NRA South West 113

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FISHERIES TECHNICAL REPORT

BIOLOGICAL PROBLEMS ASSOCIATED WITH IFIM AND IMPLICATIONS FOR REGIONAL FISHERIES STUDIES

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Author: FRCN/95/06

AUTHOR: D J BIRD
Assistant Fisheries Scientist

National Rivers Authority
South Western Region

M G Booth
Technical Manager

CONTENTS

EXECUTIVE SUMMARY

The objectives of the Instream Flow Incremental Methodology (IFIM) are appropriate for addressing a wide variety of water resource management problems. The Region has used the technique in recent studies and is interested in expanding its use to additional ecological types of river (e.g. River Tavy, Malmesbury Avon).

Concerns have been identified in this review regarding the modelling of habitat selection data by the Physical Habitat Simulation System (PHABSIM) to predict flow requirements. These difficulties are summarized below:

* Lack of cost effective strategies for developing habitat suitability criteria
* Physical habitat not limiting populations
* Inappropriate choice of species/life stages
* Inadequate choice of habitat variables
* Ignorance of the relative importance and interaction of habitat variables
* Sampling error in habitat variable measurements
* Unrealistic interpretation of habitat suitability criteria.
* Inappropriate transferability of habitat suitability criteria
* Inappropriate choice of PHABSIM reach
* Ignorance of temporal habitat variation

For salmonids, many of these issues can be addressed in properly designed studies. Detailed, field based habitat selection studies should be restricted to critical periods and life stages (e.g late summer juveniles) and should be supported by carefully chosen criteria from the literature for other periods and life stages. These criteria should be transferable to a variety of streams that share the same ecological attributes. To this end, it is proposed that criteria are developed and selected for high gradient, soft water streams within the Region and used for the Tavy ALF investigation.

Sampling and biotic problems are presently too great for IFIM to be applied successfully in coarse or mixed fisheries. Consequently, it is not recommended for the Malmesbury Avon.

1. INTRODUCTION

1.1 The Instream Flow Incremental Methodology (IFIM) is a technique developed in the US (Bovee, 1982) to resolve the conflict between offstream and instream (e.g fisheries) uses of water. A set of habitat suitability criteria are collected for target species based on the microhabitat variables depth, velocity, substrate and, in some cases, cover. These 'curves' are fed into a suite of computer programmes called Physical Habitat Simulation (PHABSIM) which calculates the amount of physical habitat available at different streamflows.

1.2 There are 3 main categories of habitat suitability curve. Category 1 curves are subjectively based on expert judgement of habitat requirements from visual assessment of reaches (e.g. Chaveroche and Sabaton, 1989), other IFIM studies (see Thomas and Bovee, 1993), or knowledge of life history strategies (Armitage and Ladle, 1989). Category 2 curves are derived from field based studies of habitat use (e.g. Cunjack, 1986; Bird *et al.*, 1995). Category 3 curves express habitat preference by factoring out habitat availability from the category 2 function (e.g. De Graaf and Bain, 1986; Heggenes and Saltveit, 1990; Greenberg *et al.*, 1994).

1.3 IFIM has been used in South Western Region to investigate the ecological implications of summer low flow conditions in recent years. Applications have initially focused on chalk streams and utilized for the first time in the UK, habitat suitability curves based on direct observation of fish (Bird *et al.*, 1995).

1.4 The Region is interested in expanding this work to other ecological types of river (e.g. River Tavy, Malmesbury Avon). The objective of this report is therefore to undertake a critical literature review of the limitations of IFIM so that best practice procedures can be used in specific investigations.

2. ASSUMPTIONS MADE BY IFIM

2.1 IFIM makes the following biological assumptions (Scott and Shirvell, 1987):

* Physical habitat regulates populations.
* Appropriate species/life stages are selected.
* The habitat variables are relevant to fish requirements.
* Habitat variables have equal importance and are independent in their influence on position choice.
* Habitat suitability criteria can be treated as probability functions.
* Large areas of suboptimal habitat have the same productive capacity as small areas of optimal habitat.
* Areas of stream not occupied by fish have no value.

* Habitat suitability criteria developed in source streams are transferable to target streams.

* The reach chosen for PHABSIM modelling represents the impacted reach.

* Extensive temporal analysis of habitat variation is not necessary.

2.2 Unfortunately, the sections below will demonstrate that many of these assumptions are violated in practice.

3. SALMONIDS

3.1 Lack of cost effective strategies for developing habitat suitability criteria

3.1.1 A large number of detailed habitat selection studies have been undertaken over the last twenty years (see below). Unfortunately, despite the high cost of such studies, a significant proportion, particularly those in Europe, have had primarily academic objectives with less emphasis on developing habitat suitability criteria for flow setting purposes.

3.2 Situations where physical habitat is not the primary regulating factor for populations

3.2.1 Habitat selection studies will not be appropriate in reaches where other factors limit fish populations. Food availability (Gibson *et al.*, 1984; Orth, 1987; Ensign *et al.*, 1990), the proximity of spawning areas (Benson, 1953; Solomon and Templeton, 1976; Beard and Carline, 1991), water quality (Egglishaw and Shackley, 1985; Degeman *et al.*, 1986), competition (Hegge *et al.*, 1993) and predation (Mittelbach, 1986; Greenberg, 1992; Gotceitas and Godin, 1993) can all act as regulatory factors.

3.2.2 Habitat suitability curves should instead be developed in unexploited streams (Orth, 1987) at approximate carrying capacity (Bovee, 1982). It is important to account for the high random component in carrying capacity if reliable fish-habitat models are to be produced (Milner *et al.*, 1985). Changes in the abundance of a fish population in a stream reach should also be clearly distinguished from temporary redistribution (Mathur *et al.*, 1984). For example, Kraft (1972) reports a redistribution of brook trout to pools following experimental flow reductions rather than a decline in stock abundance (see section 3.8.3).

3.2.3 The term used to express quantities of physical habitat in IFIM studies is 'weighted usable area' (WUA). Several investigators have tested WUA predictions from PHABSIM modelling against stock abundance to verify that physical habitat is limiting (Conder and Annear, 1987; Irvine *et al.*, 1987; Gan and McMahon, 1990). The success of predictions has varied widely in different studies (Fausch *et al.*, 1988; Shirvell, 1989; Jowett, 1992; Nehring and Anderson, 1993).

3.2.4 IFIM is, however, a tool for predicting impacts of flow changes on available habitat rather than on stock size (Gore and Nestler, 1988). Stock size is influenced by many additional factors (section 3.2.1) and no holistic model is currently available to account for this in impact assessments. Consequently, it is naive to assume that WUA will consistently relate to stock size in all situations.

3.3 Inappropriate choice of species/life stages

3.3.1 Habitat evaluations ideally should account for the needs of all life history stages of the species in the stream community. Unfortunately, this choice is often precluded in practice by knowledge and resource limitations (Garcia de Jalon, 1995).

3.3.2 IFIM studies should therefore consider the sensitivity of the target species/life stage to the habitat conditions experienced in the stream reach (Sale *et al.*, 1982). For most species, habitat requirements change throughout the life cycle and therefore habitat 'bottlenecks' will affect life stages most dependent on the habitat in short supply (Elliott, 1994).

3.3.3 Fry/juveniles are often more suited to IFIM studies than adults for the following reasons:

* distances between resting and feeding areas are shorter (Helm *et al.*, 1982). This ensures that microhabitat measurements are relevant to requirements.

* individuals often exhibit sedentary behaviour. This increases sensitivity by precluding rapid dispersal in response to short-term flow changes (Nehring and Anderson, 1993), reduces fright bias (section 3.6.2), and facilitates the use of statistically pure random sampling designs (Bovee, 1986; Bird *et al.*, 1995).

3.3.4 By contrast, IFIM can be very difficult to apply in the case of adult salmonids. Clapp et al. (1990) observed large, dominant adult brown trout roaming extensively and concluded that determination of the relative value of each habitat type used would be a difficult task.

3.4 Inadequate choice of habitat variables

3.4.1 More attention needs to be given to spatial scale in habitat selection studies (Johnson, 1980; Shirvell, 1986; Bozek and Rahel, 1991; Simonson, 1993; Vondracek and Longanecker, 1993). Unfortunately, microhabitat data are often collected over a range of habitat types but then combined for suitability curves without regard to the habitat related selection differences (Heggenes, 1991; Vondracek and Longanecker, 1993).

3.4.2 The restriction of microhabitat measurements to the focal points occupied by fish is a major weakness of IFIM. It has been shown that the location of energetically profitable positions are very important for salmonids (Fausch, 1984; Shirvell, 1989; Rincon and Lobon-Cervia, 1993). Despite this, current shear is neglected by IFIM.

3.4.3 There is, therefore, a pressing need to measure microhabitat gradients at fish stations. Bain *et al.*, (1985) provide a useful methodology where mean substrate (index of coarseness) and the standard deviation (index of heterogeneity) were computed from dominant categories recorded along a sectioned rope. There is scope for extending this method to other variables particularly water velocity.

3.4.4 Cover is an important habitat variable that is often excluded from IFIM studies. This is due to modelling difficulties created by the many forms of cover that exist (Hartman, 1965; Dolloff, 1986; Bugert *et al.*, 1991).

3.5 Ignorance of the relative importance and interaction of habitat variables

3.5.1 Disagreement exists over the relative importance of the different variables and there is often no regard to interactions between variables despite the fact that it may invalidate the simplistic limiting factors approach (Bowlby and Roff, 1986; Gibson, 1993; Elliott, 1994).

3.5.2 Multivariate statistical techniques should be used more widely to discriminate between selected variables and associated ones (Capen, 1981; Kessler and Thorpe, 1993). In addition, development of multivariate suitability functions expressing interactions (Orth and Maughan, 1982; Voos, 1981; Bullock *et al.*, 1991) should receive more attention.

3.5.3 Caution is, however, needed because the error of attributing biological significance to interactions between spurious variables is as serious as assuming independence when they are not (Williamson, 1994). Depth and velocity interactions have often been assumed to be biologically significant, but are usually artifacts of the sampling environment that are eliminated when the utilization function is corrected for availability (Williamson, 1994).

3.5.4 Univariate curves are generally more flexible than multivariate functions, but the existence of important biological interactions should be investigated prior to their use (Williamson, 1994). If these are detected, they must be accounted for in modelling. This can be effectively achieved (but without addressing correlation between independent variables) by creating habitat quality strata of one independent variable (often suitable or unsuitable) and using other independent variables as continuous value functions. Intervals of a continuous variable can also be grouped and treated as discrete variables. These conditional criteria are particularly useful in describing behavioural interactions concerning cover and substrate (Bovee, 1986; Williamson, 1994). For example, fish may use shallow water in the presence of overhead cover, fast water in the presence of large substrate and deep water in its absence, but will not use shallow water without cover (Williamson, 1994).

3.6 Sampling error in habitat variable measurements

3.6.1 Sampling error may be created by deliberately sampling where the quarry are expected to occur (e.g. Morantz *et al.*, 1987), or where sampling efficiencies vary significantly over the range of each habitat variable (Orth *et al.*, 1982). This disproportionate sampling effort is a serious problem because it is virtually impossible to detect (Bovee, 1986).

3.6.2 Inaccuracies are also introduced where fright bias or the capture method impedes the determination of focal points. This will usually be higher for more mobile fish (e.g. adult life stages) and for more active sampling techniques (e.g. electric fishing) (Williamson, 1994).

3.6.3 An adequate sample size is important to obtain adequate precision levels for criteria and to facilitate fitting a function to the observed frequency distribution. Typically, 150 to 200 observations are needed to construct a reasonably smooth histogram (Bovee, 1986; Williamson, 1994). The required sample size can be estimated from the variance of samples (Williamson, 1994). Estimates below 150 could, however, reflect restricted habitat availability, suggesting that a more diverse study reach should be used (Williamson, 1994).

3.7 Unrealistic interpretation of habitat suitability criteria

3.7.1 The mathematical interpretation of suitability curves by IFIM (Bovee and Cochnauer, 1977; Bovee, 1986) is flawed as it can lead to the false implication that fish are found with certainty at locations exhibiting modal levels of occurrence of a habitat variable (Scott and Shirvell, 1987).

3.7.2 The probabilistic interpretation of curves is extended by multiplying weighting factors for two or more habitat variables together to calculate WUA (Bovee and Cochnauer, 1977; Bovee, 1986; Scott and Shirvell, 1987). Using this convention, several combinations of depth, velocity, and substrate can give similar levels of WUA. In reality, however, the quantities of available habitat will probably differ significantly (Mathur *et al.*, 1984) due to variations in the importance of the habitat variables (section 3.5).

3.7.3 The assumption that small areas of optimum habitat have the same productive capacity as large areas of suboptimal habitat (Scott and Shirvell, 1987) ignores habitat fragmentation effects (Heggenes *et al.*, 1994). Baldes and Vincent (1969) found that brown trout would not use preferred habitat in an experimental flume if the area with those conditions became smaller than 0.14 m. Consequently, in streams with highly variable flow regimes there are few core habitat areas but pools are more stable and provide low flow refuges (Heggenes *et al.*, 1994).

3.7.4 IFIM interprets non-occupied areas to have no value for the fish population. These areas may, however, produce food, or provide some other attribute to the ecosystem (Shirvell, 1986). IFIM could therefore reject certain flows that are perceived from habitat suitability criteria as having little benefit to the fish population. A good example are the flushing flows which might be expected to produce low values of WUA but indirectly benefit salmonid fish populations by cleaning gravels for spawning.

3.8 Inappropriate transferability of habitat suitability criteria

3.8.1 Inappropriate spatial transferability

(a) Adequate consideration should be given to habitat availability in the development of suitability criteria (Heggenes *et al.*, 1991; Williamson, 1994). This is because fish will tolerate and adapt to suboptimal habitat when preferred habitat is in short supply (Heggenes and Saltveit, 1990; Taylor, 1991; Heggenes, 1994).

(b) The importance of transferability of criteria has been shown empirically by comparing PHABSIM outputs using sensitivity analysis. For example, Williamson (1994) re-examined data by Waddle (1992) to test depth and velocity criteria for adult brown trout from two separate studies (Raleigh *et al.*, 1986; Thomas and Bovee, 1993). He found significant differences in the habitat limiting flows and concluded that habitat descriptions were more sensitive to selection of suitability criteria than to hydraulics.

(c) Similar results were also obtained by Willis (pers. comm.) in a southern chalk stream. One set of generalised category 1 curves (Armitage and Ladle, 1989) and two sets of chalk stream specific category 2 curves (Johnson *et al.*, 1993; Bird *et al.*, 1995) were tested. Outputs using the latter criteria showed close convergence and correlated with the habitat recognition of sites. By contrast, convergence and correlation were absent when the category 1 curves were tested.

(d) This perceived absence of 'universal' responses to habitat variables (Heggenes and Saltveit, 1990) has prompted the US Fish and Wildlife Service (USFWS) to strongly recommend that the transferability of criteria are validated before use. Nonparametric statistical methods for transferability testing have been developed by Thomas and Bovee (1993) and USFWS suggest that, at the very least, criteria are critically evaluated by fisheries biologists.

(e) Although preference functions match habitat use against availability, they too can be highly stream specific (Heggenes, 1990; Williamson, 1994), and have some undesirable statistical and mathematical properties. When both the use and availability distributions simultaneously enter the limits of their distributions there is a risk of misrepresenting actual preference simply because of the small probability ratios involved (Morhardt and Hanson, 1988; Williamson, 1994).

(f) These problems can, however, be alleviated. Williamson (1994) suggests applying nonparametric tolerence limits to recalculate utilization and preference curves using only frequency values falling within the tolerence levels established. Greenberg et al. (1994) produced D-value preference criteria using Jabob's (1974) formula but simplified the modelling of habitat quantities by using discrete preference, indifference and avoidance categories.

3.8.2 <u>Inappropriate temporal transferability</u>

(a) A major difficulty in the application of IFIM is the seasonal shift in habitat use (Rimmer *et al.*, 1984; Baltz *et al.*, 1991; Maki-Petays *et al.*, 1995). For example, newly emerged fry are usually associated with slow flowing, possibly marginal habitats in early summer but may move to faster riffle dominated habitats by the end of the season (Heggenes and Saltveit, 1990). Diurnal variations in habitat use have also been observed in response to shifts in activity (Campbell and Neuner, 1985; Fraser *et al.*, 1993).

(b) Despite these considerations, many preference curves used today are based on daytime preferences for feeding during summer (Morantz *et al.*, 1986; Moore and Gregory, 1988). These curves are frequently extrapolated to recommend stream flows throughout the year (Shirvell, 1986). This erroneously implies that behavioral adaptations to changing microhabitat availability and other factors (e.g. temperature) do not occur (Vondracek and Longanecker, 1993; Heggenes, 1994).

3.8.3 Inappropriate hydraulic transferability

(a) A popular approach to suitability criteria development is to undertake observations under intermediate flows when microhabitat diversity is perceived to be greatest (Bovee, 1986; Gore and Nestler, 1988).

(b) Unfortunately, the above approach by discounting high or low flows, does not account for the behavioural switches that are known to occur (Heggenes, 1994). These range from downstream displacement, movement to pools or stranding at low flows to sheltering behind large substrates at high flows (Heggenes, 1994). This suggests that projections to discharges substantially different from those for which the suitability curves were developed are invalid (Gore and Nestler, 1988).

3.8.4 Inappropriate biotic transferability

(a) Transferability of criteria may be inappropriate because the nature and intensity of competition and/or predation differ between source and target streams (Hindar *et al.*, 1988; Gibson *et al.*, 1993).

(b) In sympatric situations it is often difficult to determine whether species are using preferred habitat or are displaced to suboptimal habitat by a more dominant species (Cunjack and Green, 1983; Hearn, 1986; Bird *et al.*, 1995; Heggenes *et al.*, 1995).

(c) In non-saturated environments where biotic effects are at low levels (e.g. Heggenes, 1991) habitat criteria are likely to be narrowly defined and will consequently have low transferability (Thomas and Bovee, 1993). To broaden curves the alternative approach is to choose streams with a sufficiently high standing crop to force individuals into suboptimal locations (Thomas and Bovee, 1993).

3.9 Inappropriate choice of PHABSIM reach

3.9.1 The Representative Reach habitat mapping approach has so far been favoured for habitat mapping in UK studies due to the discrete nature of most affected reaches (Johnson *et al.*, 1993). In the US, however, there has been a shift towards a more extensive habitat typing approach (Williamson, 1994). This method uses fewer transects which can be placed in specific locations for specialised purposes.

3.10 Ignorance of temporal habitat variation

3.10.1 Examination of temporal water flow regimes has received insufficient attention

(Heggenes, 1994), despite the fact that population size at a given time may be determined by past habitat limitations (Orth, 1987). Microhabitat availability does not operate continuously to limit fish populations. Responses of populations to discharge changes may involve a significant time lag (Conder and Annear, 1987).

3.10.2 Without extensive analysis of outputs the potential exists for intentional manipulation of results by users (Gan and McMahon, 1990). Identification of 'habitat bottlenecks' (i.e. physical factors that act to limit populations) and their frequency for vulnerable life stages should be key tasks in instream flow assessment (Sale *et al.*, 1982; Stalnaker *et al.*, 1994). Habitat bottlenecks defined in terms of WUA could also be compared with fluctuations in stock abundance (Stalnaker *et al.*, 1994). For example, the availability of fry habitat in the first months of life was the biggest indicator of year class strength for trout in Colorado streams (Bovee, 1988).

4. COARSE FISH

4.1 Reasons for the paucity of studies

4.1.1 Not surprisingly, IFIM studies involving coarse fish species (e.g. Moyle and Baltz, 1985; Grossman and Freeman, 1987; Leonard and Orth, 1988; Smith, 1989) have been rare compared to salmonids. The main problems associated with extending the method to coarse fish species are listed below:

* The physical environment in which coarse fish live (e.g. water turbidity and depth) is not conducive for making direct observations.

* Suitability criteria for single coarse fish species are confounded by the occurrence of multi-species assemblages with complex biotic interactions (Baker and Ross, 1981; Moyle and Vondracek, 1985; Hawkes *et al.*, 1986; McNeely, 1987).

* Juvenile stages are characterised by several ontogenetic stages, each with important, but differing habitat requirements (Copp, 1990, Copp and Kovac, 1995).

5. CONCLUSIONS AND RECOMMENDATIONS FOR SALMONIDS

5.1 The future for IFIM in the Region

5.1.1 Despite the wide range of problems, particularly the difficulty in obtaining accurate suitability criteria, **IFIM should still be regarded as a key tool for addressing Regional water resource problems.** It should be recognised that there are presently no superior alternatives to IFIM. In addition, the latter presents biological information in a format suitable for incorporation into the water resources planning process.

5.1.2 **It is therefore recommended that IFIM is expanded within the Region, but with better designed habitat selection and impact assessment studies that address the main problems** (see below).

5.2 Recommendations for habitat selection studies

5.2.1 To improve cost effectiveness detailed field based studies should be confined to critical periods and sensitive life stages:

* A diverse sample of pristine sites at approximate carrying capacity should be selected by expert judgement and HABSCORE (Wyatt *et al.*, 1995).

* Microhabitat criteria should be stratified into mesohabitats (e.g. riffles, pools, glides) to account for scale effects in habitat selection.

* Flow dependent behavioural habitat switches should be accounted for in separate criteria.

* Microhabitat gradients at fish locations should be quantified, particularly water velocity shear zones.

* Improving the use of cover as a habitat variable is a challenging objective that should be considered in an R&D Project or a Regional Operational Investigation.

* The relative importance and interaction of habitat variables should be assessed by multivariate statistical analysis.

* A statistically pure sampling design should be used with sample sizes large enough for criteria to meet precision requirements. To this end, adequate habitat availability measurements should be collected and modelling techniques should be used to smooth criteria.

5.2.2 Literature based habitat selection criteria will be adequate for non-critical periods and less sensitive life stages **provided they are carefully screened for transferability**.

5.3 Recommendations for impact assessment studies (PHABSIM)

5.3.1 The selection of a Representative or Extensive Reach approach should be appropriate to the investigation.

5.3.2 Temporal habitat variation should be analysed to identify habitat bottlenecks and these should be validated by fish abundance data if possible.

5.3.3 Sensitivity analysis should be used to compare the different types of habitat criteria and the effects of various flow setting scenarios.

5.4 Recommendations for the Tavy ALF investigation

5.4.1 A proposal incorporating the above improvements is being considered for upland softwater streams in the Region. It is anticipated that the resultant criteria will be used in the River Tavy ALF investigation (Bird, 1995).

6. CONCLUSIONS AND RECOMMENDATIONS FOR COARSE FISH

6.1 It should be recognised that the problems associated with IFIM applications in coarse or mixed fisheries are considerably greater than for salmonids. Consequently, IFIM studies should not take place on the Malmesbury Avon.

6.2 Instead, it is recommended that a habitat mapping exercise is undertaken, similar to that described by Johnson *et al.,* (1993). This exercise should be conducted when habitat is most likely to be limiting and calibrated against electric fishing survey results in each mesohabitat type.

6.3 IFIM studies on coarse fish should take the form of R&D Projects or Regional Operational Investigations. The following points should be considered by the contractor:

* The use of multivariate statistics are essential to determine the relative importance of habitat variables and their interaction within and between species.

* Juvenile life stages are most appropriate for habitat selection studies as the strength of a year class is determined early in the life cycle. Furthermore, point abundance sampling (PAS) (Copp and Penaz, 1988; Copp, 1990) is mainly a juvenile sampling strategy with considerable promise for producing useful habitat suitability criteria.

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