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Modelling habitat requirements of coarse fish in lowland rivers

The University of Hull
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MODELLING HABITAT REQUIREMENTS OF COARSE FISH IN LOWLAND RIVERS

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Foreword

Fisheries science and the methods available to fisheries managers are currently undergoing a rapid evolution. This is generated by an improvement in our understanding of fisheries ecology and environmental impact, an increase in the quantity and accessibility of environmental data, and the development of more sophisticated and computer-intensive methods.

If coarse fisheries are to be effectively managed, it is necessary to understand the factors affecting the distribution and abundance of fish populations, and to assess the likely consequences of different management activities. Habitat modelling techniques are becoming increasingly utilized by the salmonid fishery manager to assist with decision-making: for coarse fish, however, progress has been slower. There are a number of possible reasons for this including relatively less research into their ecology, increased difficulties with sampling lowland populations and the more complex dynamics of multi-species communities where populations are often dominated by the influence of stochastic factors.

In this report, a number of contrasting approaches to modelling the relationships between coarse fish populations and environmental factors are illustrated. These fall into three broad areas: theoretical single-species models, empirical multivariate models and ecological indices. Each approach has advantages and disadvantages, and the descriptions within this report should be taken as an outline of the possible ways forward for the NRA.

The single species models illustrated in this report are Habitat Suitability Index (HSI) models. These assess the carrying capacity of a site for a single species by identifying one limiting environmental factor. As such it is an oversimplification since in real systems environmental variables are correlated, their impacts on a fish species interact and the abundance of fish species at any moment at a site will also be determined by stochastic influences and biotic factors.

Three types of multivariate technique are illustrated. Canonical Correspondence Analysis (CCA) can be used to summarize and graphically illustrate the relationships within and between the environmental and fishery variables. The simultaneous analysis of environmental and fishery data can create interpretational problems, and any resulting tool may not be particularly transparent. Two-Way Indicator Species Analysis (TWINSPAN) is a method for grouping together fishery sites that have similar species compositions. As with many classification techniques, it will generate discrete classes regardless of whether this represents the true underlying structure of the data. Discriminant Function Analysis (DFA) can then be used to develop classification rules based on environmental data that will predict the TWINSPAN class. The combination of TWINSPAN and DFA therefore forms the basis of a system that will predict the likely species community class from environment data, in a similar manner to the application of RIVPACS to benthic macroinvertebrate data.

The ecological index illustrated in the report is the Abundance/Biomass Comparison (ABC) Method, which provides an index of ecosystem disturbance based on the biomass and the abundance of species present. It was developed primarily for marine macrobenthic communities, which respond to disturbance by shifting from species with high individual weights and low abundance, towards species with low individual weights and high abundance. The presence of strong year classes and the variable life history strategies within some coarse fish species create interpretational difficulty with such an approach.

This report provides an illustration of a few of the common modelling techniques that could be used to describe the relationship between environmental factors and the distribution and abundance of coarse fish. There are many unresolved problems with some of these techniques and these are discussed in the report. Problems include realism of the models, appropriateness of assumptions and interpretational problems. In addition, problems with data quality and quantity are discussed.

There is still a long way to go from the types of modelling exercises illustrated here to a robust management tool that could be used to assist the fisheries manager. Primary issues include the manner in which the considerable variability inherent in lowland fisheries is addressed, and the validation of the models in the context of their proposed application. This report should therefore be viewed in this context and act as an excellent starting point for future debate and research in this area.

ACKNOWLEDGEMENTS

The project team are extremely grateful to the many people who assisted in the implementation of this project. In particular, they wish to thank all NRA Fisheries staff who provided the data on which the project is based, for their useful discussions about problems affecting coarse fish in lowland rivers, and in guiding the project team towards the most appropriate information.

1 INTRODUCTION

For the purposes of integrated river and fisheries management it is vital to understand the critical factors which affect the distribution and abundance of coarse fish species in lowland rivers. Consequently, mechanisms for determining the specific habitat and environmental needs of coarse fish species living in rivers are required. To meet this requirement, computer models, which correlate environmental and fisheries data have been developed. The project team adapted two fisheries community modelling techniques to meet the specific needs of this study. The approaches were:

- ❑ Habitat suitability Index (HSI) models;
- ❑ Multivariate statistical methods (CANOCO, TWINSPAN & DISCRIMINANT).

Impinging upon these factors are anthropogenic activities through river engineering, pollution and river management activities. To show the impact of human activities on coarse fish stocks the project team have adapted the Abundance/Biomass Comparison (ABC) technique (Warwick 1986).

2. HABITAT SUITABILITY INDEX MODELS

2.1. Introduction

Habitat Suitability Index (HSI) models are an integrated part of the Habitat Evaluation Procedure (HEP) developed in the United States by the Fish and Wildlife Service (Anon. 1980a,b,c). In this approach it is assumed that the carrying capacity of a system for a species is linearly related to the quantity and suitability of the habitat. The abundance of a habitat fluctuates less than the abundance of a species and therefore provides a better estimate of the conservation value of a system.

The HSI can be defined as a numerical index that represents the capacity of a given habitat variable to support a selected species. The index is a ratio of an estimate of the habitat conditions in the study area and the optimum habitat conditions for a species. The mathematical expression of this relationship varies between 0 (unsuitable habitat with no potential for use by the species) and 1 (optimum habitat conditions). The relationship between the observed habitat conditions for a variable and the suitability index is usually given as a suitability index graph or histogram. A HSI model consists of a number of variables which define the habitat or at least have influence on the performance of a species. In a HSI model the suitability indices of all variables are combined using simple arithmetics, such as minimum functions or averages, to give an overall HSI value.

Model constructing can be split up in two phases.

- i Constructing models from information in relevant literature.
- ii Testing and adjusting of models using fisheries and habitat data.

To make a HSI model, an extensive literature review on the ecology of selected coarse fish species was carried out to determine important factors which influence the performance of these species (Cowx *et al.* 1993). This information is used to relate the performance, in terms of relative abundance in the community, density, biomass, growth and mortality, to habitat characteristics. Although the literature review focussed on the most extensive studies carried out in the UK, additional overseas studies were used where necessary. Models were constructed for roach (*Rutilus rutilus*), dace (*Leuciscus leuciscus*), chub (*Leuciscus cephalus*), bream (*Abramis brama*) and pike (*Esox lucius*). The preliminary models were tested using NRA fisheries and habitat data. In this report, details of the methods and procedures used to construct the HSI models are exemplified for roach. The HSI models for the other species are given as appendices (Appendix A-D).

2.2 Habitat Suitability Index Model

2.2.1 Model description

Roach habitat quality is represented by food, cover, water quality and reproduction components (Figure 2.1). The variables that are considered to be direct or indirect measures of the relative ability of a habitat to meet these requirements are included in the appropriate component. However, some variables can be placed in more than one components. In these cases the variables were placed in the component where they were considered to be the most important. Variables which were difficult to measure quantitatively, such as intra- and interspecific competition, were not included in the model.

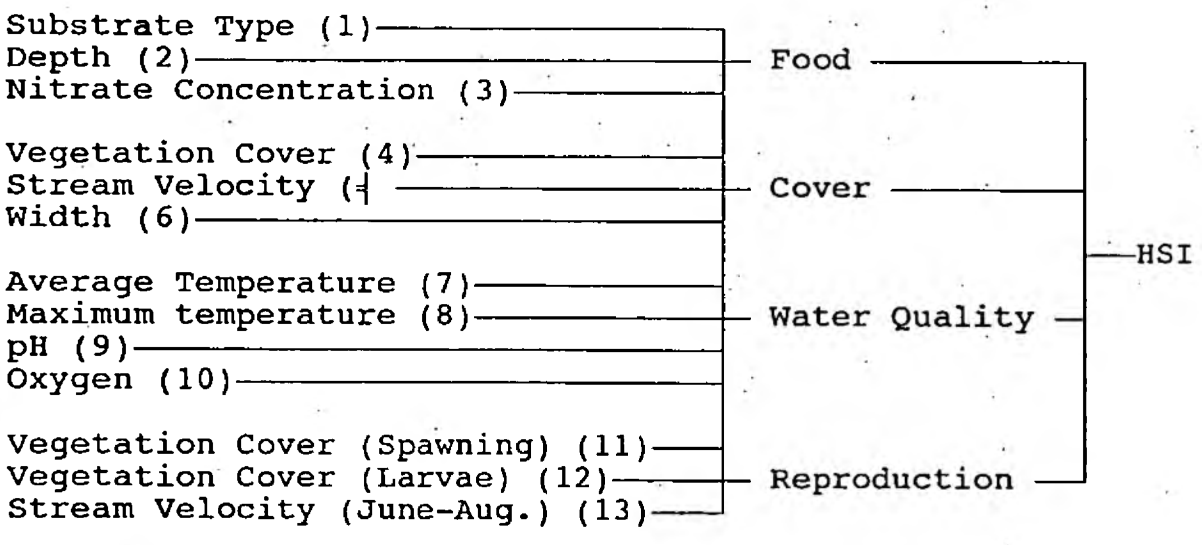

Figure 2.1. Tree diagram showing the relationships between variables, components and Habitat Suitability Index (HSI) for roach.

The performance of adult roach in the rivers selected from the literature review was assessed in terms of relative abundance in the fish community, density, biomass growth and mortality (Table 2.1). The performance was related to specific habitat attributes such as substrate type, vegetation cover, depth, width, nitrate concentration, temperature, pH and dissolved oxygen. Other studies were used to describe suitable spawning and juvenile areas.

Table 2.1. Performance of roach in selected rivers in the United Kingdom. L_{oo} = asymptotic length from von Bertelanffy growth model, (f) = female, m = (male), Z = total instantaneous mortality rate.

River	Site	Relative performance	density (m^{-2})	biomass (gm^{-2})	L_{oo} (cm)	Z (yr^{-1})	Source
Exe/Culm		abundant to 30-80% (nrs) in lowland reaches, low abundance in more upland reaches	0.4-0.5 (Culm)		24.1-37.0	0.257 (Exe) 0.204 (Culm)	Cowx 1980 Cowx 1988
Nene	1	26% (nrs)	0.013-0.16	1.7	29.4	0.31	Hart 1971
	2	80% (nrs)	0.1	49.5	27.3	0.42	Hart & Pitcher 1973
Willow Brook		highly dominant in some places, other main species dace, chub, perch, pike.			35.8 (f) 27.8 (m)		Cragg Hine 1964 Cragg Hine & Jones 1969
Thames		44 % (nrs), co-dominant with bleak	1.0	19.2		0.2-1.4	Williams 1965 Williams 1967
Mole		commonest,with gudgeon small numbers of dace and chub	0.4-4.2 0.4-1.7				
Stour		frequent not dominant			37.0 (f) 24.0 (m)		Mann 1973
Frome		frequent not dominant			43.0 (f) 40.0 (m)		Mann 1973
Lugg		least abundant cyprinid			31.0 (f) 24.0 (m)		Hellaweli 1972

V1 Substrate

A high abundance of roach is found in rivers with a substrate consisting of clay or silt (Table 2.2). Roach often predominate in reaches with such a substrate (Cragg-Hine, 1964; Cragg-Hine & Jones, 1969; Hart, 71; Barnabas, 1973; Hart & Pitcher, 1973; Cowx, 1980; 1988). In stretches where the substrate changes to gravel, boulders and cobbles, roach can still be present, but not dominant (Hellawell, 1972; Cowx, 1980).

Table 2.2. Substrate type of selected rivers.

River	Substrate description
Dee [1]	depositing substrate, roach abundant
Exe [2]	roach tend to be dominant in stretches with a silty substrate but are also present in low numbers in stretches with cobble and gravel
Nene [3]	roach dominate in reaches with silt and gravel
Willow Brook [4]	gravelly riffles and deeper silted sections
Lugg [5]	mainly gravel and boulders

1) Barnabas, 1973; 2) Cowx, 1988; 3) Hart & Pitcher, 1973;
4) Cragg-Hine & Jones, 1969; 5) Hellawell, 1972.

Figure 2.2a describes the habitat requirements of roach in terms of substrate preference, as a suitability index graph. Substrate conditions are optimum when the bed consists mainly of fine sediments. The suitability decreases gradually as particle size of bed material increases.

V2 % Vegetation Cover

Macrophytes are important for roach because they provide shelter from high water velocities and predation, and are also an important food item. In slow flowing rivers, with poor weed growth such as the Thames (Williams, 1967) and Dee (Barnabas, 1973), roach can be present in high numbers (Table 2.3). In faster flowing rivers roach can be found in the lowland reaches where macrophytes such as *Myriophyllum*, *Elodea* and *Potamogeton* are also more pronounced (Cragg Hine, 1964; Cowx, 1980). In more upstream reaches where the vegetation cover mainly consists of *Ranunculus*, roach are rarely abundant (Hellawell, 1972; Cowx, 1980). Extensive reed beds such as in the Stour (Mann, 1973) and the Mole (Stott, 1967) also provide cover for roach. However, a very high vegetation cover limits mobility and feeding efficiency of large roach.

Optimum habitat conditions are present when the vegetation cover is between 10 and 40% surface cover (Figure 2.2b). At less than 10% vegetation cover the suitability slowly decreases. At > 40% vegetation cover the suitability also decreases due to constraints in mobility and feeding efficiency of large roach.

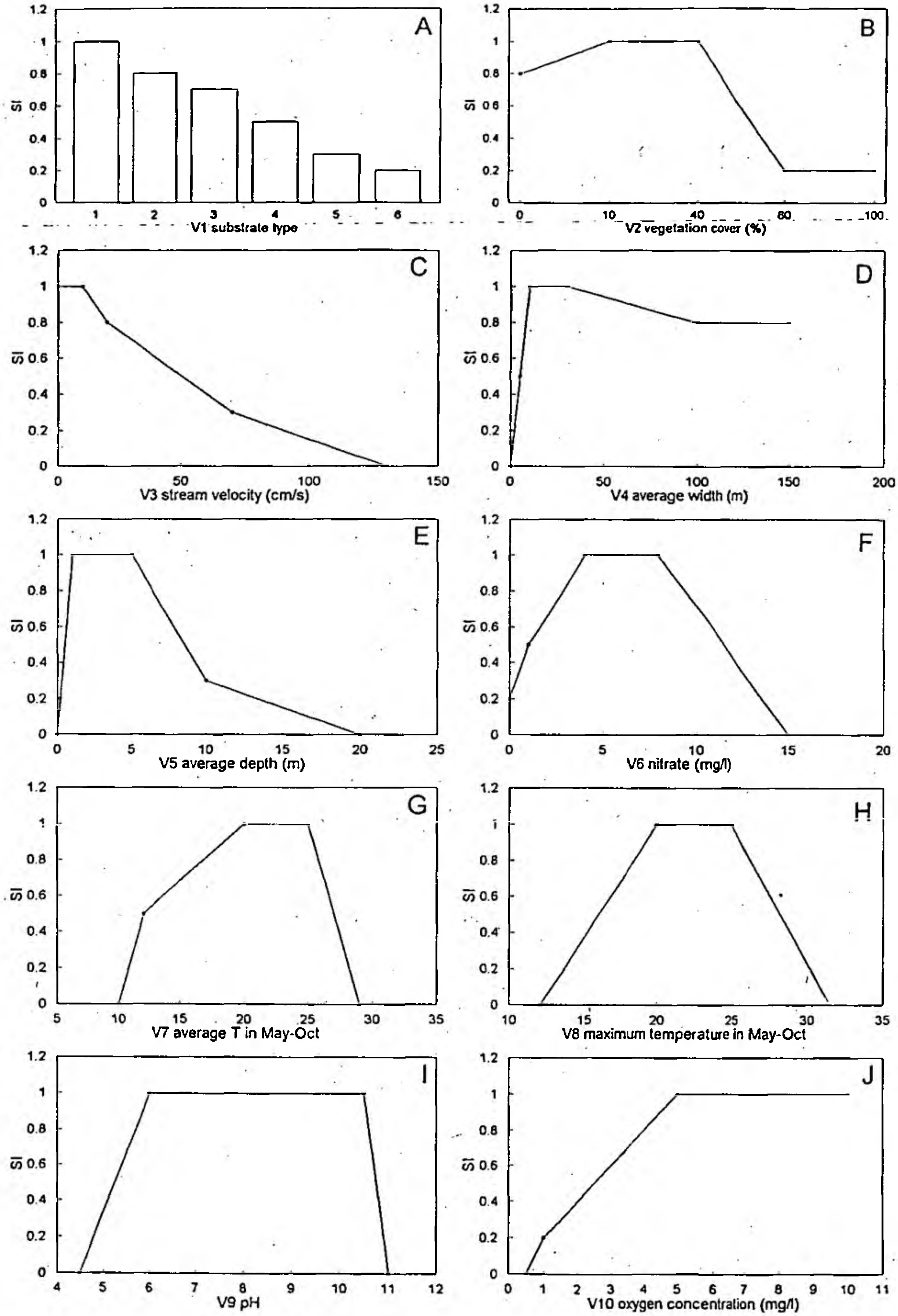

Figure 2.2. Suitability Index graphs for roach. See Figure 2.3 for explanation of A, K and L. All variables are assumed averages in the growing season (1 April- 31 October) unless noted.

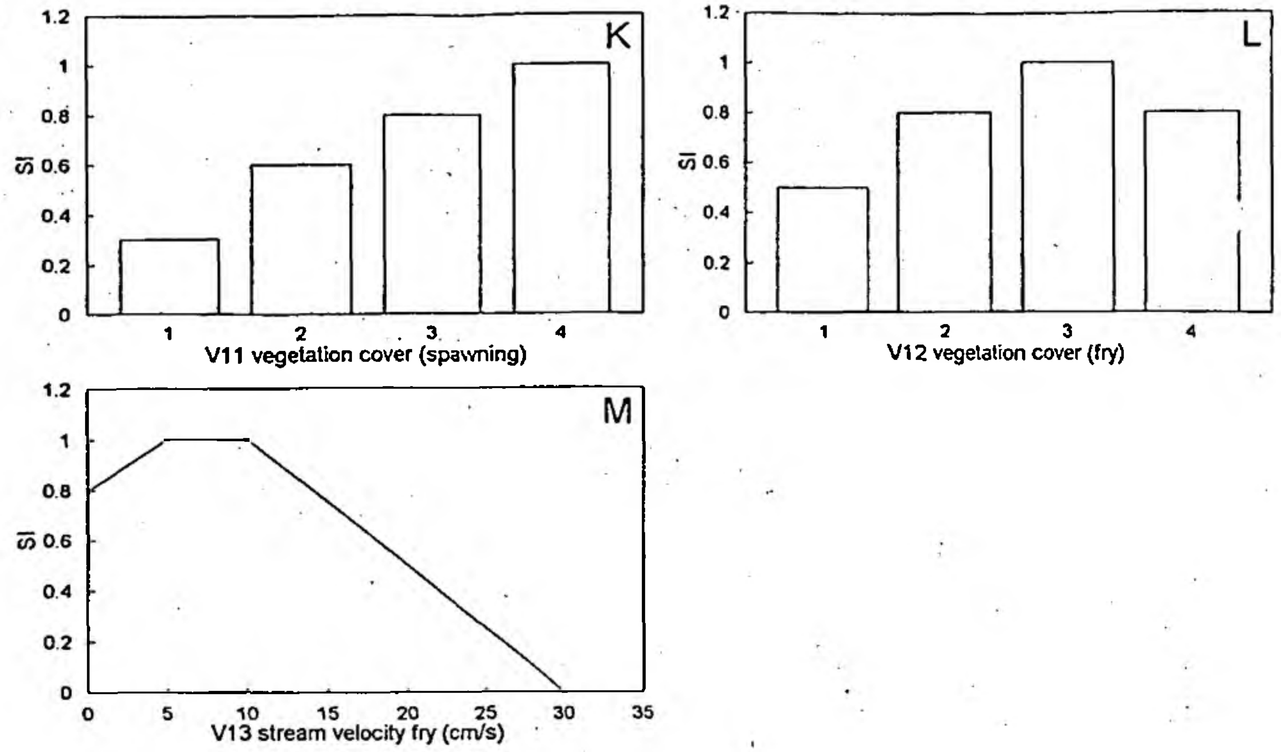

Figure 2.2 (continued). Suitability Index graphs for roach. See Figure 2.3 for explanation of A, K and L. All variables are assumed averages in the growing season (1 April- 31 October) unless noted.

Table 2.3. Vegetation Cover in selected rivers.

River	Vegetation Cover
Exe/Culm [1]	upstream reaches Ranunculus, downstream *Elodea, Potamogeton* and *Myriophyllum*. Margins covered with *Glyceria* and *Iris* or riparian vegetation of Willow and Alder.
Nene [2]	in September- October the vegetation covers 10% of the surface.
Willow Brook [3]	in fast flowing reaches *Ranunculus* in slower flowing reaches *Myriophyllum* and *Callitriche.*
Thames [4]	paucity of submerged vegetation, in the centre there is no vegetation, along the banks *Acorus* and *Nuphar* are present
Mole [5]	some places severe banks of *Typha*
Stour [6]	reeds present to mid water
Frome [6]	prolific *Glyceria* along the margins, *Ranunculus* profusely in midstream, no riparian vegetation
Lugg [7]	vigorous beds of *Ranunculus*, riparian vegetation of Alder and Willow.
Dee [8]	poor weed growth, extensive beds of *Nuphar* at mouth of tributaries

1) Cowx, 1980; Cowx, 1988; 2) Hart & Pitcher, 1973; 3) Cragg-Hine & Jones, 1969; 4) Williams, 1965; Mathews, 1971; 5) Stott, 1967; 6) Mann, 1973; 7) Hellawell, 1972; 8) Barnabas, 1973).

V3 Stream Velocity

Lowland reaches with low velocities in summer (< 20 cms^{-1}) are preferred by roach (Williams, 1965; Cragg-Hine & Jones, 1969; Bray, 1971; Hart & Pitcher, 1973; Cowx, 1988). In faster flowing reaches, roach can still be present but are less abundant (Cowx, 1988). In Poland a high density and biomass was found in reaches with a flow of 15 cms^{-1}. A low biomass is found in reaches with a flow of 70 cms^{-1} (Penczak *et al.*, 1976; Penczak, 1981). According to Fitzmaurice (1981), roach are present at velocities of 60-100 cms^{-1}. Larger individuals are more resistant to the occurrence of high velocities. According to L'Abee Lund *et al.* (1987) the average length of roach was 15.5 cm when the flow exceeded 100 cms^{-1} 13% of the time; when the flow exceeded 100 cms^{-1} 80% of the time the average length was 17.8 cm.

However, optimum conditions for roach occur when the average stream velocity doesn't exceed 20 cms^{-1} (Figure 2.2c). At higher average velocities the suitability gradually decreases and is unsuitable at 130 cms^{-1}.

V4 Average Width

In rivers with an average width of > 5 m, roach can be abundant (Cragg-Hine, 1964; Stott, 1967; Cowx, 1980) (Table 2.4). In very wide rivers, such as the Thames and Dee, roach can be present in very high numbers. Due to a lack of habitat diversity overcrowding can occur which can cause stunting of growth (Williams, 1965). Very wide rivers are probably suboptimal for roach.

Table 2.4. Average width in selected rivers.

River	Width
Exe/Culm [1]	5-6 m: 30% roach 100 m: 90% roach
Nene [2]	site 1: 10-15 m, site 2: 9-12 m
Willow Brook [3]	5 m
Thames [4]	40-80 m
Mole [5]	5-10 m
Stour [6]	22 m
Frome [6]	11 m
Dee [7]	60-100 m

1) Cowx, 1980; 2) Hart & Pitcher 1973; 3) Cragg-Hine & Jones, 1969; 4): Williams, 1965; Mathews, 1971; 5) Stott, 1967; 6) Mann, 1973; 7) Barnabas, 1973.

It is assumed that an average width of 10-30 m is optimum for roach (Figure 2.2d). In wider rivers the suitability very slowly decreases to 0.8 at 100 m, and remains constant in wider rivers.

V5 Average Depth

High densities of roach can be found in rivers with an average depth of 1-5 m (Table 2.5). In very shallow water no cover is present and roach are vulnerable to bird predation. The diet of roach appears to comprise partly of benthos, but feeding on benthos is restricted in very deep water.

It is assumed that the optimal depth is between and average of 1-5 m (Figure 2.2e). In shallower waters there is a sharp decline in suitability. In deeper water the suitability for roach also exhibits a sharp decline because of a lack of suitable benthic feeding conditions.

Table 2.5. Average depth in selected rivers

River	Depth
Exe/Culm [1]	1 m
Nene [2]	Site 1: 1 m
	Site 2: riffles 0.1-1.4 m, 0.7-1 m
Willow Brook [3]	0.7-0.8 m
Thames [4]	3 m maximum 5 m
Mole [5]	0.3-2 m

1) Cowx, 1980; 2) Hart & Pitcher, 1973; 3) Cragg-Hine & Jones, 1969; 4) Williams, 1965; 5) Stott, 1967.

V6 Nitrate Concentration

Nitrate concentration is a measure for the trophic level of the water. Roach prefer eutrophic water with a high availability of zooplankton and benthos. In the upstream reaches of the Exe and the Lugg, with a low nitrate concentration, abundance of roach is relatively low. In lowland parts with nitrate concentrations of 4-7 mgl^{-1} high densities of roach are found (Cragg-Hine & Jones, 1969; Cowx, 1988)(Table 2.6). A very high concentration of nitrate can lead to hypertrophic waters with anoxic conditions close to the sediment. This effects the benthic fauna and therefore the food available for roach. However, there is no information indicating the levels of nitrate concentration at which the suitability for roach decreases.

Table 2.6. Nitrate Concentration (mgl^{-1}) in selected rivers.

River	Nitrate concentration
Exe [1]	upstream 1.6
	downstream 4.0
Culm [1]	4.0
Willow Brook [2]	7.2
Stour [3]	3.56
Frome [3]	3.51
Lugg [4]	2.20

1) Cowx, 1980; 2) Cragg-Hine & Jones, 1969;
3) Mann, 1973; 4) Hellawell, 1969.

Optimal conditions occur at a nitrate concentration of 4-10 mgl^{-1} (Figure 2.2f). It is assumed that the suitability decreases sharply to 0 at a nitrate concentration of 15 mgl^{-1}. In water with a concentration less than 4 mgl^{-1} the suitability also decreases sharply but doesn't reach 0 because roach are still found at low densities in nutrient poor conditions.

V7 Average Temperature (May-October)

Growth of roach is related to temperature and starts at 10-14 °C (Kempe, 1962; Cragg-Hine, 1964; Mann, 1973; Goldspink, 1971; Broughton *et al.*, 1977; Broughton & Jones, 1978; Meili, 1987; Fahy *et al.*, 1988), although a range of 20-25 °C is preferred (Alabaster & Lloyd, 1982, Baumgart, 1984). Roach avoid temperatures of 29-30 °C and above. However, temperatures which are lethal to roach are dependent on acclimatisation temperature (Alabaster & Robertson, 1961; Wieser, 1991).

The optimum temperature conditions occur at 20-25 °C (Figure 2.2g). At temperatures higher than 25 °C the suitability quickly decreases. At lower temperatures the suitability also quickly decreases reaching 0 at 10 °C.

V8 Maximum Temperature (May-October)

If the maximum temperature is below 10-14 °C growth does not occur. The preferred temperature range is 20-25 °C (Alabaster & Lloyd, 1982). Roach can survive a temperature of 35.5 °C but only for one day (Alabaster & Lloyd, 1982). The maximum temperature variable is included in the model to take account of temperature variations. Again the optimal conditions occur at a maximum temperature of 20-25 °C (Figure 2.2h). The suitability decreases to 0 when the maximum temperature reaches the lethal temperature (31.5 °C). The suitability decreases at temperatures lower than 20 °C due to the limitations of metabolism. The conditions are assumed unsuitable when the maximum temperature doesn't exceed the temperature at which growth starts (average 12 °C).

V9 Average pH

A pH of 4.5 is lethal to roach. At a pH over 5 no death occurs (Alabaster & Lloyd, 1982). However, adult roach avoid a pH of 5.6 (Alabaster & Lloyd, 1982). Within the range of 5.6-10.5 roach do not show any preferences (Alabaster & Lloyd, 1982).

Optimum habitat conditions occur at a pH of 6-10.5 (Figure 2.2i). At lower pH values the suitability decreases to 0 at a pH of 4.5. At higher pH values than the optimum, the suitability also shows a sharp decline to 0 at pH 11.

V10 Minimum Oxygen Concentration

According to Holcik *et al.* (1989), roach have a moderate oxygen need. An oxygen concentration of 5-6 mgl^{-1} is preferred. High densities of roach occur at an oxygen concentration of 10 mgl^{-1} (Penczak *et al.*, 1976; Penczak *et al.*, 1981). Roach have a high tolerance for low oxygen concentrations. They avoid oxygen concentrations lower than 1 mgl^{-1} at a temperature of 24 °C, and die at 0.82 mgl^{-1} at a temperature of 30 °C (Alabaster & Lloyd, 1982).

Optimum oxygen concentrations are above 5 mgl^{-1} (Figure 2.2j). At lower oxygen concentrations the suitability gradually decreases to 0 at 0.5 mgl^{-1}.

V11 % Vegetation Cover in Spawning Period (April-June)

Spawning usually occurs on macrophytes (Bray, 1971; Broughton *et al.*, 1977; Mills, 1981). There is some evidence that roach return to the same spawning site every year (Goldspink, 1971). According to Copp (1992), spawning takes place throughout the River Great Ouse. In rivers with poor weed growth high numbers of roach can be present. It is therefore assumed that the presence of vegetation is important, but very low coverage can be sufficient for a roach population to spawn successfully.

Optimum spawning conditions are present at a high vegetation cover (Figure 2.2k). The suitability gradually decreases to 0.3 when there is no vegetation cover present.

V12 % Vegetation Cover (April-July)

Vegetation cover is very important for fry, it protects them from predation and high water velocity. According to Broughton *et al.*(1977), in the River Hull fry are abundant among the vegetation or in the margins. In the first month, until a size of 15 mm, they are restricted to the vegetated sites with mostly *Sparganium*. Later they are also present in less vegetated sites. (Broughton & Jones, 1978). Besides its function as cover, vegetation influences the food chain so that more food is available for fry. According to Copp & Penaz (1988), fry exploit the spawning sites or similar habitats in summer. In areas with a very high cover of macrophytes (75-100%) feeding of fry is less efficient (Scott, 1987). At the end of summer in River Great Ouse they prefer reedbeds but are also present in non-vegetated stretches, the presence of 0+ is not related to submerged macrophytes (Copp, 1992).

Optimum conditions for fry are assumed to be at high vegetation covers (Figure 2.2l). Extremely high vegetation cover and a lack of vegetation cover reduces the suitability.

V13 Average Velocity (June August)

High water velocity and areas with a lack of cover may wash out fry to less preferred habitats (Copp & Cellot, 1988). Fry are particularly vulnerable to high velocities in the first months, and seek cover in vegetation or backwaters of rivers (Scott, 1987). In the River Hull in their first month fry occupied habitats with a velocity of less than 5 cms^{-1}. At two months they can withstand velocities of 10-20 cms^{-1} (Lightfoot & Jones, 1976). At a size of 6.9-11.0 mm larvae tolerate flows of 3.5-5.5 cms^{-1} and at a size of 13.1-15.0 they can tolerate flows of 13.6-16.3 cms^{-1} (Mutsin'sh, 1981). In water with low velocities roach fry often perform better than in still water (Lightfoot & Jones, 1976). According to Scott (1987), this is because less competition occurs as all the individuals remain stationary within the shoal feeding on prey that is transported to them by the passing current.

Optimum conditions are present at velocities of 5-10 cms^{-1} (Figure 2.2m). Lower velocities slightly decreases the suitability because of a reduction in food availability. Higher velocities increase the risk of displacement and it is assumed that a river is not suitable when the velocity exceeds 30 cms^{-1}.

Calculation of the HSI

In these preliminary models it is assumed that the least suitable factor limits the suitability in each of the components food, cover, water quality and reproduction. The minimum value of these components determines the HSI value.

2.2.2 Applicability

The model is applicable to rivers in the United Kingdom within the native and introduced range of roach. For use in Europe and in lacustrine environments some variables may have to be adjusted. The model describes the habitat needs of all life stages but focuses on the adult stage in summer habitat.

The model represents the authors' interpretation of how selected habitat variables limit the potential carrying capacity. The selection of variables used in the model depended upon the availability of combined fisheries and habitat data. The model has not yet been tested and evaluated and therefore in its present form should not be used for management purposes. Once the models have been tested they will provide a valuable tool for this function.

2.3 LOTUS 123 HSI Model

2.3.1 Suitability Index graphs

A model has been constructed to calculate the suitability index for each of the variables using LOTUS 123 spreadsheet software. These values are then combined into an overall HSI value.

The calculation of a SI value for a particular variable is based on interpolation between coordinates on the suitability index graph. Each suitability index graph is divided into linear sections between coordinates. If a value of a habitat variable falls within this section then the suitability index for that variable is calculated by interpolation.

	Variable description	Value	SI
V1	Substrate type (menu 1-6)	6	0.20
V2	% surface vegetation cover	90	0.20
V3	avg velocity in April-Oct (cm/s)	2	1.00
V4	avg width (m)	5	1.00
V5	avg depth (m)	2	1.00
V6	nitrate (mg/l)	7	1.00
V7	avg temperature in May-October (C)	20	1.00
V8	max temperature in May-October (C)	25	1.00
V9	pH	6	1.00
V10	oxygen concentration (mg/l)	4	0.80
V11	% surface vegetation cover (menu 1-4	4	1.00
V12	% surface vegetation cover (menu 1-4	4	0.80
V13	avg velocity in June-August (cm/s)	20	0.50
		HSI	0.2

V1
1) mainly clay or silt > 50%
2) equal amount of clay or silt and gravel
3) mainly gravel > 50%
4) equal amount of gravel and cobbles
5) mainly cobbes > 50%
6) equal amount of cobbles and boulder

V11
1) none
2) low max 25%
3) moderate 25-75%
4) high 75-100%

V12
1) 0-25%
2) 25-50%
3) 50-75%
4) 75-100%

Figure 2.3. HSI model in LOTUS 123.

<u>Example</u>

The suitability index graph for vegetation cover for the roach HSI model (Figure 2.2) described in the LOTUS model as:

```
@IF(V<=10,0.8+V*0.2/10,@IF(V>10#AND#V<=40,1,@IF(V>40#AND#V<=80,(1-(V-40)*0.8/40,@IF(V>80,0.2))))
```

In this model V represents the position of the "cell" in the spreadsheet at which vegetation cover value at a site is entered. The calculation of the SI is divided in 4 sections by IF statements.

Suitability index graphs can be adapted by changing the if statements, that is by changing the interval over which changes in the suitability index occur and adjusting the constant and slope in the calculation of the suitability index.

2.3.2 A HSI model in LOTUS 123

To calculate the HSI from all the variables in the model a LOTUS 123 model was constructed in which all suitability graphs are linked together (Figure 2.3).

Values for all the variables can be entered at the appropriate places in the spreadsheet and then the model will calculate the suitability index for that variable. All suitability indices are then combined in a statement to calculate the overall HSI value.

2.4 Testing of the HSI model

The literature review-based HSI model was adapted to the variables for which reliable information was available from the NRA. Temperature variables were excluded because too few observations were made throughout the year. Total oxidized nitrogen concentration (TON) was used instead of nitrate concentration because more data were available for TON.

The HSI for a certain species is assumed to be related to the carrying capacity of the system for that species. A test of how well the HSI describes habitat, assuming that habitat is limiting the carrying capacity, is a linear regression between the estimate of carrying capacity, in this case biomass, and to the calculated HSI value.

2.4.1 Data collection

The river systems chosen for the analyses were those from NRA regions where suitable fisheries and habitat data were available and accessible. This restricted the analysis to 3 different NRA regions:

- Thames -Kennet, Mole, Stort, Thame and Wey;
- Severn-Trent -Anker, Blithe, Blythe, Carlton, Churnet, Cole, Derwent, Idle, Mease, Penk, Sence, Soar, Sow, Swarbourne and Trent;
- Anglian -Bure, Gipping, Tud and Wensum.

Suitable fisheries and habitat data were available in other regions but they were either in insufficient quantities or were not included in the analysis because of time constraints. [NB. Suitable habitat data are not collected routinely by Anglian region. However, some habitat data were available in an unpublished PhD thesis (Smith 1989)].

The fisheries data were based on routine monitoring surveys carried out routinely at sites across the regions to assess the status of the fish stocks. Sites that were sampled from 1 April to 31 October were used in the testing of the model. This restriction was made because fish species show seasonal changes in behaviour and habitat preferences. Also habitat characteristics such as vegetation cover and stream velocity show large seasonal variations.

For sites in the Thames and Severn-Trent regions, the habitat data were recorded at the time of the fishery survey and were noted in the NRA fishery survey reports. Habitat variables measured included channel depth, channel width, substrate type and vegetation cover.

Water quality and hydrology data were obtained from sampling points as close as possible to the fisheries sites, although no data were available for a number of fisheries sites. Average summer stream velocities (cms^{-1}) were calculated by dividing average summer discharge data (1 April-31 October) by the transectional profile of the river at the fishery site. The transectional profile was calculated by multiplying average depth and average width of the fishery site as recorded at the time of the fishery survey. For the rivers in the Angia region all habitat data were recorded in June-July 1988, not necessarily at the same time as the fisheries surveys (Smith 1989). Surface velocity was measured at the point of maximum depth at the fisheries sampling sites using a C2 Ott meter.

Table 2.7. Fisheries data of the Thames and Severn-Trent region used to test and adjust the Habitat Suitability Index model for roach.

RIVER	N.G.R.	DATE	SITE NR.	TOTAL	BARBEL	BREAM	CARP	CHUB	DACE	GUDGEON	PERCH	PIKE	ROACH	TENCH
THAME	SP720093	09-Apr-91	1	23.5	0.0	1.3	0.0	1.6	0.5	0.2	0.0	8.5	11.2	0.2
THAME	SP652064	23-Apr-91	2	57.4	0.0	0.2	0.0	33.5	1.1	0.7	2.0	5.3	14.6	0.0
THAME	SP611033	25-Apr-91	3	77.3	0.0	0.9	0.0	26.5	3.0	4.2	7.3	9.1	24.2	2.1
THAME	SP602014	16-Jul-91	4	33.1	0.0	0	0.0	21.1	0.6	0.1	2.1	7.3	1.9	0.0
KENNET	SU490671	10-Oct-89	5	49.2	16.5	0.0	0.0	8.8	3.1	0.1	5.0	15.4	0.3	0.0
KENNET	SU612670	07-May-88	6	41.4	0.0	3.5	0.3	0.0	0.0	0.1	1.5	13.9	6.7	15.4
KENNET	SU683708	16-Sep-88	7	17.5	1.5	0.0	0.0	11.5	0.1	0.1	0.0	1.4	2.2	0.7
KENNET	SU705710	23-Sep-88	8	62.5	46.2	0.0	0.0	1.0	0.1	0.0	0.1	14.9	0.2	0.0
KENNET	SU684714	16-May-89	9	34.2	4.8	0.0	0.0	25.1	0.7	0.2	0.5	1.4	1.5	0.0
KENNET	SU637703	17-May-89	10	43.4	20.0	0.0	0.0	13.5	1.6	0.5	0.1	3.8	2.7	1.2
MOLE	TQ284420	11-Oct-90	11	39.5	0.0	0.0	0.0	1.9	16.9	9.7	0.9	3.5	6.6	0.0
MOLE	TQ270450	01-Oct-92	12	39.2	0.0	0.0	0.0	2.0	4.1	2.1	4.4	1.5	23.3	1.8
MOLE	TQ274431	17-Sep-92	13	40.9	0.0	1.9	4.1	2.5	0.3	0.3	1.9	3.0	24.9	2.0
MOLE	TQ285419	22-Sep-92	14	45.6	0.0	0.0	0.0	12.8	7.2	9.3	1.8	0.0	14.2	0.3
MOLE	TQ242474	13-Oct-92	15	27.5	0.0	0.0	0.0	5.5	5.7	4.4	1.7	0.0	10.2	0.0
WEY	SU948439	05-Jun-87	16	51.9	0.3	0.0	0.0	41.6	0.3	0.6	0.3	6.7	2.1	0.0
WEY	TQ008578	18-May-88	17	25.9	0.0	0.0	0.0	20.2	0.5	1.3	0.0	0.6	3.3	0.0
BLYTHE	SP212909	04-Apr-90	18	62.9	0	19.3	13.9	5.9	1.5	0.1	0.7	8.9	3	8.7
CHURNET	SK106393	16-Sep-92	19	32	0	10.4	0	1.3	0	0.3	3.4	11.2	3.9	0
COLE	SP201906	16-May-89	20	21.5	0	0	0	15.5	3.6	1	0	0	1.4	0
MEECE	SJ874291	12-Jun-91	21	19.4	0	0	0	16.8	2.4	0.1	0	0	0	0
PENK	SJ932189	27-Sep-90	22	27.2	0	0	0	15.8	2.3	2.2	1.9	3.8	0.7	0
SOW	SJ885266	03-Jul-91	23	24.8	0	8.3	0	7.3	0.3	0	0.1	6.3	0.3	1.4
TRENT	SJ885456	11-Sep-91	24	20.4	0	0	0	1.4	0	0	0	0.6	18.4	0
DERWENT	SK346517	05-May-93	25	42.68	12.8	0	0	23.48	0.1	0	4.3	0.1	0	0
DERWENT	SK445327	28-Apr-93	26	36.2	0	0.6	0	26.1	1	0	0	0	6.9	1.5
SOAR	SK512944	28-May-92	27	23.24	1.2	0	0	15.94	3.2	0	0.6	0	1.7	0
SOAR	SK581034	10-Jun-92	28	22.5	0	14.4	3.3	0	0	0	0.1	3	1.7	0
SOAR	SK588062	27-Aug-92	29	24.4	0	4.8	1.6	0	0	0	4	5.5	6.9	1.6
SOAR	SK551208	29-Jul-92	30	23.9	3.6	0	0	14.3	1.9	0	1	0	3	0
SOAR	SK352453	21-Apr-93	31	61	2	3.6	0	28.8	1.1	0	7.1	1.3	17	0
DERWENT	SK381343	22-Apr-93	32	54.3	0	7.1	0	13.7	1.5	0.1	16.7	8.2	5.7	0.1

Table 2.8. Habitat data of the Thames and Severn-Trent region used to test and adjust the Habitat Suitability Index model for roach.

SITE NO	MEAN WIDTH (M)	MEAN DEPTH (M)	% CLAY/ SILT	% GRAVEL	% TOTAL VEGETATION	% AQUATIC	EMERGED	SUBMERGED	pH	DO (MG L-1)	T.O.N. (MG L-1)	STREAM VELOCITY (CM S-1)
1	7.7	1.4	10	60	40	20	20	20	7.7	7.8	9.6	3.7
2	10.8	0.8	20	80	15	5	10	5	7.8	8.6	9.9	11.4
3	7.1	0.8	15	84	35	5	30	5	7.9	9.3	8.8	27.7
4	9.7	1.0	20	65	55	50	5	50	7.9	9.3	8.8	12.4
5	17.5	0.8	10	90	85	85	0	15	7.6	8.9	4.7	42.0
6	11.0	1.2	80	20	20	20	0	20	7.9	11.4	4.0	66.0
7	12.0	1.8	40	60	75	25	50	15	7.8	8.5	3.3	28.5
8	14.0	1.2	60	40	90	40	50	15	8.0	10.2	4.1	36.6
9	9.5	1.0	40	60	65	30	35	30	7.9	8.5	4.0	15.7
10	8.2	0.3	20	80	95	20	75	10	7.9	8.5	4.0	60.8
11	5.0	0.4	30	70	80	60	20	40	7.0	7.7	8.9	22.1
12	7.0	0.6	15	3	50	35	15	25	6.9	7.9	13.2	25.2
13	9.9	0.8	20	0	63	33	30	3	7.0	8.6	12.0	12.8
14	5.6	0.4	18	50	62	60	2	10	6.8	6.3	15.7	24.5
15	6.8	0.5	10	10	25	15	10	10	7.3	8.2	11.1	73.1
16	12.3	1.0	20	80	65	25	40	15	7.5	10.5	4.0	21.0
17	5.5	0.5	80	0	10	5	5	0	7.3	9.6	5.5	12.9
18	12.5	0.6	40	50	5	0	5	0	7.9	8.7	8.7	13.3
19	10.0	1.0	10	30	5	5	0	5	7.8	10.7	4.3	9.8
20	8.0	0.4	15	70	70	70	0	70	8.1	13.8	3.0	21.0
21	3.8	0.6	0	0	8	3	5	3	8.0	11.2	6.1	9.1
22	8.5	0.7	10	15	5	5	0	5	8.0	11.1	10.3	13.0
23	6.0	1.1	5	15	90	90	0	90	7.9	10.4	6.4	6.8
24	5.7	0.4	80	0	10	5	5	5	8.0	11.5	2.2	10.2
25	25.0	1.2	5	60	5	5	0	5	8.1	11.5	3.1	23.8
26	28.0	1.4	20	60	15	10	5	10	8.0	10.1	5.3	26.5
27	5.0	0.4	5	70	55	50	5	50	7.9	11.1	11.3	29.7
28	40.0	0.8	100	0	115	110	5	70	7.9	10.3	11.9	1.9
29	40.0	1.8	100	0	60	50	10	30	7.9	10.1	10.5	0.8
30	17.5	0.6	10	70	70	20	50	20	7.8	10.4	12.9	37.9
31	28.0	2.5	30	10	0	0	0	0	8.1	12.3	3.8	12.1
32	36.0	1.5	20	60	10	5	5	5	8.1	11.1	4.0	15.8

Water quality data were obtained from sampling stations as close as possible to the fisheries sites. Annual means were used for the water quality variables because they showed less seasonal variation than characteristics such as velocity and vegetation cover.

Only those sites with a complete fisheries and habitat data set were used (Table 2.7, 2.8). The habitat variables used were average channel width, average channel depth, cover of submerged, emergent and floating vegetation, percentage clay/silt, average stream velocity, average oxygen concentration, average pH and average total oxidized nitrogen (TON). In the Thames region one site with an extremely high biomass in the spawning period, which was probably caused by a spawning aggregation, was excluded from the analysis.

Testing procedure

Testing of the models involved comparing biomass for a species at a site with the calculated HSI for that species at that site. It was assumed that the biomass sampled at a site was related to the carrying capacity and therefore to the HSI (Anon. 1980a, b). The relationships were tested using linear regression models. The correlation of these linear relationships was improved by changing individual suitability index graphs or the calculation of the overall HSI. Changes in suitability index graphs were made if plots of biomass against the above mentioned habitat variables did not agree with the suitability index graphs. More objective techniques based on frequency distribution analysis (Anon, 1982b) could not be used because insufficient sites were available. Statistical significance of the regression lines was calculated using t-tests (SPSS for Windows 5.0.2).

The HSI models were adjusted during testing to make a general model for each species which best explains variation in biomass between sites. The HSI models were tested for each river system separately because there was considerable variation in abundance between the systems. No information was available to explain variation in abundance between different rivers. The same HSI models were used to test the performance of each species in different rivers.

A separate suitability index graph for velocity was derived for the Anglian rivers. Velocity appeared to be much faster in the rivers from this region. This could be the result of the different methods of assessment of flow between data sets (see 4.1), such that the Anglian data are based on spot measurements whilst the rest are derived from discharge and channel morphology data. The Anglia data, however, were not used to test the roach model because the abundance of roach was generally very low in these rivers.

2.4.2 Results

Model adaptations

The following are adjustments made to the HSI model based on the literature review after testing the model using NRA data.

Width
A high biomass of roach was found in rivers as wide as 5 m (Figure 2.4a). The initial gradient in habitat suitability with width was therefore increased from a SI of 0.5 at 5 m to a SI of 0.8 at 5 m width. The suitability index further increases to 1 over the width interval of 5-10 m.

Depth
The same adaptation as with the width variable was made to the depth variable. Roach biomass in the HSI test sites was already high in relatively shallower rivers than expected from the literature review model (Figure 2.4b). Therefore the steepness of the initial increase in SI was changed from 0.5 at a depth of 0.5 m to an SI of 0.8 at a depth of 0.5 m. From 0.5 m to 1 m the SI further increases from 0.8 to 1.

Substrate Type
In the literature review model the dominant substrate type was used in the substrate variable of the HSI model. However, this proved to be insufficiently precise in the testing procedure and was therefore replaced with the percentage cover of clay and silt (Figure 2.4c). The general impression of high suitability at relatively high percentage cover of clay/silt is expressed in the model. It is assumed that at an extremely high clay/silt cover (80-100%) the suitability decreases because of a lack in habitat differentiation.

Total vegetation cover
A high biomass of roach was observed between a total vegetation cover of 10 and 65% (Figure 2.4d). However, adjusting the suitability index graph did not improve the correlation in HSI and biomass. It was therefore assumed that the suitability of vegetation cover was inter-dependent with stream velocity (see stream velocity).

pH
All observations are within the optimal pH interval with low and high biomass occurring at the same pH values (Figure 2.4e). The suitability index graph for pH therefore remained unchanged.

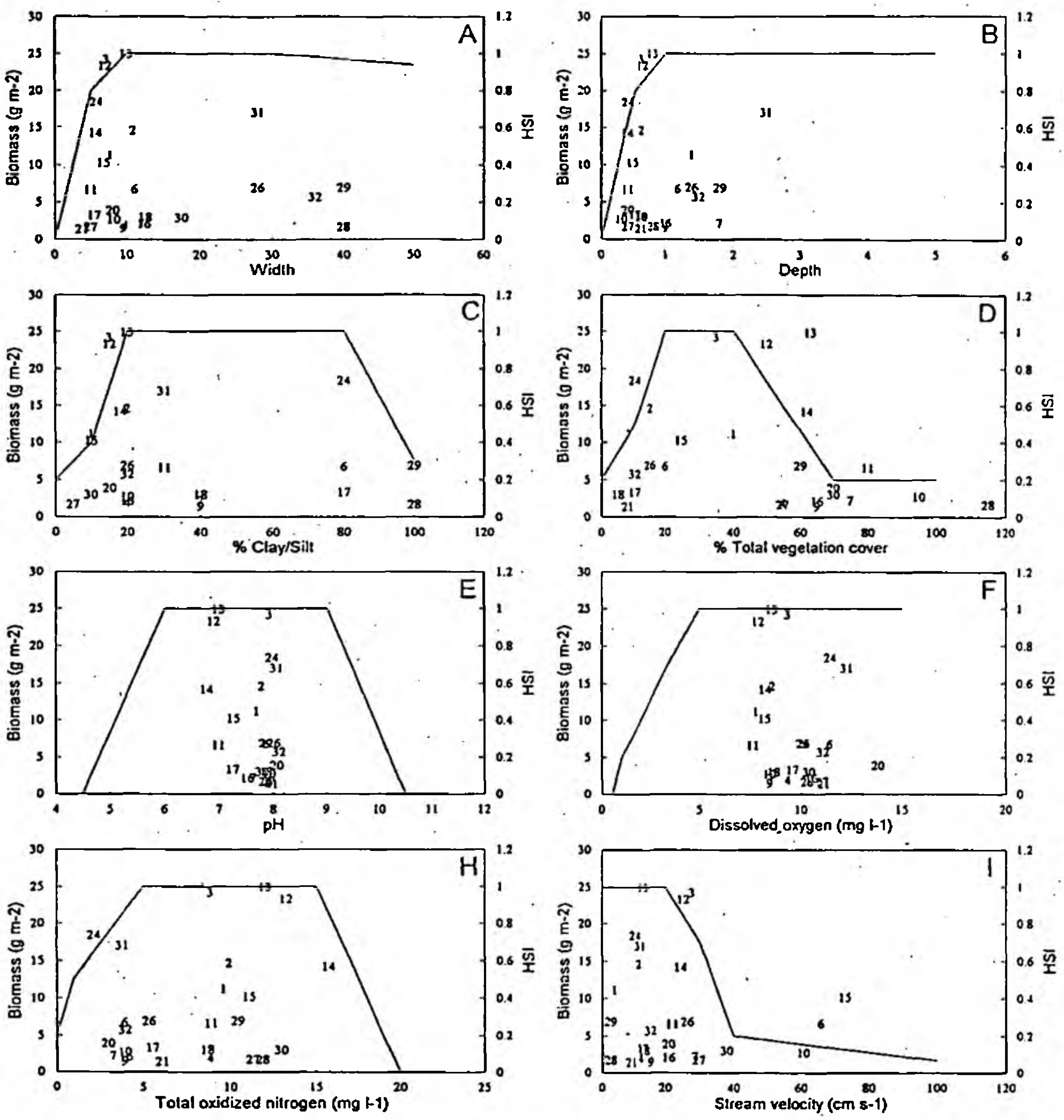

Figure 2.4. Scatter plots of biomass on habitat variables and Suitability Index graphs for roach. All variables are assumed to be averages in the summer period (1 April- 31 October).

Dissolved Oxygen
See pH (Figure 2.4f).

Total Oxidized Nitrogen
The suitability graph of nitrate concentration in the literature review model was tested using total oxidized nitrogen (TON) data. The optimal interval (SI=1) was extended to a TON of 15 mg l^{-1} because NRA data showed high biomasses of roach at 10-15 mgl^{-1} (Figure 2.4g). Between a TON concentration of 15-20 mgl^{-1} the suitability is assumed to decrease from 1 to 0.

Stream velocity
A high abundance of roach was found at sites with higher stream velocities than expected from the models derived from the literature review (Figure 2.4h). The optimal interval (SI=1) was therefore extended to 0-20 cms^{-1}. The suitability decreases gradually to 0.7 at 30 cms^{-1} and to 0.2 at 40 cms^{-1}. It appeared that sites with relatively high stream velocities and a high vegetation cover (e.g. sites 3, 12, 13) contained high biomasses of roach. However, sites with a high vegetation cover and low stream velocity (e.g. sites 28, 29) contained low biomasses of roach. Sites with a high stream velocity and a low vegetation cover also contained low biomasses of roach (e.g. sites 6,10). As a result the interdependency of these two variables has been accounted for in the model by the inclusion of an "IF" statement which replaces the two separate variables in the original HSI model. The statement is:

if $a < 20$ cm s^{-1} and $b < 50$ % : SI(a)
if $a > 20$ cm s^{-1} and $b < 50$ % : average SI(a), SI(b)
if $a < 20$ cm s^{-1} and $b > 50$ % : SI(b)
if $a > 20$ cm s^{-1} and $b > 50$ % : minimum SI(a), SI(b)

where a=stream velocity (cm s^{-1}), b=vegetation cover (%) and SI is the suitability index.

These "IF" statements account for the compensation effects which occur between vegetation cover and stream velocity conditions. Under these circumstances the unsuitability caused by a high stream velocity may be compensated by vegetation cover. If both the vegetation cover and stream velocity are high it is the minimum variable which determines the suitability index. At a low stream velocity it is only a very high vegetation cover (>50%) which lowers the suitability.

Overall HSI

The overall HSI is calculated as the minimum of the 6 described variables and the combined vegetation cover and stream velocity statement.

Regression of biomass on HSI

The HSI model explains 52 and 59 % in the variation of roach biomass in the Thames and Severn-Trent region, respectively (Figures 2.5 and 2.6). The HSI is significant related to biomass ($P<0.03$, 0.02 respectively) and the constant is not significantly different from zero (Figures 2.5 and 2.6).

In the Thames region (Figure 2.5) a number of sites have a large deviation from the regression line. In the River Mole (sites 11-15) water quality is poor because of discharge from a sewage treatment work upstream of site 11 (NRA 1989). At site 11 the NH_4^+ concentration is extremely high. The effect of poor water quality at sites 11-

15 generally causes a higher roach biomass than expected from the HSI model, especially at sites 12 and 13. Only site 11, the first site downstream of the STW, has a relatively low roach biomass. The sites further downstream (12-15) contain relatively high roach biomasses. Site 1 in the River Thame was recently dredged and over-deep, and the fish community was possibly still affected by a pollution event (9 years before sampling) which killed 90% of the fish (NRA 1990b). It appears, however, to have a relatively large roach biomass. Site 2 and 3 both contain a high roach biomass, these sites were sampled on 23 and 25 April, respectively, and may contain spawning aggregations.

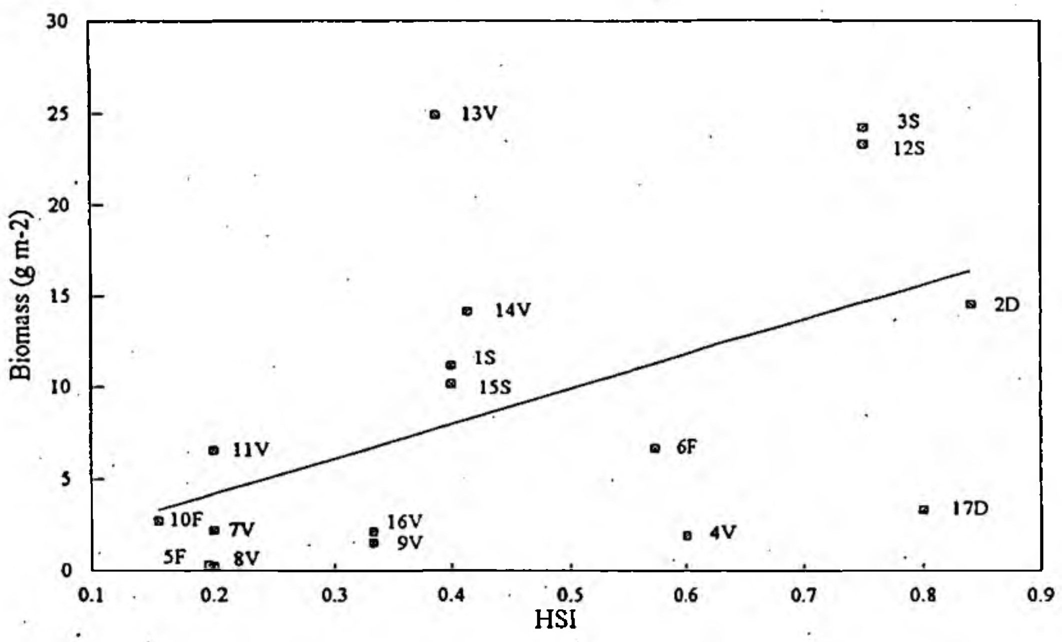

Figure 2.5. Regression of roach biomass against HSI at sites in the Thames region. (r=0.52, n=17, slope=19.1, SE slope=8.2, P<0.03, constant=0.38, SE constant=4.1, P<0.93). Factors that limit the HSI are indicated. w: width, d: depth, v: total vegetation cover, s: percentage clay/silt, f: flow, p: pH, o: oxygen concentration, t: total oxidized nitrogen.

In the Severn-Trent region (Figure 2.6) site 26, 31 and 32 sampled on 28, 21 and 22 April, respectively could hold spawning aggregations of roach. Site 18 is sampled early in April and may not represent a typical summer biomass. No apparent explanation can be given for the very high biomass at site 24, the only site in the River Trent which was sampled in September.

In the Thames region (Figure 2.5), neglecting the possibly biased sites (1-3, 11-15), total vegetation cover and flow are the most frequently limiting factors. A high total vegetation cover and low percentage of clay/silt is limiting most sites affected by the

STW (11-15). At the shallow sites, 2 and 3, which contain possible spawning aggregations, the HSI is limited by depth and percentage clay/silt, respectively.

In the Severn-Trent region (Figure 2.6), omitting the potentially biased sites (18, 26, 31, 32), substrate type is limiting the HSI in most cases. At the sites containing possible spawning aggregations (26, 31 and 32), different factors appear to be limiting the HSI.

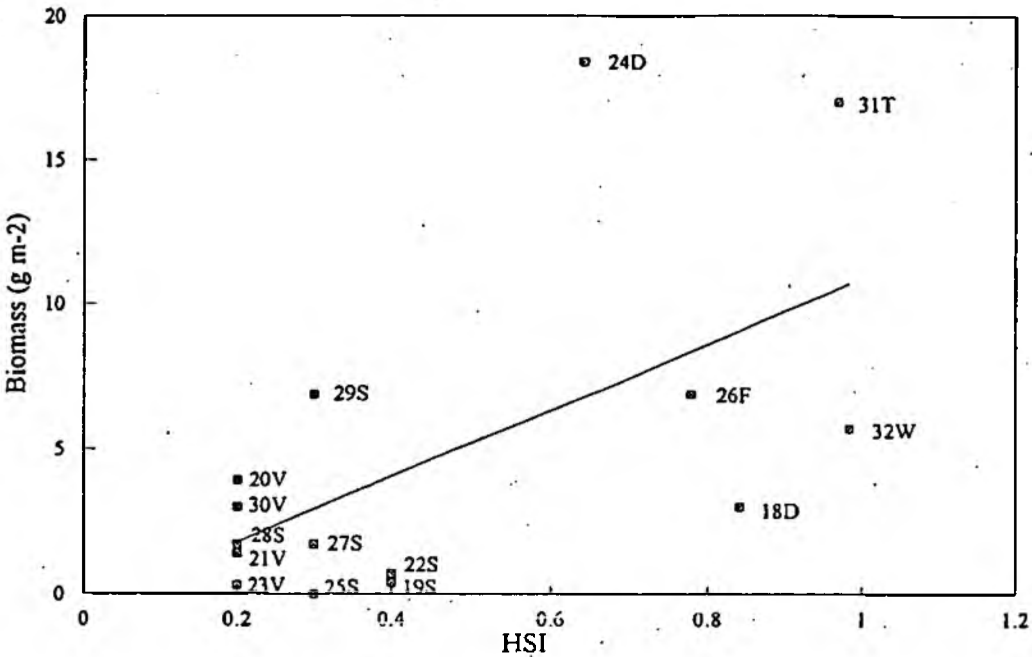

Figure 2.6. Regression of roach biomass against HSI at sites in the Severn-Trent region. (r=0.59, n=15, slope=11.5, SE slope=4.3, P<0.02, constant=-0.54, SE constant=2.3, P<0.82). Factors that limit the HSI are indicated. w: width, d: depth, v: total vegetation cover, s: percentage clay/silt, f: flow, p: pH, o: oxygen concentration, t: total oxidized nitrogen.

2.5 Discussion of HSI models

The HSI models explain 50-70% in the variation of biomasses of the 5 selected species in the tested river systems. Considering the limited availability of habitat data and the probable inaccuracies in, for instance the calculated flow and vegetation cover, which vary considerably within a summer season, this rigid approach can be regarded as promising. Nelson & Miller (1984) tested HSI models based on literature data for a number of warm-water species in the Mississippi River and made adaptations to these models to improve the correlation between HSI and standing crop. As with the presented model here the initial HSI model did not prove to be very successful in predicting the standing crop (r<0.10). After adjustments they improved the HSI model resulting in better correlations (r=0.4-0.5) which is in the same order as the developed coarse fish HSI models.

Smith (1989) developed a sigmoid regression model for chub density based on the Anglia data set with flow and tree cover as independent variables. This model explained 80% of the variation. The limited number of variables in this approach makes general applicability questionable. It does show, however, that flow and tree cover are very important variables for the distribution of chub. Tree cover could not be used in the HSI models because of inconsistency in assessment between NRA regions.

Milner *et al.* (1985) developed habitat models for salmonids which include catchment features, site features and instream features. The model explained variation in density of medium-sized brown trout in hard waters very well (r=80-94%). A habitat model for barbel was developed by Baras (1992) in the River Ourthe in Belgium. These models are all more successful than the HSI models developed, but it should be borne in mind that the former models were based on predesignated data sets. Also barbel and brown trout are more restricted in their habitat preferences than roach and therefore more convenient for habitat models. However, a more accurate HSI model for roach should be feasible if more effort is put in assembling accurate habitat data and with this the possibility of developing more precise suitability index graphs.

The outcome of a HSI model, for a particular species at a particular site does not necessarily predict the actual biomass of the species at a site. However, it does provide an estimate of the potential biomass of the species. Historical or catastrophic events, or factors that have not been included in the model, can restrict the distribution of a species and give differences between actual biomass and the outcome of the model. For example, the HSI models failed to describe the effect of STW discharges in the River Mole (see Section 5.2.2) with the data set and methods used. Other variables which are related to this impact or changes in fish density and growth rates at these impacted sites (see Section 4.2.1) will have to be incorporated in the testing procedure. So far only the presumed summer habitat of the two species has been modelled. In the testing procedure, sites with possible spawning aggregations in April appeared to be outliers on the regression line of HSI against biomass, e.g. chub in the Thames and Severn-Trent regions (Cowx *et al.*, 1994). Excluding these sites in the testing procedure, by defining the summer habitat as starting after the spawning period, will increase the fit of the models. If recruitment success determines the standing-stock at a site, not including factors controlling recruitment as in the model presented here may cause large deviations between the predicted and observed biomass.

To gain complete insight in the possible performance of a species the model needs to be expanded. Suitable habitats for spawning, nursery and overwintering are vital to sustain fish populations. Habitat utilization even changes diurnally (Winfield & Townsend 1988). When distinct habitats are used by a species these different requirements can be modelled by defining different cover types, each consisting of specific variables or with the same variables but different SI graphs. For example, a fry cover type would be backwaters or littoral zones while the adult cover type could be the main river. Effort has to be put in describing and quantifying habitat conditions in these areas and migration patterns of species between these cover types.

Another improvement would be to use a more objective method in developing the suitability index graphs. This can only be done if a large number of observations are available which allow good frequency distribution analyses (Anon. 1982b).

The suitability of a habitat has been tested without relating it to an area available within this habitat. A further improvement would be to link the habitat suitability indices to the available area per cover type. The suitability of an area and the quantity of that area are both assumed to be related to the carrying capacity. Multiplication of these two factors gives the number of habitat units (HU) which is used in a complete HEP procedure and assumed to be an expression of the value of a system for a certain species. The number of HUs is used to compare the value of different systems and to predict changes in the value of systems by changes in the quantity or suitability as a result of human impacts (Anon. 1980a,b,c).

In the HSI models, roach were limited by high flow rates and a low percentage of silt/clay. This is in agreement with the general qualitative habitat description for the species (Wheeler 1969). Biological interactions between species, such as competition, are not directly incorporated into the models. Competition between species could cause bias between observed and predicted performance when species with overlapping habitat requirements, such as dace and roach (Cowx 1989), are compared with HSI models. A further development of the models might result in grouping of species in one model to overcome this problem.

3. MULTIVARIATE MODELS OF THE HABITAT REQUIREMENTS OF COARSE FISH IN LOWLAND RIVERS.

3.1 Introduction to multivariate methods.

Multivariate statistics are contrasting, but complementary, approaches to the HSI method in assessing the distribution of organisms within ecosystems. Instead of taking a species by species and environmental parameter by environmental parameter approach, as in the HSI, multivariate methods use all variables (species and environmental) simultaneously. These types of study are known as synecology. The results of these analyses are intended to summarize the vast database from which they are derived and to show which of the underlying environmental parameters are the most important in determining species distribution. These results usually take the form of correlations, classifications and regressions.

Three multivariate techniques were used on data provided by the NRA:

i) Canonical Correspondence Analysis (CCA), using the FORTRAN program CANOCO (ter Braak 1987), was performed on both the environmental and fisheries data. The method produces axes which are linear combinations of the environmental variables (Figure 3.1). These axes are known as 'Canonical axes'. The variables are plotted with respect to their relationship with these axes. Those which have the longest lines exert the greatest influence and those which point in the same direction are closely correlated and *vice versa*. Species are plotted with respect to their relationships with the variables. Fish species plotted closely together show a high correlation in their abundance at sites and those which are adjacent to variable lines are strongly influenced by that environmental factor. Hence, this analysis shows graphically which variables and species are related and which are unrelated.

ii) Two-Way Indicator Species Analysis, TWINSPAN (Hill 1979), was performed on fisheries data combined from the two regions to classify sites according to similarities in the composition and abundance of species present. The output from this analysis will indicate which fish species have similar habitat preferences. If these habitat preferences can be identified and quantified it may be possible to formulate models as a tool for integrated fisheries management.

iii) Discriminant Function Analysis (DFA) was performed, with the SPSS sub-program DISCRIMINANT (Klecka 1975), on environmental data from both the Thames and Severn-Trent regions. The TWINSPAN site groupings were used as the factor for discrimination in the analysis. This method produces graph axes in the form of linear equations. These linear equations are combinations of the environmental variables which have been selected to maximise segregation between the different TWINSPAN site groups. The linear equations can be used as a management tool to identify habitat requirements for each fishery type or to predict the species composition at new sites when only the environmental information is known.

A combination of the TWINSPAN and DISCRIMINANT provide the best option for utilization in management strategies for coarse fish in lowland rivers.

Detailed accounts of the models and procedures can be found in Gauch (1982) and Jongman *et al.* (1987).

3.2 Materials and methods.

3.2.1 Data collection

The river systems chosen for the analyses were those from regions in which suitable fisheries and habitat data were available and accessible. This restricted the multivariate analysis to 2 NRA regions, i.e.:

- Thames — Kennet, Mole, Stort, Thame and Wey;
- Severn-Trent — Anker, Blithe, Blythe, Carlton, Churnet, Cole, Derwent, Idle, Mease, Penk, Sence, Soar, Sow, Swarbourne and Trent;

The fisheries data were based on surveys carried out routinely at sites across the regions to assess the status of the fish stocks. These surveys determine the community structure in terms of biomass and density of each species present. For the purpose of multivariate analysis, biomass estimates (gm^{-2}) were used from the fisheries survey reports. From the tributaries of the Rivers Thames and Trent 34 and 33 fisheries survey sites were chosen respectively. These sites were selected according to the following criteria:

i) they were a good fishery (>30 gm^{-2} fish biomass);
ii) they represented a good cross- section of coarse fish species;
iii) they did not appear to be heavily impacted by human activities.

Habitat data were recorded at the same time as the fishery survey was carried out and were noted in the NRA fishery survey reports. Habitat variables measured included channel depth, channel width, substrate type and vegetation cover. Water quality and hydrology data were obtained from sampling points as close as possible to the fisheries sites. Water quality and hydrology data used were in the form of annual means (1 Jan to 31 Dec).

3.2.2 Data transformation and analysis.

Data were entered into a spreadsheet package (LOTUS 123) for data manipulation (e.g. Log_{10} transformations). When data had been transformed they were saved as ASCII files. Data from the ASCII files were converted into Cornell Condensed Format using the FORTRAN program COMPOSE (Mohler 1987). These data (both environmental and species) were analysed using the CCA procedure available in the CANOCO program (ter Braak 1987). Species data which were converted using COMPOSE were also analysed using the FORTRAN program TWINSPAN (Hill 1979). When TWINSPAN group classifications were known these values were entered alongside the original environmental data in the LOTUS 123 spreadsheet. These data were then entered into the SPSS/PC+ program using the Data Entry (DE) option. The sub-routine DISCRIMINANT was executed on the environmental data using the TWINSPAN groupings as the basis for discrimination. The codes for the naming of variables and species in the CANOCO figures are listed in Table 3.1 and 3.2 respectively. The illustrated output models (Figures 3.1 and 3.2) were obtained using the computer software packages CANODRAW (Smilauer 1990) and SLIDEWRITE (Advanced Graphics Software 1992).

Table 3.1 Explanation of the variable name codes used in CANOCO.

Code	Variable (units)
Temp	Temperature (°C)
Discharg	Discharge (Ml d^{-1})
Width	Mean width (m)
Depth	Mean depth (m)
Bare	Bare rock substrate (%)
Boulder	Boulder substrate (%)
Stone	Stone substrate (%)
Gravel	Gravel substrate (%)
Sand	Sand substrate (%)
Mud/silt	Mud/silt substrate (%)
Float ve	Floating vegetation (%)
Subm veg	Submerged vegetation (%)
Emer veg	Emergent vegetation (%)
Shade	Bankside vegetation cover (%)
pH	Acidity (pH)
Cl-	Chloride (mgl^{-1})
Susp sol	Suspended solids (mgl^{-1})
Oxygen	Dissolved oxygen (mgl^{-1})
BOD	Biochemical oxygen demand (mgl^{-1})
Ammonia	Ammonia and ammoniacal nitrogen (mgl^{-1})
T.O.N.	Total oxidised nitrogen (mgl^{-1})
PO4	Phosphate (mgl^{-1})

Table 3.2 Explanation of the species code names used in CANOCO.

Code	Latin name	Common Name
Abra bra	*Abramis brama* (L.)	Common bream
Albu alb	*Alburnus alburnus* (L.)	Bleak
Angu ang	*Anguilla anguilla* (L.)	Eel
Barb bar	*Barbus barbus* (L.)	Barbel
Cypr car	*Cyprinus carpio* L.	Carp
Esox luc	*Esox lucius* L.	Pike
Gobi gob	*Gobio gobio* (L.)	Gudgeon
Hybr hyb		Hybrids
Gymn cep	*Gymnocephalus cernua* (L.)	Ruffe
Leuc cep	*Leuciscus cephalus* (L.)	Chub
Leuc leu	*Leuciscus leuciscus* (L.)	Dace
Perc flu	*Perca fluviatilis* L.	Perch
Ruti rut	*Rutilus rutilus* (L.)	Roach
Salm tru	*Salmo trutta* L.	Brown trout
Scar ery	*Scardnius erythrophthalamus* (L.)	Rudd
Thym thy	*Thymallus thymallus* (L.)	Grayling
Tinc tin	*Tinca tinca* (L.)	Tench

3.3 Interpretation of multivariate models

3.3.1 CANOCO results.

The species and environmental variables which do not exhibit great variation in the data distibution tend to aggregate close to the origin of the CANOCO graph. To avoid untidiness these species and variables are not labelled in the CANOCO output.

In the CANOCO model derived from data combined from both NRA regions 56.1% of the species abundance variation is explained (Figure 3.1). Those variables which appear to show the greatest influence upon these species distributions are width, discharge, gravel, BOD, TON and mud/silt substrate.

Three associations of species abundance distributions are evident; one between perch, bream, bleak and carp; another between chub, dace and trout and finally an association between barbel and grayling. The first of these associations appears to be dominated by aspects of channel dimensions (width and depth) and a mud/silt substrate type. The chub, dace and trout association shows a close relationship with gravel substrate and shading from bankside vegetation. The barbel and grayling group seems to be strongly influenced by aquatic vegetation factors (both submerged and emergent) and levels of discharge. Parameters associated with poor water quality (BOD, TON, ammonia and phosphate) are all closely correlated in this model. Although the distribution of gudgeon and rudd are not related, they do appear to be influenced by the parameters associated with poor water quality.

3.3.2 TWINSPAN Results.

TWINSPAN classified the 67 sites combined from the two regions into four groups:

Group 1	15 sites dominated in species composition by barbel grayling and trout;
Group 2	25 sites dominated in species composition by chub and dace;
Group 3	21 sites dominated in species composition by perch and roach;
Group 4	6 sites dominated in species composition by bream, carp and tench.

3.3.3 Discriminant Function Analysis (DFA) results.

The first two Discriminant Function (DF1 & DF2) axes explain 91.6% of the variation in TWINSPAN site groups according to the environmental data (Figure 3.2). The analysis also classified 80.6% of the 67 sites (i.e. 54 sites) into the correct TWINSPAN group. TWINSPAN group centroid coordinates for groups 1,2,3 and 4 are (2.08, 0.92), (0.58, 0.63), (-1.39, 0.51) and (-2.72, -2.12). Detailed output from the analysis indicates that, of the parameters measured, the following are among those which appear to be the most important in the discrimination between TWINSPAN groups; discharge, mean channel width, the gravel substrate, mud/silt substrate, submerged vegetation, emergent vegetation and bankside shade.

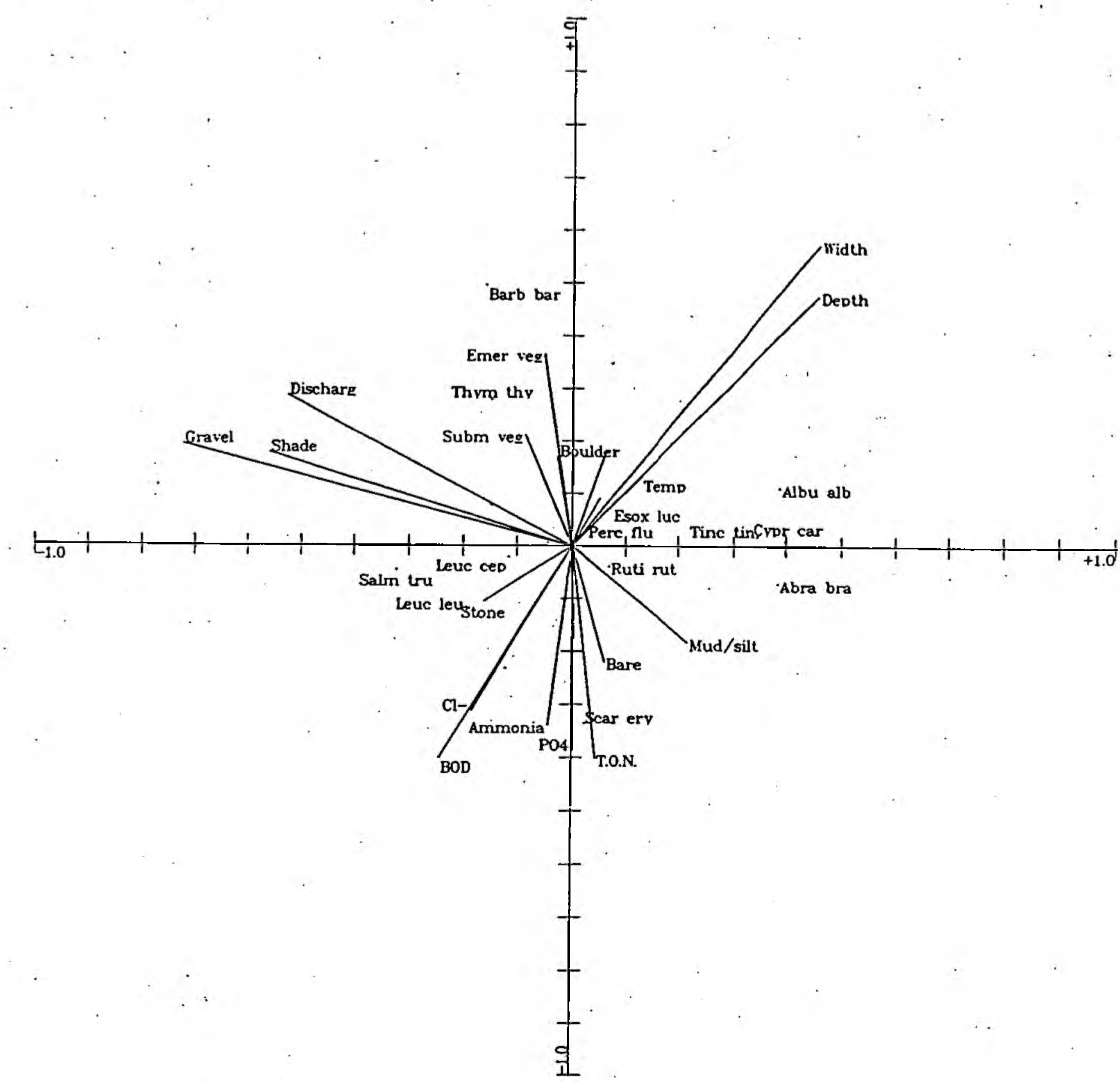

Figure 3.1 CANOCO Model based on NRA data.

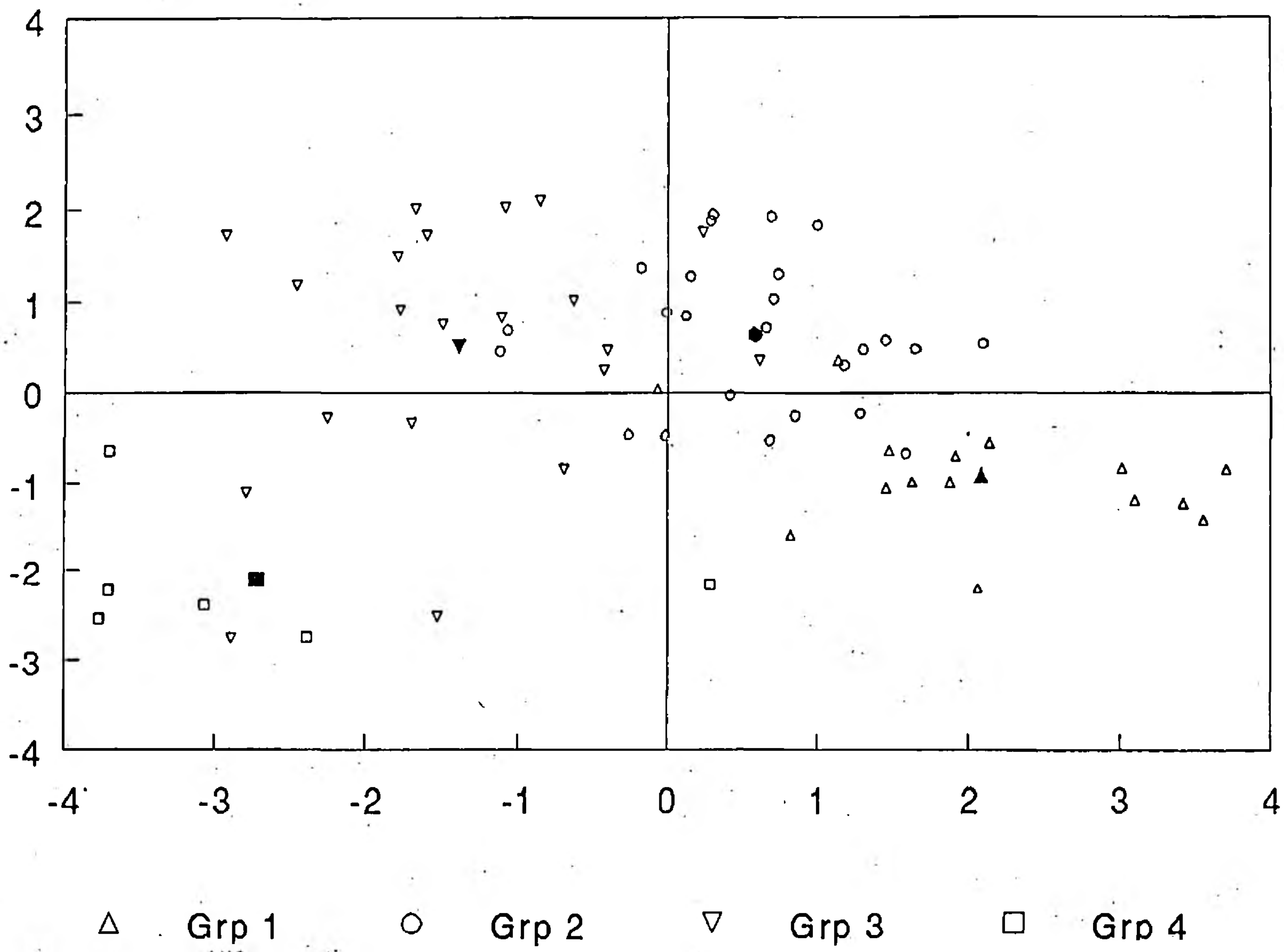

Figure 3.2 **DISCRIMINANT model for data combined from both catchments (Thames & Trent): Open symbols are sites, closed symbols are group centroids.**

3.4 Conclusions and recommendations.

Species associations have been identified from the CANOCO and TWINSPAN output. The measured environmental variables which show close correlations with each other have been identified. Hence there is potential for a reduction in the number of parameters measured at any one site. The models have identified which of the measured environmental variables are influencing the distribution of coarse fish in lowland rivers and should be recorded in all future studies to assist in the interpretation of factors influencing coarse fish populations in lowland rivers.

These multivariate techniques have demonstrated that they have the capacity to predict changes in the fish community structure when environmental parameters are modified. However, to develop such models further it is essential that there are some minor modifications in the collection of fisheries, habitat and physicochemical data in the NRA regions. To fulfil this objective successfully a standard approach to data collection across the regions with regard to environmental and fisheries information is required. Similarly, age & growth and length & weight data need to be collected in a standard format across the NRA regions. The multivariate models can then be used to assess the performance of each species under different types of environmenmtal conditions using length, age and growth data to assess growth and mortality rates.

The present models are crude since they are based on annual and summer averages of environmental data. However, there is enormous potential to develop these models to assess seasonal habitat requirements of coarse fish, i.e.

Spawning habitat requirements (Spring);
Nursery habitat requirements (Spring/Su;mmer)
Feeding habitat requirements (Summer);
Over-winter requirements (Winter).

When seasonal habitat requirements have been established, it will be possible to examine more critically, river systems with poor fisheries, to identify which environmental factors are limiting the distribution and abundance of coarse fish populations in lowland rivers. If distinct habitats are used by coarse fish during the annual cycle, factors influencing migration patterns between these habitats will be identified from the models. In addition, the present models are based on data from good fisheries (>30 gm-2 biomass). They can be developed further to include poor fisheries and hence determine why these fisheries do not perform as well as the good fisheries.

4 THE ABUNDANCE / BIOMASS COMPARISON METHOD

4.1 Background

The Abundance/Biomass Comparison (ABC) Method (Warwick 1986), has been developed as an indicator of pollution stress in marine macrobenthic communities. It is an indicator of stress affecting many types of ecosystem, including riverine fish communities (Coeck *et al.* 1993). The theoretical basis of disturbance on communities can be explained in terms of the intermediate disturbance hypothesis (Connell 1978) and the species diversity hypothesis (Huston 1979). These suggest that under "stable" conditions, where disturbance levels are low, interspecific competition will result in a community which is dominated by K-selected species. This type of community is exemplified by individuals with a large body size, long lifespan and a population biomass which is close to the carrying capacity of the system (Pianka 1970). Under "unstable" or disturbed conditions a competitive equilibrium is prevented, diversity increases and the community is dominated by smaller, shorter-lived, r-selected species.

The ABC method reveals critical differences in community structure using K-dominance plots for species biomass and numbers (Lambshead *et al.* 1983). To do this, species are ranked in decreasing order of importance on the *x*-axis, for *both* biomass and abundance, with percentage dominance on a cumulative scale on the *y*-axis (Figure 4.1). The expected K-dominance curve for undisturbed communities (Figure 4.1a) shows the biomass curve above the abundance curve. In this situation, one species forms a much larger proportion in terms of total biomass than numbers. In a moderately disturbed community (Figure 4.1b), the biomass and abundance curves are closer together and cross. Indication of large levels of disturbance is represented by the abundance curve being situated above the biomass curve (Figure 4.1c). Meire and Dereu (1990) referred to these conditions as unstressed or undisturbed, moderately stressed or moderately disturbed and heavily stressed or heavily disturbed systems.

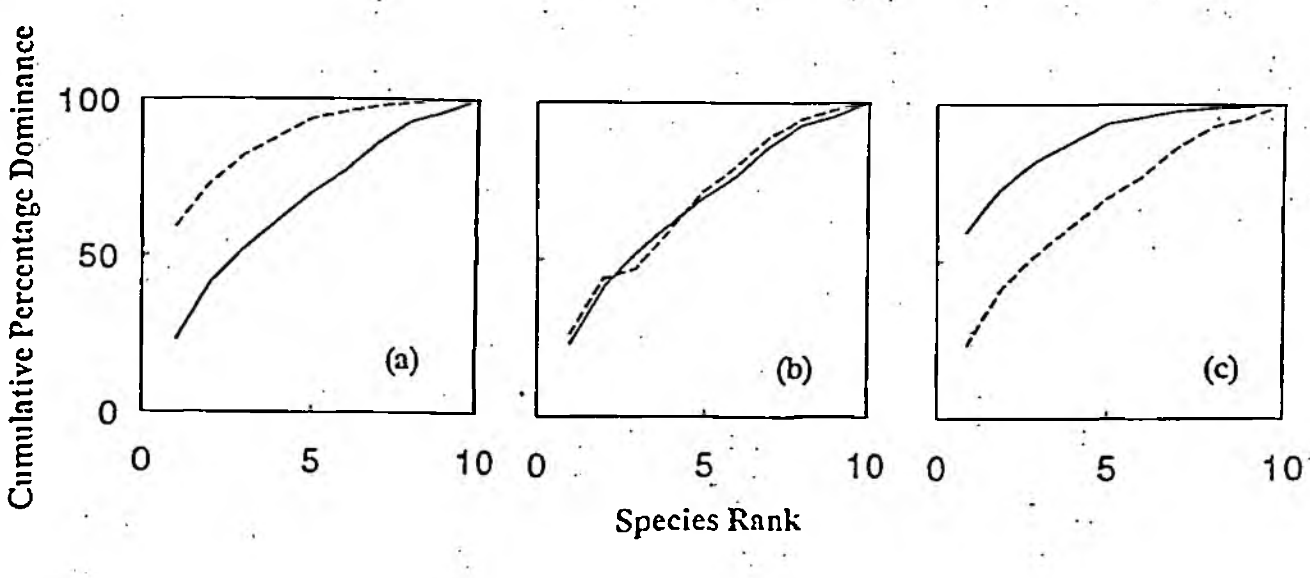

Figure 4.1 Hypothetical K-dominance curves for species abundance (——) and biomass (------), showing unstressed (a), moderately (b) and heavily stressed (c) conditions (after Warwick 1986).

Meire and Dereu (1990) proposed the ABC index, and was calculated empirically according to the formula:

$$\text{ABC Index} = B_i - A_i / N$$

where B_i is the percentage dominance of species i (ranked from the highest to the lowest biomass), A_i is the percentage dominance of species i (ranked from the most to the least abundant species) and N is the total number of species present. The ABC Index is negative in heavily stressed situations, near zero in moderately stressed situations and positive in unstressed situations.

4.2 Materials and methods

Data required for this analysis technique are paired estimates of the biomass and density of all fish species present in the community. An example of a suitable data set is given in Table 4.1. Similar data were collected from NRA archives in all regions. Calculation of the ABC Index was performed using LOTUS 123 spreadsheet software.

4.3 Results

The ABC Index values were calculated for the data presented in Table 4.1, and the index values are given in Table 4.2. The changes in fish community produced both by channelisation of a stretch of river and by the succession of different year classes are illustrated by plotting ABC Index values against the year of sampling (Figure 4.2). An example of the ABC Index applied to NRA data to illustrate differences between sections of the River Great Ouse, with frequent and few backwaters, is given in Table 4.3.

Table 4.2 Abundance / Biomass Comparison Index values calculated from fishery survey data from the River Soar at Croft (data from Cowx *et al.* 1986).

Site	Date	Total Biomass (g m-2)	Total Density (nos m-2)	ABC Index Value
Natural	Oct-78	4.9	4.0	5.0505
Natural	Oct-79	12.8	7.1	-4.0768
Natural	Nov-80	17.8	7.6	-4.9261
Natural	Oct-82	27.4	14.3	-2.9759
Natural	Jul-83	19.3	10.5	1.4113
Natural	Apr-84	49.2	12.6	0.9537
Natural	Apr-85	41.9	24.3	-5.5569
Regraded	Oct-78	5.3	5.4	-0.1488
Regraded	Oct-79	0	0	#
Regraded	Nov-80	0	0	#
Regraded	Oct-82	0	0	#
Regraded	Jul-83	3.4	3.5	4.9580
Regraded	Apr-84	9.7	4.8	0.0000
Regraded	Apr-85	14.2	6.9	-5.2325

not possible to calculate ABC Index.

Table 4.1 Fishery survey data from the River Soar at Croft in natural and regraded sections, to illustrate the ABC method (data from Cowx *et al.* 1986).

Site	Date	Years Since Channeln.	Biomass (g m-2)						Density (nos m-2)					
			Roach	Pike	Perch	Gudgeon	Chub	Dace	Roach	Pike	Perch	Gudgeon	Chub	Dace
Natural	Oct-78	-0.5	1.6	0.5		0.3	2.5		1.2	0.2		1.7	0.7	0.2
Natural	Oct-79	0.5	5.0	1.7		0.6	5.5		4.5	0.5		0.9	1.2	
Natural	Nov-80	1.5	8.1	2.0		0.3	4.5	2.9	4.8	0.3		0.5	0.9	1.1
Natural	Oct-82	3.5	16.2		0.5	9.1	1.6	10.9		0.5	1.8	1.1		
Natural	Jul-83	4.5	13.9	0.6	0.6	0.4	2.2	1.6	7.7	0.4	0.6	0.5	0.4	0.9
Natural	Apr-84	5.5	26.3	3.4	1.0	0.5	14.2	3.8	9.6	0.6	0.9	0.4	1.9	2.2
Natural	Apr-85	6.5	20.4	7.1	7.7	0.6	5.5	0.6	10.0	0.9	11.8	0.4	1.0	0.2
Regraded	Oct-78	-0.5	1.5	0.7		0.4	2.7		1.2	0.2		3.0	0.7	0.3
Regraded	Oct-79	0.5												
Regraded	Nov-80	1.5												
Regraded	Oct-82	3.5												
Regraded	Jul-83	4.5	0.6		0.5	1.4	0.9	0.6		1.1	0,8	1.0		
Regraded	Apr-84	5.5	1.4	1.1	0.4	0.4	4.6	1.8	1.0	0.2		0.4	1.5	1.7
Regraded	Apr-85	6.5	0.7	1.4	1.5	3.5	6.1	1.0	0.8	0.2	1.7	7.1	1.7	0.9

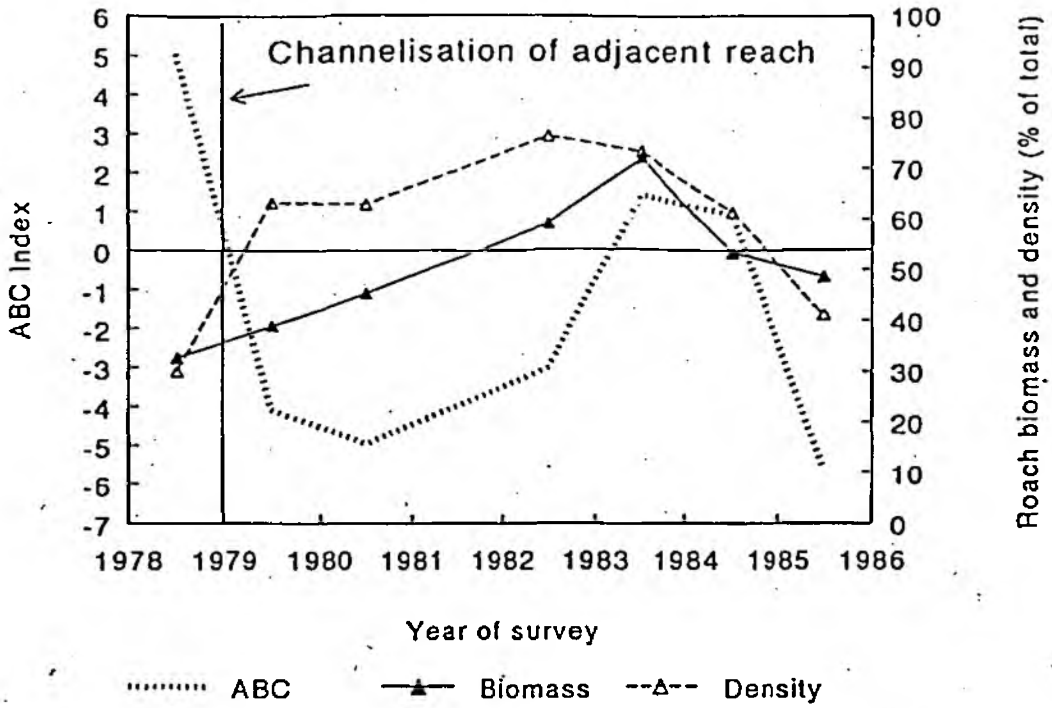

Figure 4.2 The effects of channelisation and succession of year classes on the fish community of the River Soar (after Cowx *et al.* 1986).

Table 4.3 Comparison of total estimated biomass, total estimated density and the Abundance/Biomass Comparison Index for fishery survey sites between adjacent sections of the River Great Ouse (Anglia), July to September 1992.

River section	Survey site number	Total fish biomass (gm^{-2})	Total fish density ($no.m^{-2}$)	ABC Index value
Br.-St.I. #	406	17.87	0.83	-6.13
Br.-St.I.	407	13.62	0.54	-2.85
Br.-St.I.	408	13.62	0.3	3.84
Br.-St.I.	409	8.08	0.31	0.85
Br.-St.I.	410	32.47	0.70	0.33
Br.-St.I.	411	10.39	0.49	-1.58
Br.-St.I.	412	13.69	0.75	-2.06
Br.-St.I.	413	7.13	0.43	-3.36
Br.-St.I.	415	12.1	0.52	-3.02
Br.-St.I.	416	7.15	0.35	0.89
Br.-St.I.	417	18.53	0.75	-3.29
Mean		14.06	0.54	-1.49
St.I-Ea. @	460	3.61	0.26	-2.66
St.I-Ea.	461	7.71	0.45	-22.36
St.I-Ea.	462	5.48	0.17	2.25
St.I-Ea.	463	2.3	0.17	-18.33
St.I-Ea.	464	19.87	0.42	-6.02
St.I-Ea.	465	1.48	0.1	-6.9
St.I-Ea.	466	0.75	0.08	1.56
Mean		5.98	0.23	-7.49

Brampton to St. Ives - backwaters frequent; @ St. Ives to Earith - backwaters infrequent

4.4 Discussion

A major advantage of this method is that a single sample may be used to calculate the ABC Index for that site, and hence be used to measure the degree of stress to which a fish community is subject.

The example from the River Soar (Figure 4.2) shows that the ABC Index is suitable for measuring temporal variation in coarse fish communities. During the period immediately after channelisation, when fish were absent from the impacted reach, the community biomass was dominated by a strong year class of roach. As these fish aged, they decreased in density but increased in biomass relative to the contribution of subsequent year classes, as indicated by the increase in the ABC Index. When fish re-colonised the channelised section, the contribution of larger individuals to community biomass was greater than in the natural section, possibly due to increased water velocity requiring greater swimming ability (see Cowx *et al.* 1994).

The ABC method is equally applicable to measuring spatial variation in fish communities, influenced by natural or anthropogenic factors (see Cowx *et al.* 1994). In riverine coarse fish communities, disturbance by anthropogenic activities may lead to increased importance of smaller species with shorter lifespans and/or a shift to more r-selected life history strategies, within the ranges of phenotypic expression of larger species (Mann *et al.* 1984, Cowx 1990). The example from the River Great Ouse (Table 4.3) illustrates the effect of backwaters on the coarse fish communities. The ABC Index for the section with frequent backwaters (-1.49) was significantly (at the 90% level) greater than the index value for the section with few backwaters (-7.49). Water quality throughout is classified as "excellent" under the Lincoln Index (biological quality). As both sections contain approximately the same major coarse fish species (roach, silver and common bream, pike, tench, perch, chub, dace, rudd and carp), the index values show that the fish community biomass of the Brampton to St. Ives stretch comprised either larger individuals of the same species as were present in the downstream section, or that species which attain a greater ultimate length comprised more of the upstream community. As the percentage contribution of each species to the community does not vary greatly between the sections, the former would seem to be the case.

Comparison of the ABC Index values produced by temporal or spatial data series may be used to quantify the efficacy of rehabilitation works in reducing the total stress acting upon a fish community, thereby leading to a more "stable" community with a balanced distribution of year classes.

The above examples show the value of the Abundance / Biomass Comparison Index as a management tool for the measurement and quantification of impacts upon coarse fisheries.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Habitat requirements of coarse fish in lowland rivers

For the purposes of integrated river and fisheries management it is vital to understand the critical factors which affect the distribution and abundance of coarse fish species in lowland rivers. Consequently, mechanisms for determining the specific habitat and environmental needs of coarse fish species living in rivers are required. To meet this requirement, computer models, which correlate environmental and fisheries data, were developed. The project team adapted two fisheries community modelling techniques to meet the specific needs of this study. The approaches were:

- Habitat Suitability Index (HSI) models; and
- Multivariate Statistical models (CANOCO, TWINSPAN and Discriminant Analysis).

Preliminary HSI and multivariate models were developed by the HIFI project team to identify the main environmental factors influencing the distribution and abundance of coarse fish in lowland rivers. These models show that one or two key factors are important in limiting the distribution and abundance of each species during their adult life stages.

In their present form, the models are applicable to adult life stages of the major coarse fish species; insufficient data were available to include early life stages. **To improve their accuracy for management purposes, it is recommended that habitat requirements for all life stages of coarse fish and seasonal habitat changes are researched and documented for inclusion in the models.**

The response of fish species to a sudden change in habitat caused by a human activities, particularly as a result of habitat restoration projects, also needs to be monitored in detail. When these responses are incorporated into the models they will provide a useful management tool to assess positive, as well as negative, human impacts on fish populations.

5.2 Anthropogenic activities

Impinging on the physicochemical factors affecting coarse fish are human influences through river engineering, pollution and river management activities. *In Phase I, the project team adapted trend analysis techniques and the Abundance/Biomass Comparison (ABC) method to show the impact of human activities on coarse fish populations in lowland rivers* (see R&D Report 0429/6/N&Y for details).

From the available data, it was possible to make generalizations about the gross changes in fish community and population structure brought about by various anthropogenic activities. These were described using the ABC community index method. To understand these impacts more fully further extensive studies are required to assess the mechanisms which cause the changes in the fish populations.

During Phase I the HSI and multivariate models were used to define the optimal habitat of the major coarse fish species. The models have gone some way to quantifying the factors which influence the spatial variability in the fish species distribution and abundance. However, it has not been possible to use the models to define the effects of various anthropogenic activities on riverine habitats and fisheries. **In Phase II it is recommended that the HSI and multivariate models are used to**

focus attention on how anthropogenic activities modify the habitat and the influence this will have on the fisheries dynamics. The change in habitat availability for each species associated with various anthropogenic activities will be determined using the HSI and multivariate models, and the impact on fisheries determined quantitatively. This evaluation will form the basis of predictive assessment of different management activities to determine the potential impact on fisheries population dynamics. As such, it will allow decisions on various river management schemes to be formulated on a rational basis.

To complement this activity, it is recommended that during Phase II the ABC method is further refined, as it is a vital supportive tool in the use and testing of the HSI and multivariate computer models to help identify the factors responsible for the various changes observed.

5.3 Data collection and analysis

During the project, the HIFI project team encountered problems with the information examined due to the lack of compatibility between fisheries, habitat and physicochemical data. The data collected at present have a strategic value in providing baseline information about fish populations in rivers. They rarely, however, target specific management problems or activities, and do not necessarily provide the empirical data on population and stock dynamics essential for formulating rational management activities. The completeness of data available for the analyses conducted in Phase I, therefore was constrained in certain areas, and the accuracy of models and conclusions will be enhanced by additional data.

It is therefore recommended that the NRA give due consideration to their routine monitoring programme and the objectives of this activity. It is also recommended that the data collected during routine coarse fish surveys are standardised between regions.

To maximise on the information gained from routine fisheries monitoring, it is recommended that the NRA Fisheries Departments initiate a policy of collecting appropriate environmental data at the time the fisheries survey is conducted. Implicit within this exercise is the need to standardize data archiving, analysis and reporting.

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Appendix A. Habitat Suitability Index model for Chub

In the chub HSI model the sum of submerged and floating vegetation was used for the variable aquatic vegetation cover.

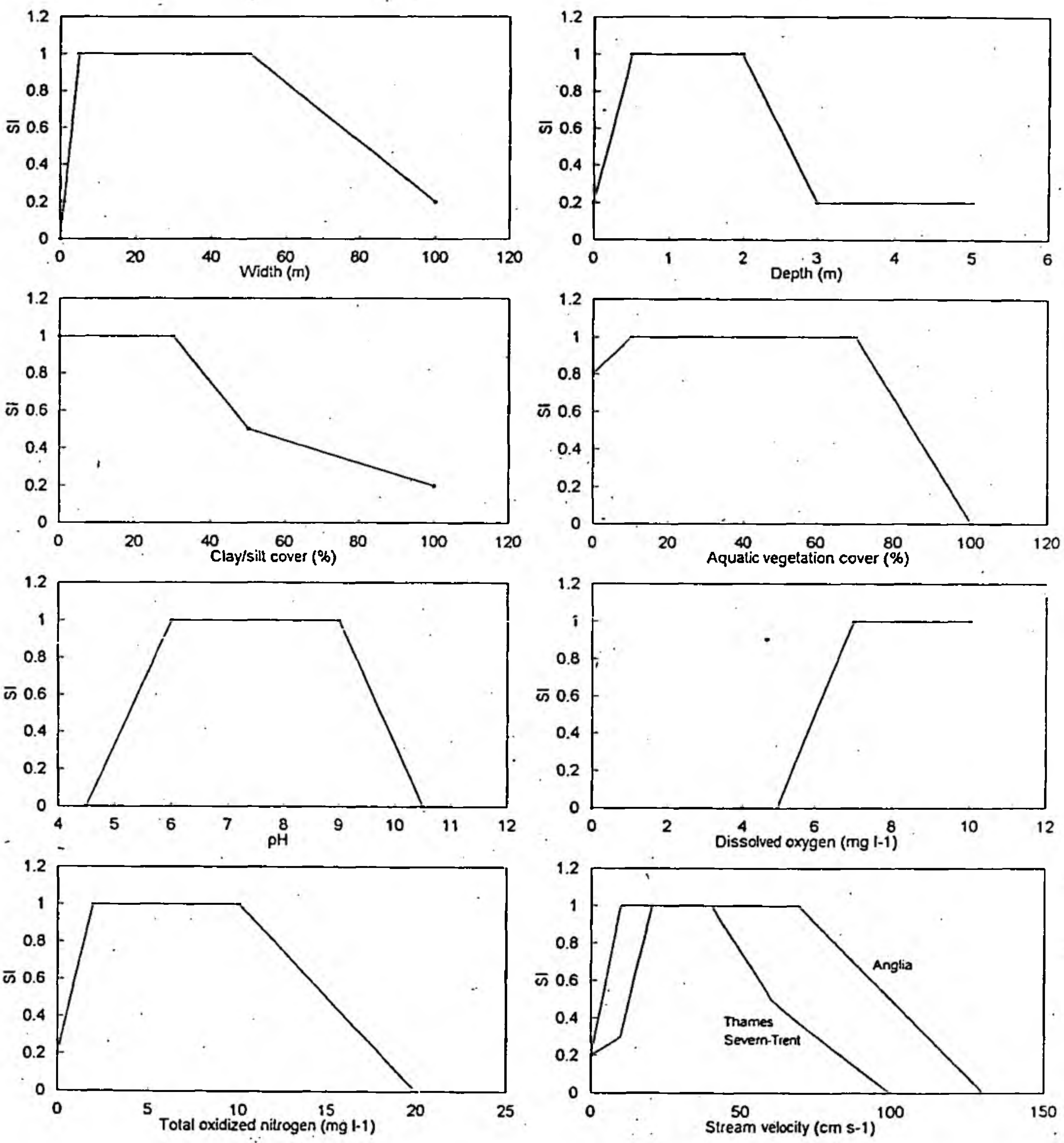

Figure A.1. Suitability index graphs for chub. All variables are assumed to be averages in the summer period (1 April-31 October).

The chub model is based on data from Thames, Severn-Trent and Anglia regions, the regression analysis is shown in Figure A2, A3 and A4 respectively.

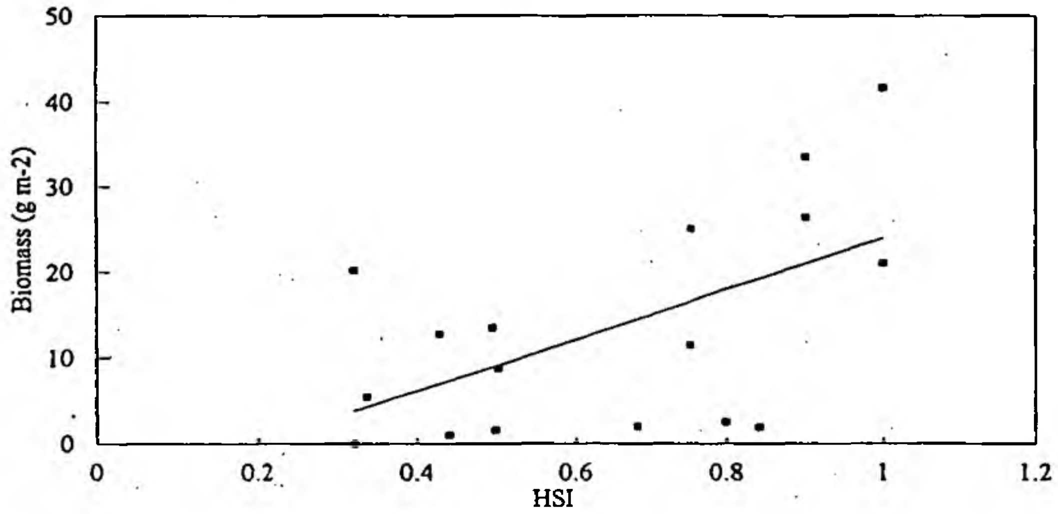

Figure A.2. Regression of chub biomass against HSI at sites in the Thames region (r=0.57).

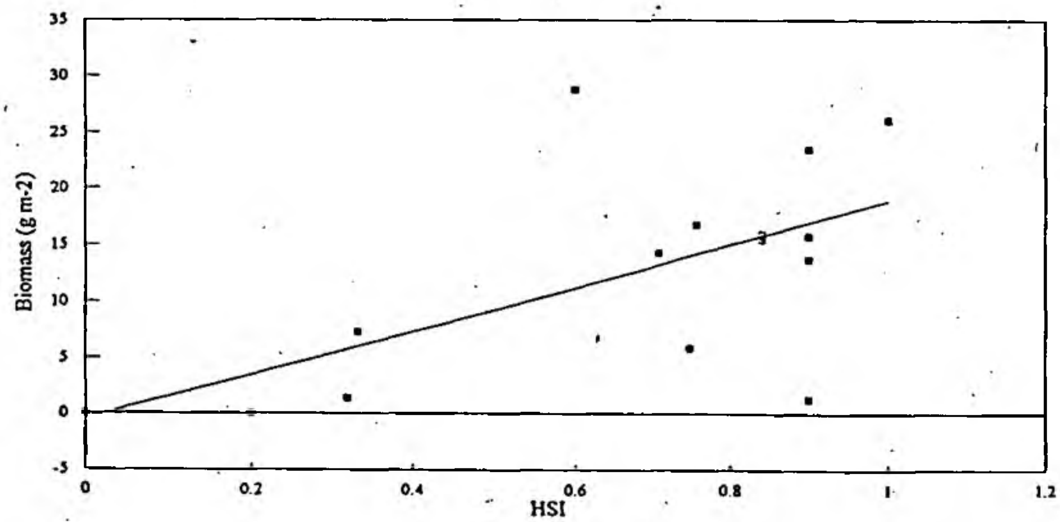

Figure A.3. Regression of chub biomass against HSI at sites in the Severn-Trent region (r=0.62).

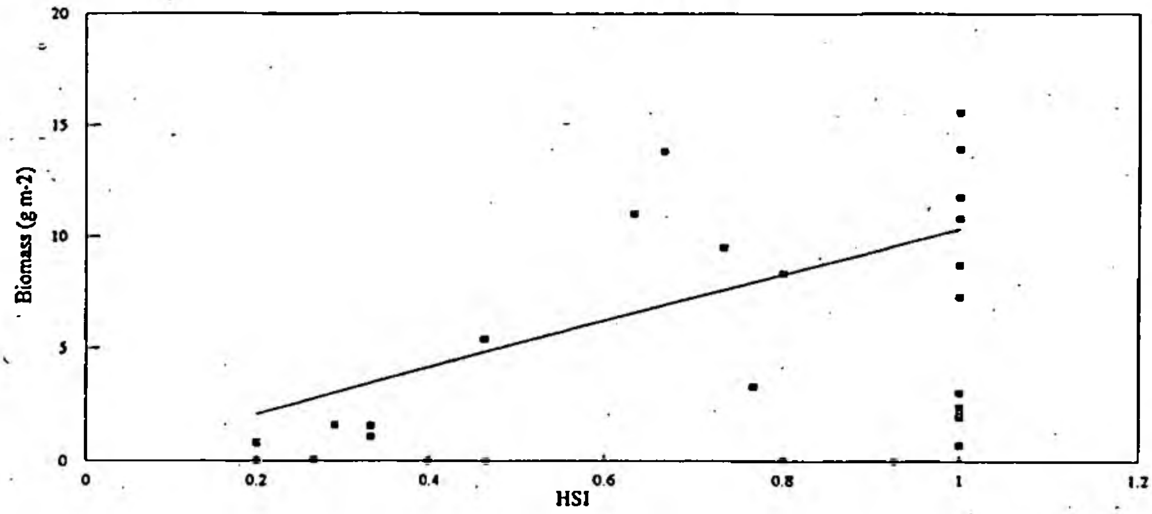

Figure A.4. Regression of chub biomass against HSI at sites in the Anglia region (r=0.50).

Appendix B. Habitat Suitability Index model for Dace.

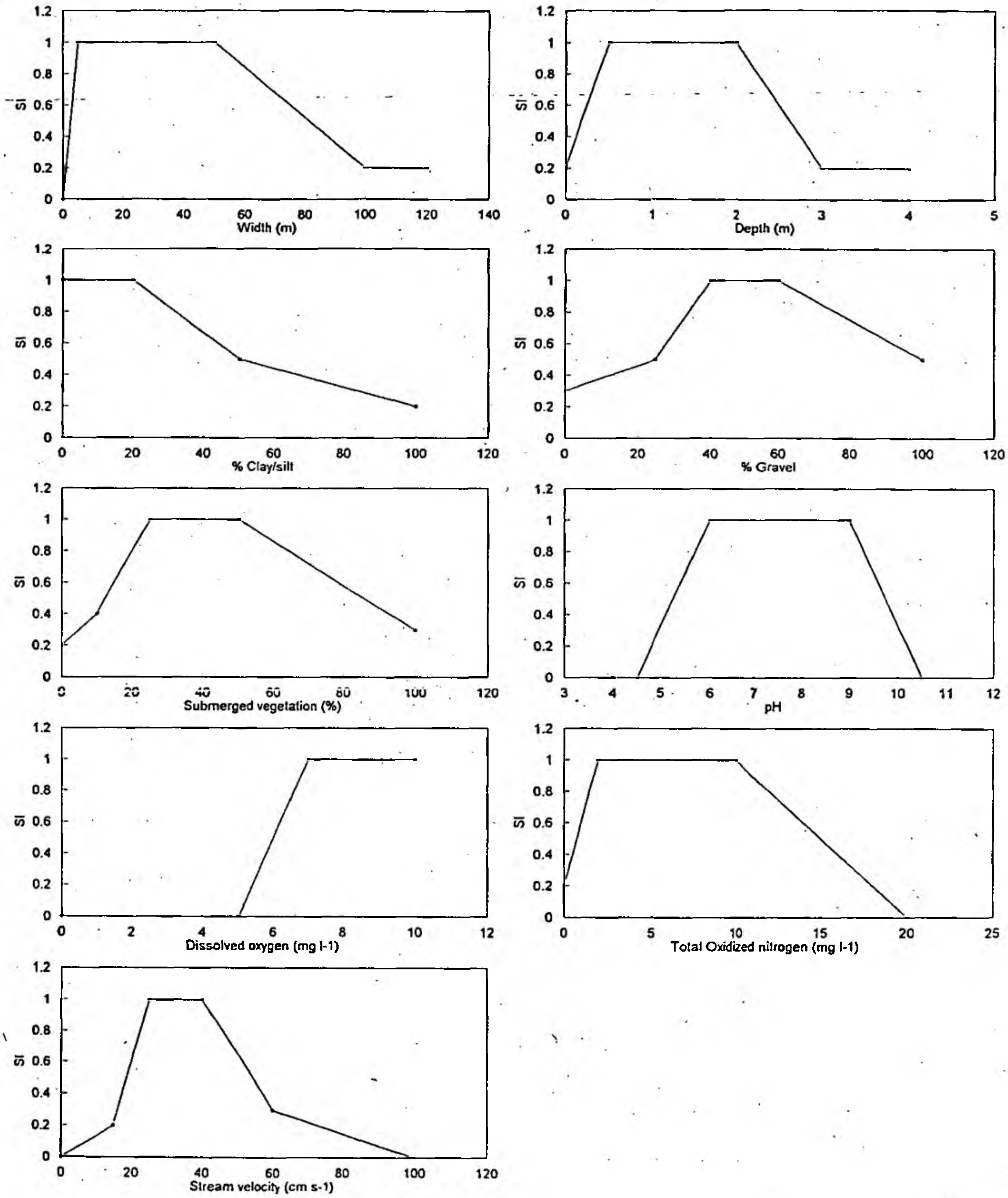

Figure B.1. Suitability index graphs for dace. All variables are assumed to be averages in the summer period (1 April-31 October).

The dace model is based on data from Thames region (Figure B.2). In Severn-Trent and Anglia region the biomass of dace appeared to be too low for the testing.

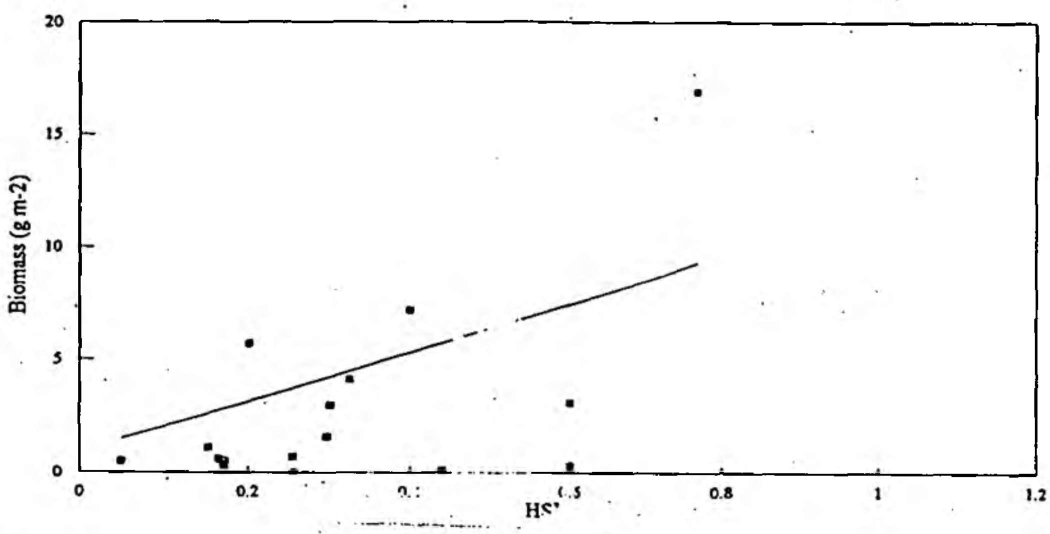

Figure B.2. Regression of dace biomass against HSI at sites in the Thames region (r=0.51).

Appendix C. Habitat Suitability Index model for Pike.

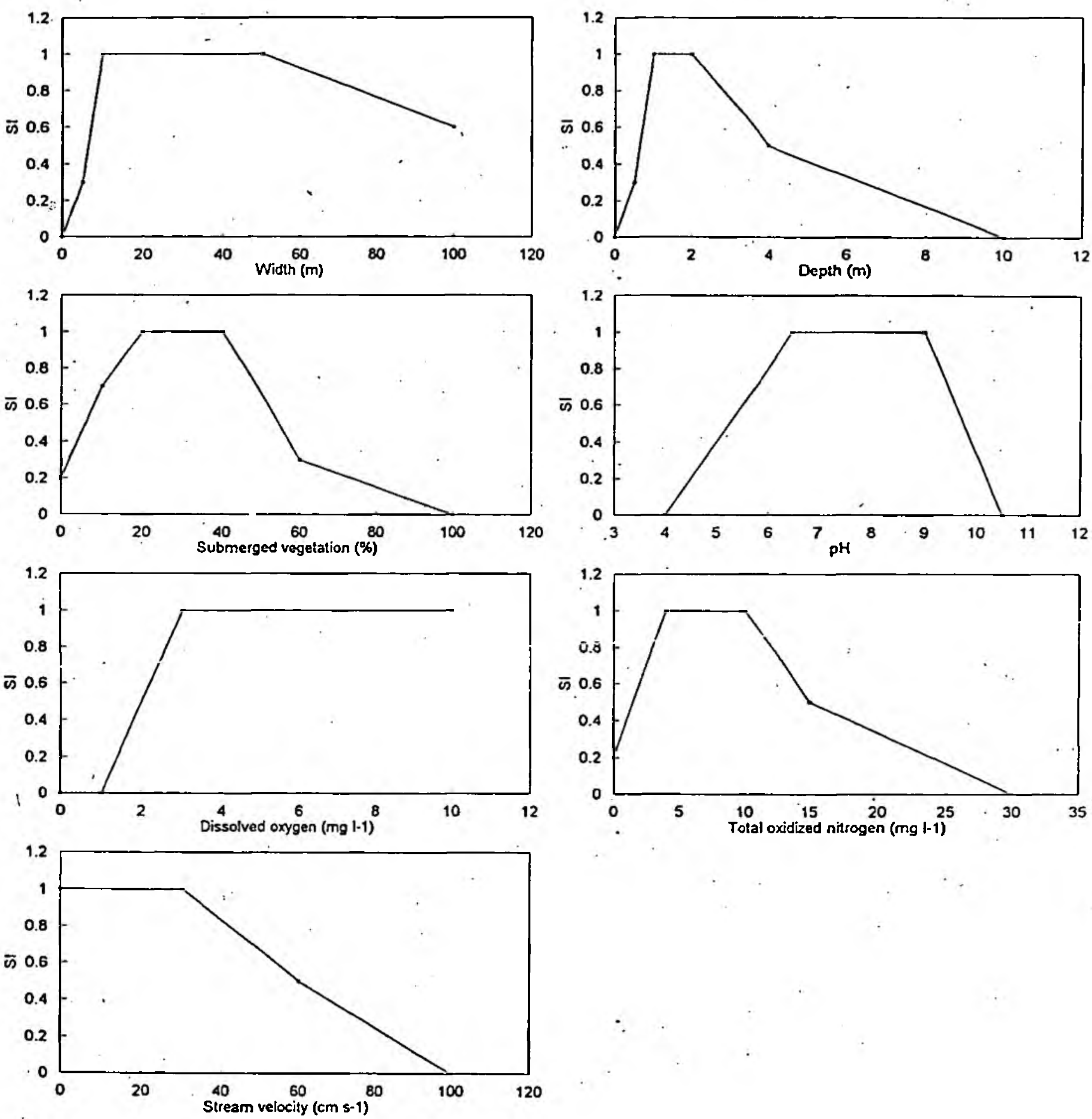

Figure C.1. Suitability index graphs for pike. All variables are assumed to be averages in the summer period (1 April-31 October).

Two if statements are used in the model to link variables.

i) If the emergent vegetation cover is higher than 30% the width of the stream is lowered with the width occupied by the emerged vegetation.

ii) An if statement has been used to link submerged vegetation cover with stream velocity such that:

if F<20 and V<20, SI(V);
if F>20 and V<20, Average SI(F) and SI(V);
if F<20 and V>20, SI(V);
if F>20 and V>20, Average SI(F) and SI(V);

where F is the stream velocity (cms^{-1}), V is the vegetation cover and SI( ) is the suitability index of variable ( ).

The HSI is calculated as the minimum of the combined vegetation and stream velocity variable and the other 5 variables. Stream velocity and submerged vegetation cover are not used as individual variables in the calculation of the HSI.

The pike model is based on data from Thames region (Figure C2). In Severn-Trent and Anglia region the biomass of pike appeared to be too low for the testing

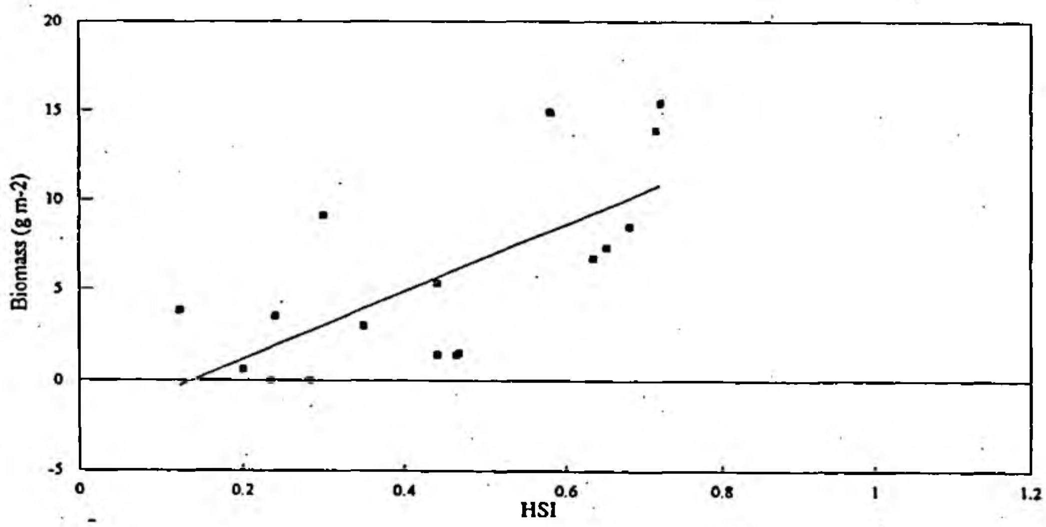

Figure C.2. Regression of pike biomass against HSI at sites in the Thames region (r=0.70).

Appendix D. Habitat Suitability Index model for Bream.

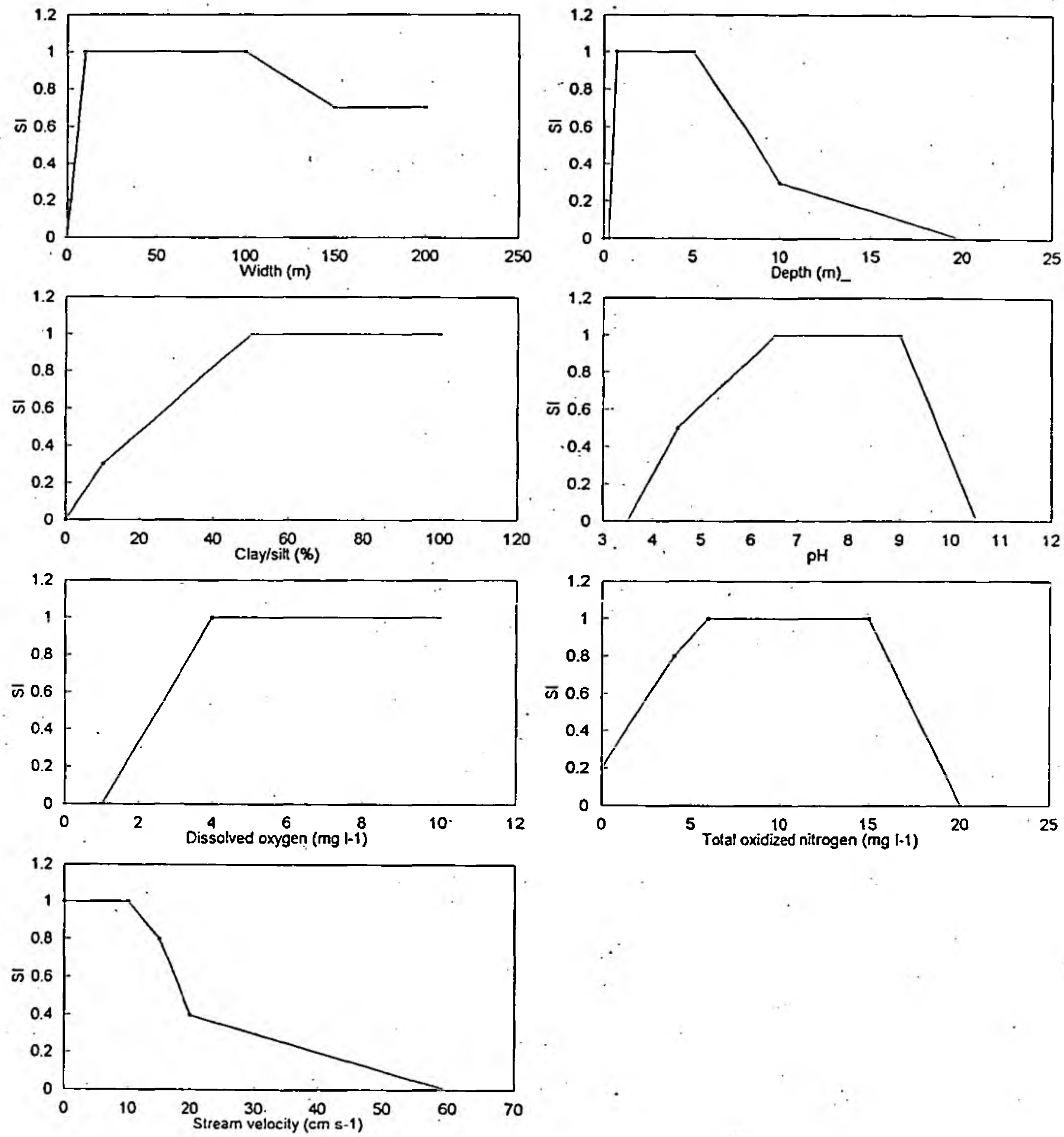

Figure D.1. Suitability index graphs for bream. All variables are assumed to be averages in the summer period (1 April-31 October).

One if statements is used in the model.

If the clay/silt cover is less than 10% and the total vegetation cover (sum of emerged, floating and submerged vegetation cover) is higher than 50 % the SI for the variable clay/silt cover equals 0.6.

The HSI is calculated as the minimum SI of the 7 variables.

The bream model is based on data from Severn-Trent region (Figure D.2). In Thames and Anglia region the biomass of pike appeared to be too low for the testing.

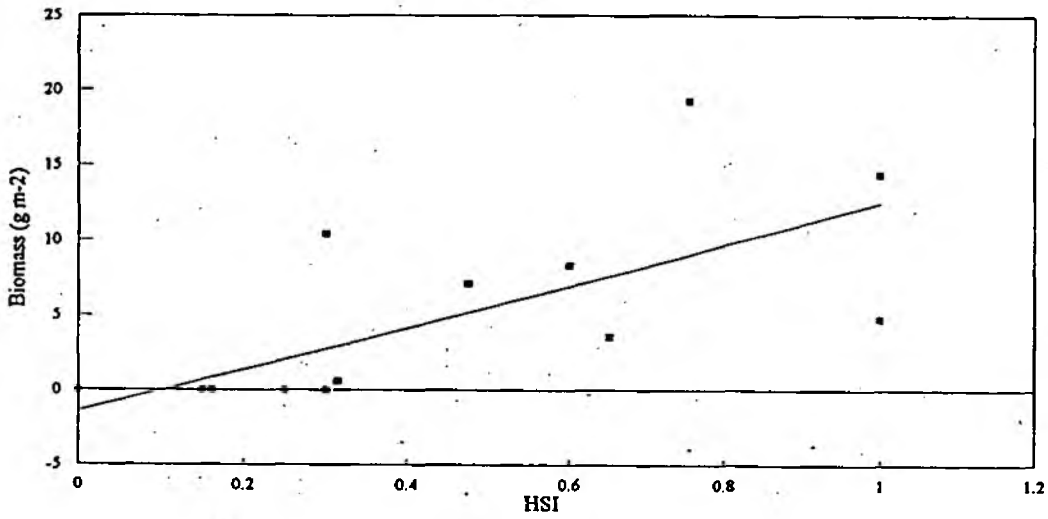

Figure D.2. Regression of bream biomass against HSI at sites in the Severn-Trent region (r=0.69).