermore, advances in the automation of map-based variable measurement from GIS (Coley, 2003), better coverage of habitat data from HabScore and RHS, longer time series of fish population data and better data storage with the National Fish Population Database (NFPD) all provide the potential for immediate improvements.

The development of the modelling procedures as part of this R&D project will make future model refinement a relatively straightforward exercise. It is recommended that ongoing model refinement and recalibration is undertaken as part of the National Fisheries Technical Programme (NFTT) work programme.

9.3 Implementation of the RFHI for salmonids

9.3.1 Hydrologic modelling of salmon rivers

One important requirement to implement the RFHI is the derivation of a hydrological model for each river catchment. As part of this R&D project, this was undertaken for relatively few catchments (Section 3.2). However, since the completion of the project, the Environment Agency has developed 'hydro-tools' for ArcGIS, which is being used to derive river networks for all catchments in England and Wales, which will greatly facilitate the implementation of the RFHI.

9.3.2 Conservation limits

One of the primary purposes of this project was to improve the salmon habitat inventory currently used to set salmon CLs. However, the new 1:50,000 inventory is incompatible with the original 1:250,000 smolt production estimates from the River Bush (Section 4.4). There are two options regarding the implementation of RFHI for setting CLs.

The first option would be to use the RFHI in the context of the Salmon Lifecycle Model (Wyatt and Davidson, 2003), and calculate alternative Biological Reference Points (BRPs) for salmon based on the prevailing conditions, river-specific data and local (English and Welsh) estimates of smolt production. The use of the Salmon Lifecycle Model and RFHI to estimate a range of BRPs is currently being investigated by the Phase III of the Salmon Lifecycle Model R&D project. When this is complete, the role of the RFHI and SLM in setting BRPs will be more clearly understood, and recommendations will be made for the quantitative management of freshwater salmon fisheries.

The second option would be to apply the 1:50,000 RFHI model to the River Bush to re-estimate smolt production rates. This would require purchasing GIS data for elevation and river networks for Northern Ireland, and re-modelling the annual stock-recruitment data for the River Bush. It is recommended that the need for re-modelling the River Bush be assessed once the Phase III of the Salmon Lifecycle Model is complete.

9.3.3 Availability of field data

The ease with which the RFHI can be implemented is very dependent upon the particular component that is required and on the desired application

(*Table 9.1*). An important factor is the data requirements, with many models requiring the collation of field data, such as annual electrofishing data (E), wetted widths (W) and field-based habitat survey data (H). The ease of implementation depends on the accessibility of these data in suitable electronic formats from the National Fish Population Database (NFPD) and River Habitat Survey (RHS) database.

Table 9.1 Data requirements for implementing the RFHI for salmonids.

Obj	Model	Typical outputs	Data* A	R	W	E	H
1	Habitat quality (map-based)	Description of habitat requirements (e.g., *Figures 2.1*, *2.3*)					
2	Habitat quality (map-based)	Catchment maps (e.g., *Figure 3.2*)	✓	✓			
3	Width	Areas by tributary (e.g. Table 4.1)		✓	✓		
2	Habitat quality (map-based)	River totals for Conservation Limits (e.g., *Table 4.2*)	✓	✓	✓		
4	Abundance	Catchment maps (e.g., *Figure 5.3*)	✓	✓		✓	
4	Abundance	Population estimates (e.g., *Table 5.1*)	✓	✓	✓	✓	
5	Habitat quality (map and field)	Description of habitat requirements (e.g., *Figure 6.2*)					
6	Field-based data	Maps of interpolated field data (e.g., *Figure 7.4*)		✓			✓
7	Habitat quality (map and field)	Catchment maps (e.g., *Figure 8.3*)	✓	✓	✓		✓
7	Habitat quality (map and field)	River totals for conservation limits (e.g., *Table 4.2*)	✓	✓	✓		✓

***Data required for implementation**
A Access to migratory salmonids
R GIS river network
W Catchment-specific widths
E Annual electrofishing data
H Field-based habitat data (e.g., RHS)

9.3.4 Requirement for statistical and GIS modelling skills

Implementation of models that utilise field data (W, E and H, *Table 9.1*) also requires a calibration exercise for each individual catchment, which necessitates the iterative process of model checking and adjustment. The inclusion of between-reach or between-site correlations to help interpolate field data also means that these models can only be implemented within statistical modelling software rather than directly within a GIS. The implications of this are that much of the RFHI will have to be provided as a service by the statistics and GIS staff in the NFTT, rather than being offered as a product for use by Area fisheries staff.

9.4 Priorities for further salmonid work

The immediate priorities for the salmonid RFHI are:

1. Complete technical write-up for peer review (*Section 9.1*)
2. Re-evaluate database of reference sites and recalibrate national *model (Section 9.2*)
3. Complete hydrologic modelling of all major salmon rivers (*Section 9.3.1*)
4. Complete the Salmon Lifecycle Model Phase III R&D, and assess role of RFHI in setting salmon BRPs (*Section 9.3.2*).
5. Dependent on 4 above, re-model stock-recruitment data for River Bush if necessary, and plan for the use of revised BPRs for salmon management (*Section 9.3.2*).
6. Dependent on the development of the National Fish Population Database (NFPD) and data availability, consider the feasibility of RFHI for impact assessments and the national reporting of juvenile salmonid populations (*Section 9.3.3*).

9.5 Development of a RFHI for coarse fish

While Phase II of the RFHI R&D project concentrated on juvenile salmonid populations, many of the issues addressed are generic issues that face both salmonid and coarse fish habitat assessment. These include to:

- model complex habitat-fish relationships (Section 2.2, Section 6);
- model geographical trends (Section 2.3);
- integrate spatial and temporal factors (Section 2.4);
- allow for the diversity of fish sampling procedures (Section 2.5);
- describe model outputs in probabilistic terms (Section 2.6);
- model river networks (Section 3);
- derive map-based variables from GIS (Section 3);
- estimate rivers widths and areas of habitat (Section 4);

- assess catchment-scale patterns in fish abundance (Section 5);
- allow for habitat measurement errors (Section 7.2);
- extrapolate field-based habitat data (Section 7.3);
- compare observed populations to reference conditions (Section 8).

The modelling methods developed for salmonids could be applied directly to coarse fish data. However, a number of issues may encourage a somewhat different approach for coarse fish:

- The dominance and persistence of particular year classes in some coarse fish species places greater emphasis on the need for a time series of data rather than on data from a single year.
- The numbers of different coarse fish species in many rivers may favour the inclusion of between-species interactions in an integrated fish community model, rather than the use of several single-species models.
- Spatial and temporal variability in coarse fish recruitment, survival and growth may make these parameters more suitable than absolute abundance for assessing the influence of habitat.

It is recommended that the development of a habitat inventory for coarse fish (RFHI Phase III) adopts two complementary approaches.

The first approach would be to develop a National multi-species version of the RFHI II model using time-series of density or biomass data from the National Fish Population Database (NFPD). This would include data from a diversity of sites from England and Wales. This would address the first two issues above.

To address the third issue requires estimating recruitment, survival and growth. Phase II of the R&D project 'Factors Affecting the Recruitment of Riverine Coarse Fish' (FARRCoF) has recently developed new reliable methods to estimate coarse fish recruitment, survival and growth from routine monitoring data (Wyatt et al 2005). So far, the method has been applied to single species and only considered temporal factors that affect coarse fish recruitment, such as temperature, flow and spawner abundance. It would be possible to integrate the spatial methods for salmonids described in this report (RFHI Phase II) with a multi-species version of the temporal (recruitment, survival, growth) methods developed for coarse fish (Wyatt et al 2005). However, there is likely to be limited availability of numbers-at-age data required for this approach, which could only be applied to selected case study catchments.

The work programme for coarse fish is outlined below. The first two tasks will be an iterative process of matching analysis methods to the data available within the time-scale of the project. The detail for the rest of the project can only be confirmed when this is complete. The work programme is:

1. assess fish population data availability, and select species;
2. develop and refine RFHI II and FARRCoF III methodologies to model spatial patterns in coarse fish;

3. select a short-list of habitat variables from the literature and/or expert opinion;
4. collate habitat data from (a) GIS river networks (e.g., gradient) and (b) RHS (e.g., substrate types);
5. analyse data using RFHI II and FARRCoF III methodologies to establish habitat–species, species–species and geographical relationships;
6. apply the method to selected case-study catchments (e.g., Nidd and Stour) (National density model only);
7. produce an R&D report and peer-review paper.

10 References

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