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Impact of fish and fishery management on the conservation of the West Midland Meres

Sampling methodology

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Impact of Fish and Fishery Management on the Conservation of the West Midland Meres - Sampling Methodology

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CONTENTS

SUMMARY

1. Information available in seven documents and the wider literature was examined to provide detailed proposals for appropriate fish sampling methodologies, with approximate costings, for Aqualate Mere, Berrington Pool, Betley Mere, Bomere Pool, Cop Mere, Crose Mere, Fenemere, Hatch Mere, Marton Pool near Chirbury, Quoisley Big Mere, Quoisley Little Mere, Tabley Mere, Tabley Moat, and White Mere of the West Midland Meres. Similar information sources were used to provide a specification for a biomanipulation experiment, although this may need to be modified when fish data become available.
2. Descriptions of 18 fish sampling techniques, including fishery-based, passive and active methods, were given with particular emphasis on their feasibility in the West Midland Meres. Basic fish examination procedures were also described.
3. Recommended sampling methods were made on a site by site basis for each of the above meres. For adult fish, angling catch-per-unit-effort and catch examination, gill netting and vertical quantitative echo sounding were recommended as the best general approach, although the use of fyke and seine nets may also be of value in specific cases. For underyearlings, point electrofishing and gill netting were recommended, while for larvae the most appropriate techniques were suggested to be dip netting and point electrofishing. Three alternative strategies, with approximate costings, incorporating all or some of the above techniques were described. All three strategies also included a bathymetric survey of each mere which is essential before detailed fish sampling can be planned.
4. The most appropriate mere for a biomanipulation experiment was found to be Fenemere, which, not by coincidence, also sustains a fishery for carp (*Cyprinus carpio* L.).

5. Rather than attempt to divide Fenemere or construct a large enclosure, it is recommended that a biomanipulation experiment would be best undertaken by a whole lake removal of fish. Such an approach is more robust against practical problems and is equally valid in scientific terms, given that 'control' areas or enclosures are not truly controlled in such manipulations. Given local angling interests and the nature of the fishery, it is strongly recommended that fish are removed alive by angling, trapping, fyke netting, perhaps seine netting, and section electrofishing, and transferred to another fishery.

6. The degree of monitoring required for a biomanipulation experiment is very flexible, depending in part on whether the aim is to obtain a full understanding of events or simply to determine success or failure with respect to a given set of conservation-based criteria. Consequently, and partly as a function of the present scarcity of fish data for Fenemere, detailed recommendations and costings are not given.

7. Before any efficient progress can be made in either conservation or fisheries management of the West Midland Meres, the production and adoption of an overall management strategy acceptable to English Nature, the National Rivers Authority and at least parts of the angling community, is suggested to be essential.

CHAPTER 1 INTRODUCTION

1.1 Background

The Meres of the Clwyd-Shropshire-Cheshire-Staffordshire plain form a series of standing water bodies of national and international importance in a conservation context. Consequently, 29 of the 60 sites have been designated as SSSIs.

As with any SSSI, it is important to identify the management options most appropriate to the site's protection and, in cases where it has been damaged, its restoration. Such activities, however, themselves require an understanding of the system and its plant and animal communities. In the general context of standing water bodies, research carried out particularly during the 1980s and 1990s has shown that in some situations the activities of fish populations can have dramatic effects on the water body as a whole. Such effects are typically negative in a general conservation context because they tend to promote phytoplankton populations at the expense of macrophytes, through indirect effects involving zooplankton or extensive physical disturbance of the bottom sediments (reviewed for cyprinid fishes by Winfield & Townsend, 1991). During the late 1980s and early 1990s, a number of attempts have been made to exploit such interactions in the newly emerging science of biomanipulation in which fish populations are typically removed or reduced in abundance (reviewed by Reynolds, 1994).

During 1990 and 1991, Moss *et al.* (1992) were commissioned by English Nature to assess the current limnological condition of a group of the West Midlands Meres that bear SSSI status.

They concluded that several meres were seriously threatened by eutrophication and recommended appropriate management options, one of which was fish removal. However, they also noted a paucity of fish information for many of the meres and a second commission was made by English Nature to gather fish information from 31 meres, most of which were SSSIs (Smith & Moss, 1994). While this second study collated considerable information by questionnaires to angling clubs, it found little from statutory sources (i.e. files of English Nature and the National Rivers Authority) and the published literature.

1.2 Objectives

Given the paucity of fish data for the meres revealed by the study of Smith & Moss (1994), the present study was commissioned by English Nature to determine the most appropriate ways in which such data could be gathered and to advise on the design of a biomanipulation experiment.

The objectives of this project were

1. To examine information available in seven documents (Giles, 1992; Morin, 1984; Moss *et al.*, 1992; Smith & Moss, 1994; Wright & Phillips, 1992, Wigginton, 1980; Wigginton & Palmer, 1989) and other relevant sources.

2. From 1, to provide detailed proposals for the determination of fish species, numbers, biomass, age classes and growth rates (preferably in a non-destructive way) from Aqualate Mere, Berrington Pool, Betley Mere, Bomere Pool, Cop Mere, Crose Mere, Fenemere, Hatch Mere,

Marton Pool near Chirbury, Quoisley Mere, Tabley Mere and Moat, and White Mere (following discussions with English Nature's Nominated Officer, Mary Gibson, it was agreed to produce recommendations for both Quoisley Big Mere and Quoisley Little Mere. Tabley Mere and Tabley Moat were also considered as discrete sites).

3. To produce a detailed specification for a biomanipulation experiment, involving either the construction of an enclosure or the division of the water body, for a specified mere. Initially, such a project was expected to run over a three year period.

1.3 Approach

Much of the work required in the present project involved the application of the authors' combined personal experience. To this were added appropriate literature searches of Aquatic Sciences and Fisheries Abstracts (1978 to 1994), personal contacts with individuals (from English Nature, the Institute of Freshwater Ecology, the National Rivers Authority, and the University of Wolverhampton) experienced in specific areas of fish sampling or the West Midlands Meres, and site visits to selected meres (Berrington Pool, Betley Mere, Bomere Pool, Cop Mere, Crose Mere, Fenemere and White Mere) during 6 and 7 February 1995.

CHAPTER 2 FISH SAMPLING AND EXAMINATION TECHNIQUES

2.1 Introduction

Given their obvious affiliations with fisheries, there is an understandably diverse body of fish sampling techniques, many of which have histories as old as or older than the science of ecology. There is, however, no one perfect method for obtaining a representative sample of fish from a lake population. All techniques have their own strengths and weaknesses, and the most appropriate approach for a given situation depends much on what information is required and what resources are available. Examination techniques, in contrast, are less diverse and to a large extent now standardised.

Many of these sampling techniques can, in theory, be used to produce estimates of fish abundance by marking and recapturing a number of individuals. An old, but still valid, review of such mark-recapture methods is provided by Youngs & Robson (1978). However, and as noted in our tender document, such estimates require extremely high marking and recapture efforts and have rarely been used with success in U.K. standing water bodies. Consequently, they are considered inappropriate in the present context and so are not considered further.

The following is a brief description of sampling and examination techniques typically used in studies of fish in standing water bodies. Particular emphasis is placed on those characteristics of the sampling techniques which are particularly relevant to their use in the West Midland Meres.

2.2 Descriptions of sampling techniques

A comprehensive classification of sampling techniques for freshwater fish in natural standing water bodies, with brief comments on their use, is presented in Table 2.1. These descriptions are amplified below, although they are still brief. Further details of most techniques may be found in Lagler (1978), while Cowx (1991), Cowx & Lamarque (1990) and Winfield & Bean (in press) provide more recent reviews of the developing fields of fishery data, electrofishing and echo sounding, respectively.

Fishery data

The exploitation of fisheries as a crude but high-volume surrogate sampling device has a long history of use in studies of freshwater fish. Obviously, such techniques are dependent on the existence of a fishery and co-operation from both its owners and anglers. They have the benefit of requiring relatively little effort on behalf of the researcher, encouraging constructive dialogue with anglers, and being non-destructive in recreational fisheries. A major limitation is that little, if any, information is acquired for underyearling fish, and the fishery is usually biased towards certain fish species.

Catch-per-unit-effort

The number or weight of fish taken in a fishery obviously bears some relation to the numbers of fish present in the water body. However, it is also influenced by the amount of effort invested

Table 2.1. Sampling techniques for freshwater fish in natural standing water bodies, with brief comments on their use. Unless stated otherwise, underyearling fish are not usually sampled and the technique is not necessarily destructive.

Category	Subcategory	Comments
Fishery data	Catch-per-unit-effort	Requires co-operation from fishery owners/anglers. Results typically noisy. Independent of water body characteristics.
	Catch examination	Requires co-operation from fishery owners/practicers. Samples likely to be biased. Independent of water body characteristics.
Passive capture	Trap	Requires little effort. Samples likely to be biased. Independent of habitat features. Traps for underyearlings are also available.
	Fyke net	Requires little effort. Samples likely to be biased. Difficult to deploy in macrophyte-rich habitats.
	Trammel net	Requires little effort. Samples likely to be biased. Difficult to deploy in macrophyte-rich habitats.
	Gill net	Requires little effort. Samples likely to be biased. Difficult to deploy in macrophyte-rich habitats. Usually destructive.
	Gill net (for underyearlings)	Requires little effort. Samples likely to be biased. Independent of habitat features. Usually destructive.
Active capture	Rotenone	Requires little effort. Samples relatively unbiased. Restricted to small or shallow water bodies. Inherently destructive.
	Seine net	Requires high effort. Samples relatively unbiased. Restricted to shallow, open water habitats with unobstructed bottoms. Seine nets for underyearlings are also available.
	Trawl	Requires relatively large boat and effort. Samples relatively unbiased. Restricted to open water habitats.
	Trawl (for larvae)	Requires moderate effort. Samples relatively unbiased. Restricted to open water habitats.
	Dip net (for larvae)	Requires moderate effort. Samples relatively unbiased. Restricted to shallow habitats.
	Bouyant net (for underyearlings)	Requires high effort. Samples relatively unbiased. Restricted to open water habitats.
	Electrofishing (section)	Requires high effort. Samples relatively unbiased. Restricted to shallow habitats.
	Electrofishing (point)	Requires moderate effort. Samples relatively unbiased. Restricted largely to underyearlings and shallow habitats.
Remote techniques	Visual	Requires high effort. Restricted to high clarity habitats.
	Quantitative echo sounder (vertical)	Requires moderate effort. Restricted to relatively deep (> 5 m), open water habitats. Advanced systems can detect underyearlings.
	Quantitative echo sounder (horizontal)	Requires moderate effort. Restricted to open water habitats. Advanced systems can detect underyearlings. Systems still largely in development phase.

by the fishery, which may itself vary considerably with time. By making some measurement of such effort, it is possible to standardise catches to catch-per-unit-effort (or CPUE) which is often robust enough to give an indication of the relative abundance of fish and trends therein. For angling fisheries in the U.K., typical units of CPUE include number (or weight) of fish per angler-day. Such information can be gathered by real-time observation and/or census, or by record collections.

Catch examination

Fishery catches can be examined or used as a source of biological specimens. Measurements of fish lengths and weights, and the removal of scales for subsequent ageing can be undertaken by anglers themselves, but angling on bodies such as the Meres typically involves the capture of too many fish for this to be feasible on a voluntary basis, requiring the presence of researchers.

<u>Passive capture</u>

Passive capture techniques largely rely on the behaviour of the fish putting themselves into a capturing device which is left in the water body for a length of time, typically overnight. As a result, they usually produce biased samples (for both fish species and size) but have the benefit of requiring relatively little effort and being largely independent of water depth. However, bathymetry does influence the ways in which such equipment is deployed and so a detailed knowledge of this aspect of the water body is usually required prior to sampling. Depending on their method of operation, passive capture techniques may be non-destructive or destructive.

Trap

Many kinds of traps have been deployed in studies of freshwater fish, although the most successful models are simple variations on the marine lobster pot. Specific traps may be constructed to catch large adults or smaller fish. Although the latter have been rarely used in the U.K., they are commonly used in North America (e.g. Mathis & Smith, 1992). Traps can be set in even very dense macrophyte stands and are usually non-destructive.

Fyke net

Fyke nets can be considered as a special form of trap which is constructed not from a rigid mesh, but from netting. They typically have long 'leaders' which help to guide fish in, but which make their deployment difficult in even moderate macrophyte stands. They are usually non-destructive.

Trammel net

The trammel net is a hybrid between a trap and a gill net (see below). The net is composed of three curtains of mesh, the middle one of which is much smaller than the others. The principle of operation is that a fish swims into the net and pushes a pocket of fine mesh through one of the coarser outer layers. In theory, the fish is captured undamaged but in some situations, particularly with small fish typical of lake populations, the method can be destructive. It is also usually selective with respect to fish size. Trammel nets are usually long and difficult to set among macrophytes.

Gill net

Gill nets have similarities with trammel nets, but they are simpler in operation. They are composed of just one curtain of mesh and capture fish by allowing the head but not the entire body to pass through. The captured individual is unable to reverse out of the net due to its gill covers. Obviously, a certain mesh size will only catch a certain size range of fish. However, in scientific use gill nets are usually deployed in the form of a survey net including many different mesh sizes so that most fish sizes present in a water body are likely to be captured, although meshes required to capture small underyearlings are so fine and thus expensive that they are usually not incorporated (but see below). Like trammel nets, gill nets are usually long, difficult to set near macrophytes and are effectively destructive.

Gill net (for underyearlings)

Gill nets designed to sample underyearlings (from a minimum body length of approximately 30 mm) and identical in their principle of operation to gill nets designed to catch older fish. They vary only in their mesh size, which may be as small as a few millimetres, and their overall length. The latter is usually short due to their high cost and the fact that the typically relatively higher abundance of underyearlings results in higher catch rates. As a result, they can be deployed among moderate growths of macrophytes (e.g. Venugopal & Winfield, 1993).

Active capture

Active capture techniques involve a greater sampling effort than do passive techniques, but generally produce relatively unbiased samples. With the exception of trawling they tend to be restricted in use to shallow habitats. With one exception, they are also largely non-destructive.

Rotenone

Rotenone is a short-lived poison produced naturally in plants of the genus *Derris*, among others. It has been used extensively in scientific studies in the past, particularly in North America, although it is obviously restricted to small and shallow water bodies. There are other obvious reservations about the use of a poison in any natural water body and the technique is now rarely used.

Seine net

The seine net is a rectangular piece of netting with one long length weighted and the other supported by floats. It is typically deployed in a semi-circle by boat from the shore to enclose a known volume of water, assuming that the water depth does not exceed the height of the net. The net is then pulled into shore and the relatively unbiased catch quickly removed. The technique is thus largely restricted to smooth-bottomed inshore areas where the water depth is typically less than 5 m and preferably less than 3 m, and where the shore is solid and unobstructed by features such as reedbeds. More unusually, seine nets can be deployed from a mobile pontoon (e.g. Jordan & Wortley, 1985) to allow sampling away from the shore. However, even in smooth-bottomed areas, problems can be encountered due to mud or silt accumulating in the net, and the technique is impossible in areas of even very limited macrophyte growths. Small-meshed seine nets are available to sample underyearlings, although they are difficult to operate effectively. The technique is usually non-destructive.

Trawl

Trawl nets used in freshwater investigations are usually smaller versions of their marine counterparts, although they are still large pieces of equipment and require a large and powerful boat. In use, the trawl net is pulled horizontally behind the boat, typically for distances of tens of metres and greater. Clearly, the technique is restricted to open water but it does produce unbiased samples of undamaged fish, usually of lengths from 50 mm upwards. The major limitation on the use of this technique in standing water bodies is its reliance on the availability of a sufficiently large and powerful boat.

Trawl (for larvae)

Much smaller versions of trawls are available for sampling fish larvae (i.e. the earliest stages of free-swimming fish, typically with very limited powers of locomotion, which have yet to metamorphose into a near-adult form). These operate much like a horizontally-towed zooplankton net and can be deployed from small and low-powered boats. Samples of larvae are usually unbiased and undamaged, although as they grow and metamorphose the catching efficiency of this technique declines markedly and differentially between fish species. In use, like larger trawls, the technique is restricted to open water.

Dip net (for larvae)

Simple dip or pond nets can be used to produce unbiased and undamaged samples of larvae from the extreme inshore zones of a standing water body, including among extensive macrophyte growths where trawling is impossible. This sampling technique can be carried out by one person and can be used as a scouting tool to precede more quantitative studies.

Buoyant net (for underyearlings)

This technique exploits the observation that underyearling fish, including larvae, tend to show less avoidance reaction to a net rising from below than they do to one approaching from the side or above. The buoyant net (described in detail by Bagenal, 1974) is a circular net, typically of a diameter of approximately 1 m, which is set on the bottom of the water body. After a period of time, typically several tens of minutes or even hours, a slowly-dissolving trigger releases the net which floats to the surface and captures any fish immediately above it. The fish are captured undamaged and, with respect to underyearlings, the sample is usually unbiased. Due to the small volume of water sampled by a buoyant net, many nets (typically several tens) must be set at one time to enable the calculation of confidence limits on a measure of relative fish abundance. When such effort is invested, estimates are truly quantitative (see Hewitt, 1979) and have been used to estimate year class strength (e.g. Cryer *et al.*, 1986). The major limitations on this technique are that relatively high effort is required, the nets cannot be set among dense macrophyte growths, and, due to an increasing probability of turning over when rising, nets set in water deeper than a few metres are usually very inefficient.

Electrofishing (section)

Classic electrofishing procedures can be used to sample fish, both adults and larger underyearlings, from shallow sections of standing water bodies. Samples may be taken from among dense macrophyte growths, although catching efficiency may be reduced in such areas. The samples produced by this technique are relatively unbiased and undamaged, particularly when a section is isolated by nets. A major limitation is the high effort required to sample even a fraction of the suitable inshore zone.

Electrofishing (point)

Instead of electrofishing entire shallow sections of a water body, samples of fish may be obtained by electrofishing discrete points which are randomly selected and approached without disturbing any fish present. This technique is often known as Point Abundance Sampling and is extensively described by Copp (1990), who has been able to demonstrate its value in studies of young fish which may be approached easily without disturbance. As its name suggests, this technique may be used to obtain an estimate of underyearling abundance which is comparable between habitat types, e.g. open water or among macrophytes, between water bodies, or over time. Like section electrofishing, the technique is restricted to shallow areas, but unlike the classic approach it requires only moderate sampling effort.

Remote techniques

In recent years, the array of sampling approaches described above has been strengthened by the addition of remote techniques in which information is gathered on fish without their capture. Such techniques can never replace more established capture-based methodologies, but they can offer information which is otherwise unobtainable. The most important of these fields is echo sounding, in which an acoustic beam is sent into the water body either vertically or horizontally in order to count the numbers of fish present. A recent review of this apparently simple, but in fact highly complex, technique is provided by Winfield & Bean (in press).

Visual

Visual techniques involving submerged cameras, snorkelling or SCUBA have been used extensively in freshwater fish surveys around the world, although less frequently in standing water bodies in the U.K. where low clarity commonly presents an insurmountable problem. The technique requires a high degree of effort involving either sophisticated equipment, trained divers, or both, which results in a high financial cost to its use.

Quantitative echo sounding (vertical)

In the last few years, vertical echo sounding has become increasingly frequently used in studies of fish distribution and abundance in standing water bodies. While the technique is still developing, it can be used to produce valid estimates of fish abundance in water of depth in excess of approximately 5 m. Depending on the sophistication of the system, indirect or direct estimates may be made of fish size, although fish species *per se* cannot be determined. Again depending on the system in use, fish as small as larvae may be detected, although approximately 50 mm is a more usual lower limit. Macrophytes may cause difficulties in data interpretation, although they are rarely abundant in water of depth 5 m and greater. The only other significant restraint on the use of this technique is the requirement for sophisticated and expensive equipment.

Quantitative echo sounding (horizontal)

Even more recently, horizontal echo sounding has been developed for use in studies of fish distribution and abundance. Apart from the difference in beam orientation, the technique is very similar to vertical echo sounding and shares most of its strengths and limitations. However, it can be used in very shallow water depths, although not in the presence of macrophytes. To the best of the authors' knowledge, the technique has not yet been used in routine surveys of standing water bodies in the U.K. and the National Rivers Authority is the only body possessing suitable equipment.

2.3 Descriptions of examination techniques

Methods for the examination of captured fish are now well established. Some can be carried out in the field on fish which may then be returned to the water unharmed, while some require that the fish is killed and taken to a laboratory. An extensive review of examination techniques is provided by Lagler (1978).

Species identification

Species identification of U.K. freshwater fish presents few problems and can usually be carried out in the field, perhaps with the aid of the key provided in Maitland (1972). The only difficulties are presented by hybrids, particularly between members of the family Cyprinidae, and by the larvae of some species, again mainly among the Cyprinidae. Both hybrids and larvae may require detailed examination in the laboratory before they can be confidently identified. A useful key for cyprinid larvae is given by Spindler (1988).

Individual length, weight and condition

Lagler (1978) describes in detail how individual length, weight and condition are best measured. Again, with the exception of larvae, measurements can be made on live fish in the field. A plethora of condition indices has been described in the literature, although the use of some of them is not recommended on statistical grounds. A simple but adequate index proposed by Mills (1987) is recommended.

Ageing and growth, including back-calculation

Fish of temperate zones typically show strongly seasonal patterns of growth, records of which may be captured as annual rings in hard body parts such as scales, opercular (gill cover) bones, or the otoliths of the inner ear. Such structures have long been used to determine the age of individual fish and Bagenal & Tesch (1978) reviews the basic techniques involved. A few scales can be removed from live fish in the field with negligible damage and are usually adequate for the ageing, by microscopic examination, of all but the most slow-growing of individuals. The latter can usually be aged by the more finely-detailed records held in the opercular bone or otoliths, although the use of such structures clearly requires the fish to be killed. In combination with length data, the age of a fish can be used to determine its growth. Moreover, by measuring the distances between the annual rings of the hard part and determining the relationship between the size of that hard part and the length of the fish, it is possible to 'back-calculate' the growth history of an individual.

Population structure

Using the above data from individual fish, it is possible to produce various descriptors of the population structure of the species. In the present context, the most important of these are simple histograms of individual length and age class composition.

2.4 Site-specific recommendations

The most appropriate sampling techniques for a given water body strongly depend on several of its features. Of particular relevance are its size, bathymetry, macrophyte abundance, and angling practices. Unfortunately, detailed bathymetry data are unavailable for the West Midland Meres and so, in their absence, the parameter of maximum depth has been considered. While this is adequate to enable broad recommendations to be made, it is strongly advised that the detailed bathymetry of each mere is established before any fish sampling is attempted. Bathymetry of adequate detail for the present purposes could be established quickly using a simple echo sounder.

An overall summary of the suitability of fish sampling techniques for each mere is presented in Table 2.2, even though the construction of such a simple table masks a considerable amount of complexity and uncertainty. The information considered when producing this table is given below on a site by site basis, together with recommended techniques for the sampling of larvae, underyearlings and adults. Where alternative sampling techniques are possible, the technique with widest applicability has been recommended because there is considerable merit in adopting a common sampling strategy for all of the sites wherever possible. However, numerous peculiar site features mean that this ideal cannot always be achieved. It is acknowledged that seine netting may be feasible in restricted parts of some meres, but this technique cannot be presently widely recommended in the absence of bathymetric information. Additional notes, where appropriate, are given in italics for each site. Issues relating to general recommendations, including details of equipment, approach and timing of sampling, and options for differing levels

Table 2.2. The suitability (✓) of fish sampling techniques for each mere, taking into account scientific, logistical and financial considerations. Abbreviations are as follows: AqM, Aqualate Mere; BeP, Berrington Pool; BeM, Betley Mere; BoP, Bomere Pool; CoM, Cop Mere; CrM, Crose Mere; Fe, Fenemere; HaM, Hatch Mere; MaP, Marton Pool, Chirbury; QBM, Quoisley Big Mere; QLM, Quoisley Little Mere; TMe, Tabley Mere; TMo, Tabley Moat; WhM, White Mere. [d] indicates that the technique is usually destructive.

Category	Subcategory	Mere													
		AqM	BeP	BeM	BoP	CoM	CrM	Fe	HaM	MaP	QBM	QLM	TMe	TMo	WhM
Fishery data	Catch-per-unit-effort	✓	✓	✓	✓	✓		✓	✓	✓			✓	✓	
	Catch examination	✓	✓	✓	✓	✓		✓	✓	✓			✓	✓	
Passive capture	Trap	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Fyke net	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Trammel net	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Gill net [d]	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Gill net (for underyearlings) [d]	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Active capture	Rotenone [d]														
	Seine net	✓		✓			✓	✓	✓	✓	✓				✓
	Trawl														
	Trawl (for larvae)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Dip net (for larvae)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Bouyant net (for underyearlings)	✓						✓	✓	✓	✓				
	Electrofishing (section)	✓		✓		✓		✓	✓	✓	✓	✓		✓	
	Electrofishing (point)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Remote techniques	Visual														
	Quantitative echo sounder (vertical)		✓		✓		✓								✓
	Quantitative echo sounder (horizontal)	✓	✓		✓		✓	✓	✓	✓	✓				✓

of available resources, are covered in a final section.

In the following site accounts, surface area and maximum depth are taken from Reynolds (1979), plant cover from Moss *et al.* (1994), and angling practices from Smith & Moss (1994), unless specified otherwise.

Aqualate Mere (National Grid Reference SJ 772 204)

Surface area (ha)	72.5
Maximum depth (m)	2.0 (Wigginton, 1980)
Plant cover (%)	Some floating, little submerged (C. Walker, English Nature, pers. comm.)
Angling practices	Up to 10 person-days/week

Recommended techniques

Larvae: Dip net, electrofishing (point)

Underyearlings: Gill net (for underyearlings), electrofishing (point)

Adults: Angling catch-per-unit-effort and catch examination, gill net

Vivien Green of the National Rivers Authority Severn-Trent Region is just starting a study of the fish populations of this mere (J. V. Woolland, National Rivers Authority Severn-Trent Region, pers. comm.).

Berrington Pool (National Grid Reference SJ 525 072)

Surface area (ha)	2.5
Maximum depth (m)	12.2
Plant cover (%)	Less than 10
Angling practices	Up to 5 person-days/week

Recommended techniques

Larvae: Dip net, electrofishing (point)

Underyearlings: Gill net (for underyearlings), electrofishing (point)

Adults: Angling catch-per-unit-effort and catch examination, gill net, quantitative echo sounder (vertical)

The National Rivers Authority hold some limited fisheries information, mostly from echo-sounding studies, for this site (J. V. Woolland, National Rivers Authority Severn-Trent Region, pers. comm.).

Betley Mere (National Grid Reference SJ 749 479)

Surface area (ha)	9.3 (including extensive reedbeds)
Maximum depth (m)	1.8
Plant cover (%)	Near 100

Angling practices Up to 15 person-days/week

Recommended techniques

Larvae: Dip net, electrofishing (point)

Underyearlings: Gill net (for underyearlings), electrofishing (point)

Adults: Angling catch-per-unit-effort and catch examination, gill net

Bomere Pool (National Grid Reference SJ 500 080)

Surface area (ha)	10.3
Maximum depth (m)	15.2
Plant cover (%)	Less than 10
Angling practices	Up to 8 person-days/week

Recommended techniques

Larvae: Dip net, electrofishing (point)

Underyearlings: Gill net (for underyearlings), electrofishing (point)

Adults: Angling catch-per-unit-effort and catch examination, gill net, quantitative echo sounder (vertical)

The National Rivers Authority hold some limited fisheries information, mostly from echo-

sounding studies, for this site (J. V. Woolland, National Rivers Authority Severn-Trent Region, pers. comm.).

Cop Mere (National Grid Reference SJ 802 298)

Surface area (ha)	16.8
Maximum depth (m)	2.7
Plant cover (%)	Greater than 75
Angling practices	Up to 50 person-days/week. Some competitions

Recommended techniques

Larvae: Dip net, electrofishing (point)

Underyearlings: Gill net (for underyearlings), electrofishing (point)

Adults: Angling catch-per-unit-effort and catch examination, gill net

Crose Mere (National Grid Reference SJ 430 305)

Surface area (ha)	15.2
Maximum depth (m)	9.3
Plant cover (%)	Less then 10
Angling practices	Almost none

Recommended techniques

Larvae: Dip net, electrofishing (point)

Underyearlings: Gill net (for underyearlings), electrofishing (point)

Adults: Gill net, quantitative echo sounder (vertical)

The National Rivers Authority hold some limited fisheries information, mostly from echo-sounding studies, for this site (J. V. Woolland, National Rivers Authority Severn-Trent Region, pers. comm.).

<u>Fenemere (National Grid Reference SJ 446 229)</u>

Surface area (ha)	9.4
Maximum depth (m)	2.2
Plant cover (%)	10 to 20
Angling practices	Up to 70 person-days/week. Some competitions

Recommended techniques

Larvae: Dip net, electrofishing (point)

Underyearlings: Gill net (for underyearlings), electrofishing (point)

Adults: Angling catch-per-unit-effort and catch examination, gill net

This site sustains a very active carp fishery and it is extremely unlikely that gill netting of any description would be welcomed by the fishery owners. In this particular case, and given the considerable amount of data which could probably be obtained from a co-operative fishery, the use of gill nets could be avoided and be substituted by the use of fyke nets.

Hatch Mere (National Grid Reference SJ 553 722)

Surface area (ha)	4.7
Maximum depth (m)	3.8
Plant cover (%)	20
Angling practices	Up to 2 person-days/week

Recommended techniques

Larvae: Dip net, electrofishing (point)

Underyearlings: Gill net (for underyearlings), electrofishing (point)

Adults: Angling catch-per-unit-effort and catch examination, gill net

Marton Pool, Chirbury (National Grid Reference SJ 295 027)

Surface area (ha)	13.7
Maximum depth (m)	3.0 (C. Walker, English Nature, pers. comm.)
Plant cover (%)	Moderate submerged (C. Walker, English Nature, pers. comm.)

Angling practices	Up to 2 person-days/week

Recommended techniques

Larvae: Dip net, electrofishing (point)

Underyearlings: Gill net (for underyearlings), electrofishing (point)

Adults: Angling catch-per-unit-effort and catch examination, gill net

Quoisley Big Mere (National Grid Reference SJ 546 456)

Surface area (ha)	4.0
Maximum depth (m)	2.4
Plant cover (%)	10 to 20
Angling practices	Almost none

Recommended techniques

Larvae: Dip net, electrofishing (point)

Underyearlings: Gill net (for underyearlings), electrofishing (point)

Adults: Gill net

Quoisley Little Mere (National Grid Reference SJ 549 456)

Surface area (ha)	2.2
Maximum depth (m)	1.8
Plant cover (%)	100
Angling practices	Almost none

Recommended techniques

Larvae: Dip net, electrofishing (point)

Underyearlings: Gill net (for underyearlings), electrofishing (point)

Adults: Gill net

Tabley Mere (National Grid Reference SJ 723 767)

Surface area (ha)	19.4
Maximum depth (m)	4.4
Plant cover (%)	Greater than 75
Angling practices	Up to 18 person-days/week

Recommended techniques

Larvae: Dip net, electrofishing (point)

Underyearlings: Gill net (for underyearlings), electrofishing (point)

Adults: Angling catch-per-unit-effort and catch examination, gill net

Tablev Moat (National Grid Reference SJ 721 774)

Surface area (ha)	2.0 (Moss *et al.*, 1992)
Maximum depth (m)	1.5 (Moss *et al.*, 1992)
Plant cover (%)	Near 100
Angling practices	Up to 40 person-days/week

Recommended techniques

Larvae: Dip net, electrofishing (point)

Underyearlings: Gill net (for underyearlings), electrofishing (point)

Adults: Angling catch-per-unit-effort and catch examination, gill net

White Mere (National Grid Reference SJ 415 330)

Surface area (ha)	25.5
Maximum depth (m)	13.8
Plant cover (%)	10 to 20
Angling practices	Almost none

Recommended techniques

Larvae: Dip net, electrofishing (point)

Underyearlings: Gill net (for underyearlings), electrofishing (point)

Adults: Gill net, quantitative echo sounder (vertical)

The National Rivers Authority hold some limited fisheries information, mostly from echo-sounding studies, for this site (J. V. Woolland, National Rivers Authority Severn-Trent Region, pers. comm.).

2.5 General recommendations and costings

The above site by site recommendations cover eight sampling techniques (taking point electrofishing for larvae and for underyearlings as effectively discrete techniques due to the timing differences). The following gives specific methodological recommendations for the equipment, approach and timing of each technique, before offering three alternative strategies with an indication of their costings. Finally, the strategy considered to be most appropriate is recommended. Before any fish sampling is attempted under any strategy, however, it is strongly recommended that a bathymetry survey as described below is undertaken for each mere. In addition to facilitating the identified sampling techniques, it is possible that such determination of the bathymetry of the meres may also reveal areas suitable for limited non-destructive seine netting.

Bathymetry survey

The bathymetry of each mere should be established using an echo sounder recording to a paper trace. Even with such simple equipment, it would be possible to produce 1 m depth contours with the investment of an average of less than a half day of field work for each mere. The only restriction on the timing of such work is that it should precede the fish sampling. Output would be bathymetric maps with 1 m depth contours.

Detailed recommendations on methodologies

Adult sampling

Angling catch-per-unit-effort and catch examination clearly depend greatly on the degree of co-operation given by the fishery, which will itself probably vary considerably between the meres. Nevertheless, it is recommended that the following approach should at least be attempted in all cases. Catch-per-unit-effort should be recorded through the voluntary completion of 'catch cards' for each day's angling, which should also have provision for details of the major species and sizes of fish taken. Direct catch examination by the researcher is only likely to be of value at heavily-fish meres, particularly those where competitions are held. Such data collection should be carried out over a full year to allow for changes in target species which typically occur over the four seasons. The likely success of both of these forms of fishery data gathering would be greatly enhanced by close and interactive contact with appropriate angling clubs and fishery owners. The importance of such dialogue should not be underestimated. Output would include species lists, relative abundance (through CPUE), description of the fishery catch, and restricted information on age class structure and growth rates (complete descriptions of the latter require data from a less biased source).

Gill nets are recommended as the principal sampling technique for adult fish because they can be deployed in a uniform manner in all of the meres and, by using a standard survey net, will produce information comparable with that of other studies in the U.K. and elsewhere. It is recommended that the monofilament S-REV Sölab survey gill net (Lundgrens Fiskredskaps-Fabrik A.-B., Stockholm, Sweden) is used in inshore bottom, offshore bottom and offshore floating (where possible in deeper meres in the absence of water sports) sets at each mere. Each duo or trio of nets should be set for a period of up to 24 hours during the summer months. All of the catch should be killed and returned to the laboratory for full examination as described earlier. In the presence of unsurmountable local opposition to gill nets, the latter could be substituted by five inshore bottom and five offshore bottom **fyke nets** which would allow species identification, individual length and weight measurement, and scale removal to be undertaken on live fish. It is also possible, depending on the presently unknown bathymetry of each mere, that **seine netting** could also be used as an alternative to gill netting at some sites. However, such sampling is likely to produce less comparable results. Output would include species lists, relative abundance (through CPUE), age class structure, and growth rates.

Vertical quantitative echo sounding should use equipment such as the Simrad EY200P with HADAS or the Simrad EY500 with EP500 which can give estimates of both the abundance and individual sizes of a fish population. Transects across the deepest part of the mere should be repeated at least over dusk, and preferably through the night, on one occasion during the summer months. Output would include abundance of various size classes of fish and their vertical and horizontal distributions.

Underyearling sampling

Point electrofishing should be carried out using equipment similar to that described by Copp (1990) deployed from a small boat. The most appropriate number of sampling points will vary with the length of the inshore zone of the mere and, rather than give an absolute value, it is recommended that one full field day of effort is expended at each mere. Such field work should include species identification and length measurements. For underyearlings, the sampling should be undertaken in September or early October when the summer's growth has ceased but the fish have not yet moved to their winter habitats where they may be uncatchable by electrofishing. Output would include species lists, relative abundance, habitat associations and growth rates.

Gill nets (for underyearlings) should be used to cover the offshore habitats of some meres which cannot be sampled by electrofishing, although the use of an inshore set would be useful for comparisons. It is recommended that monofilament mesh sizes of 6, 10 and 15 mm are used to allow for inter-specific and inter-mere differences in growth rates, and hence size at the end of the summer. Nets should be set for a 24 hour period during September or early October. All of the catch should be killed and returned to the laboratory for full examination as described earlier. Output would include species lists, relative abundance (through CPUE), limited vertical and horizontal distributions, and growth rates.

Larvae sampling

Dip nets should be of a standard design, e.g. the long-handled Freshwater Biological Association pond net, and deployed on foot around the edge of the mere. With the exception of only a few species which can be readily identified as live specimens in the field, the catch should be killed and returned to the laboratory for identification and measurement under the binocular microscope. Such sampling should commence in early May and be utilised in a flexible manner as a scouting technique to influence the design of subsequent larvae and underyearling sampling. Output would include species lists, an indication of relative abundance which would influence subsequent sampling of young fish, and growth rates.

Point electrofishing for larvae should be carried out using equipment similar to that described by Copp (1990) deployed from a small boat. As for underyearlings, the most appropriate number of sampling points will vary with the length of the inshore zone of the mere and it is again recommended that one full field day of effort is expended at a time for each mere. Such field work should include species identification and length measurements, usually by the killing of samples or subsamples and their subsequent examination in the laboratory. For larvae, the sampling should be undertaken at fortnightly intervals from early May through to the mid and late summer, depending on presently unknown local developmental rates of the fish. Output would include species lists, relative abundance, habitat associations and growth rates.

Alternative strategies and costings

In all three of the alternative strategies described below, it is assumed that overall sampling is to be undertaken at all 14 meres considered in this report. It is also assumed that the examination techniques described earlier are carried out on samples from all sites, with ageing based primarily on scale examinations.

Strategy 1: Bathymetry survey, adult, underyearling and larvae sampling

To include bathymetry survey at 14 meres, fishery catch-per-unit-effort and catch examination at 10 meres, gill netting (one visit of three sets) at 14 meres, echo sounding (one visit) at 4 meres, point electrofishing for underyearlings (one visit) at 14 meres, gill netting for underyearlings (one visit of three sets) at 14 meres, dip netting (three visits) at 14 meres, point electrofishing for larvae (three visits) at 14 meres.

Estimated costs of £1,000 for consumables, £22,450 for staffing (assuming that the project is lead by researchers with considerable experience in fish surveying). In addition, allowance must be made for travel and subsistence costs which will depend greatly upon the location from which the project is undertaken. Taking a figure of £2,200 for such costs, the total costing for the strategy is £25,650.

Strategy 2: Bathymetry survey, adult and underyearling sampling

To include bathymetry survey at 14 meres, fishery catch-per-unit-effort and catch examination at 10 meres, gill netting (one visit of three sets) at 14 meres, echo sounding (one visit) at 4 meres, point electrofishing for underyearlings (one visit) at 14 meres, gill netting for underyearlings (one visit of three sets) at 14 meres.

Estimated costs of £1,000 for consumables, £15,450 for staffing (assuming that the project is lead by researchers with considerable experience in fish surveying). In addition, allowance must be made for travel and subsistence costs which will depend greatly upon the location from which the project is undertaken. Taking a figure of £1,300 for such costs, the total costing for the strategy is £17,750.

Strategy 3: Bathymetry survey, adult sampling

To include bathymetry survey at 14 meres, fishery catch-per-unit-effort and catch examination at 10 meres, gill netting (one visit of three sets) at 14 meres, echo sounding (one visit) at 4 meres.

Estimated costs of £1,000 for consumables, £11,250 for staffing (assuming that the project is lead by researchers with considerable experience in fish surveying). In addition, allowance must be made for travel and subsistence costs which will depend greatly upon the location from which the project is undertaken. Taking a figure of £950 for such costs, the total costing for the strategy is £13.200.

CHAPTER 3 BIOMANIPULATION EXPERIMENT

3.1 Introduction

The science of biomanipulation is undoubtedly still in a phase of development, although following a period when many limnologists fell into two clearly opposed camps with respect to the validity of the technique, there is now an emerging consensus that under appropriate conditions it has a high probability of success in water bodies with a maximum depth less than 3 or 4 m (e.g. Moss *et al.*, 1994; Reynolds, 1994). Several of the West Midland Meres meet such conditions.

Biomanipulation research and application are extremely demanding fields in terms of the complexity of their science (see Gulati *et al.*, 1990) and require a considerable understanding of the limnology of the target water body, including the ecology of its fish populations. As information on the latter is very poor for the West Midland Meres, it is difficult to give anything other than general recommendations for a biomanipulation experiment. Indeed, it was noted in our tender document that most effort during the present project would be put into the fish sampling objectives in order to facilitate the production of a more critical experimental specification at a later date.

Nevertheless, the following sections describe a basic approach recommended for a biomanipulation experiment in the West Midland Meres, even though it may need to be extensively modified when further information on the fish populations becomes available.

The design of a biomanipulation experiment involves two aspects. Firstly, the site to be biomanipulated must be identified, and secondly, the methods by which it is to be manipulated and monitored must be considered. While biomanipulation can in theory be accomplished not by the direct removal of planktivorous or benthivorous fish, but by the addition of piscivorous fish, this approach has not yet been shown to be effective with the limited range of piscivores available in Europe. Consequently, the following considers only methods of fish removal.

3.2 Site recommendation

Following their extensive and comprehensive, with the exception of the fish populations, study of 23 sites among the West Midland Meres, Moss *et al.* (1992) recommended that biomanipulation through the mechanism of fish removal should be undertaken at four meres. Three of these sites, i.e. Betley Mere, Cop Mere and Fenemere, are among the 14 meres of the present project and their salient features (see concluding section of Reynolds, 1994) are given in Table 3.1.

All three meres meet most of the likely requirements for successful biomanipulation tentatively listed by Reynolds (1994), although all three are larger than his preferred maximum size of 4 ha. On the grounds of this parameter alone, the manipulation of the fish populations of Cop Mere would present great practical problems, while the treatment of Betley Mere or Fenemere would be more feasible but still present a considerable task.

It is also pertinent to note that in addition to biomanipulation, Moss *et al.* (1992) also

Table 3.1. Characteristics of Betley Mere, Cop Mere and Fenemere examined to determine the most suitable site for a biomanipulation experiment. Sources of information are as follows. [a] Reynolds (1979), [b] Moss *et al.* (1992).

Characteristic	Mere		
	Betley Mere	Cop Mere	Fenemere
Surface area (ha) [a]	9.3 (including extensive reedbeds)	16.8	9.4
Maximum depth (m) [a]	1.8	2.7	2.2
Shallow/deep classification [b]	Shallow	Shallow	Shallow
Retention time (weeks) [b]	3.6 maximum	4.0	10.8
Phytoplankton [b]	Green dominated	Green dominated	Green dominated
Macrophytes [b]	Extensive	Moderate	Potential
Daphnia [b]	Scarce	Present	Present
State [b]	Threatened	Threatened	Altered
Nutrient control recommended [b]	✓	✓	
Fish removal recommended [b]	✓	✓	✓

recommended urgent nutrient control at both Betley Mere and Cop Mere. The complicating factors of stock wastes at Betley Mere and nutrient-rich river water at Cop Mere both detract from their suitabilities as experimental biomanipulation sites.

Given the above considerations, Fenemere is recommended as the most appropriate biomanipulation site on scientific grounds.

3.3 Methodological recommendations and costings

Lake division

Most early biomanipulation studies were carried out using small or large enclosures to facilitate the manipulation of fish population densities (see Gulati *et al.*, 1990). While forming a valuable first approach to biomanipulation studies, such techniques were and still are open to the criticism that they were often grossly simplified representations of the whole water body and induced significant artifacts, even within very large 'limnocorrals' (see Bloesch *et al.*, 1988). Such criticisms are particularly appropriate with respect to fish populations which typically show marked vertical and/or horizontal migrations in a lake on a diel and/or seasonal basis.

Subsequently, research effort has been directed more towards dividing lakes, where they are shallow enough for this approach to be feasible, to provide a 'control' area (e.g. Meijer *et al.*, 1989), or even manipulating whole lakes either with or without reference to a nearby 'control' lake (e.g. Jeppesen *et al.*, 1991; Malley & Mills, 1992). Many critics and practitioners of biomanipulation accept that such 'controls' are rarely adequate. In addition, they may be impossible or simply extremely expensive and difficult to deploy.

Given the above developments in the field of biomanipulation, it is recommended that the manipulation of Fenemere should be carried out on a whole lake basis. This proposal is made in view of the scientific doubt concerning the validity of biomanipulation controls for anything other than small but replicated enclosures (which have their own problems), the difficulty and expense of erecting a zooplankton-proof dividing structure, bearing in mind the complex hydrology of Fenemere (see Moss *et al.*, 1992), and the real possibility of such a dividing structure being breached during an experiment running over several years. While an investigation of the bottom-disturbing effects, or bioturbation, of large carp in Fenemere could be made using a simple coarse-meshed divider, such an experiment would not address effects along the fish-zooplankton-phytoplankton axis more frequently considered in biomanipulation techniques. It would also have little relevance to other meres where large carp are less important members of the fish community.

Fish removal

Several techniques have been used to remove fish during biomanipulation exercises, including commercial fisheries (e.g. Van der Vlugt *et al.*, 1992), trapping (e.g. Elser & Carpenter, 1988), rotenone (e.g. Reinertsen *et al.*, 1990), and seine netting and electrofishing (e.g. Meijer *et al.*, 1989).

Given the angling interests at Fenemere, and particularly the fact that it sustains a high profile fishery for carp (*Cyprinus carpio* L.), it is recommended that fish are removed primarily by non-destructive means for transport to other fisheries. In the absence of information on the bathymetry of the mere and the abundance and composition of the fish community it is difficult to give definitive recommendations as to how such removal should be carried out, but a flexible approach involving angling, trapping, fyke netting, perhaps seine netting, and section electrofishing is likely to be successful.

Monitoring

The degree of monitoring required depends on whether English Nature desires to obtain a full understanding of events during the experiment, or simply to determine whether or not the biomanipulation has been successful with respect to a given set of conservation-based criteria.

In the absence of a knowledge of the above, it is recommended that a monitoring regime is employed similar to that carried out in 1991 and 1992 by Moss *et al.* (1992), covering water chemistry, phytoplankton, zooplankton and macrophytes. In addition, it is recommended that the reduced fish community is monitored by point electrofishing and survey gill nets.

Timing

Given English Nature's anticipation of a three year experiment and the fact that, to the best of our knowledge, the last field data were collected from Fenemere in 1992, it is recommended that a full year of pre-manipulation data are gathered before the fish populations are reduced. Taking procedural and technical aspects into consideration, a start in the late winter or early spring of 1996 is recommended.

Costings

Clearly, the nature of the proposed biomanipulation experiment depends much on fish data yet to be gathered and decisions yet to be taken by English Nature and other bodies. Consequently, it is impossible to give anything other than the most vague of total costings. Based on our experience in the present and related projects, it is suggested that even a minimal approach would require total funds in excess of £50,000 over three years.

CHAPTER 4 CLOSING REMARKS

As long ago as the early part of this century, long before most current advocates of biomanipulation were even born, Cahn (1929) commented on the detrimental effects of a dense carp population on a macrophyte community. Unfortunately, this potential incompatibility of fish and macrophytes appears to be an important feature of the fisheries and conservation management of the West Midland Meres.

As suggested by Smith & Moss (1994), before any efficient progress can be made it essential that an overall management strategy, acceptable to English Nature, the National Rivers Authority and other interested bodies, is adopted. In addition to overcoming conflicts such as that described above, a joint approach would enable the pooling of expertise and effort which is of great use in the demanding field of fish and fisheries ecology and management. In this context, the current activities of the National Rivers Authority on Aqualate Mere and their developing expertise in horizontal echo sounding, a survey technique of great potential in many of the meres, are particularly relevant.

Furthermore, any research into or management of the West Midland Meres involving the fish populations would benefit greatly from the co-operation of parts or all of the angling community. To this end, it is strongly recommended that contacts are nurtured with fishery owners, angling clubs, and individual anglers. It is also critically important that such dialogue is interactive rather than simply informative in only one direction.

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REFERENCES

Bagenal, T. B. (1974). A buoyant net designed to catch freshwater fish larvae quantitatively. *Freshwater Biology* 4, 107-109.

Bagenal, T. B. & Tesch, F. W. (1978). Age and growth. In *Methods for Assessment of Fish Production in Fresh Waters, 3rd Edition* (Bagenal, T. B., ed.), pp. 101-136. Oxford: Blackwell Scientific Publications.

Bloesch, J., Bossard, P., Buehrer, H., Buergi, H. R. & Uehlinger, U. (1988). Can results from limnocorral experiments be transferred to in situ conditions? (Biomanipulation in limnocorrals 6). *Verh. Int. Ver. Theor. Angew. Limnol.* 23, 762-763.

Cahn, A. H. (1929). The effect of carp on a small lake: the carp as a dominant. *Ecology* 10, 271-274.

Copp, G. H. (1990). Experimental design in fluvial ichthyology: getting the most for your money. *Freshwater Biological Association Annual Report 1990*, 68-87.

Cowx, I. G. (1991). *Catch Effort Sampling Strategies: their Application in Freshwater Fisheries Management.* Oxford: Fishing News Books, a division of Blackwell Scientific Publications Limited.

Cowx, I. G. & Lamargue, P. (1990). *Fishing with Electricity.* Oxford: Fishing News Books, a division of Blackwell Scientific Publications Limited.

Cryer, M., Peirson, G. & Townsend, C. R. (1986). Reciprocal interactions between roach, Rutilus rutilus, and zooplankton in a small lake: prey dynamics and fish growth and recruitment. *Limnology and Oceanography* 31, 1022-1038.

Elser, J. J. & Carpenter, S. R. (1988). Predation-driven dynamics of zooplankton and phytoplankton communities in a whole-lake experiment. *Oecologia* 76, 148-154.

Giles, N. (1992). Wildlife After Gravel. *Twenty Years of Practical Research by the Game Conservancy and ARC.* Fordingbridge: Game Conservancy Limited.

Gulati, R. D., Lammens, E. H. R. R., Meijer, M. -L. & van Donk, E. (1990). *Biomanipulation - Tool for Water Management.* Dordrecht: Kluwer Academic Publishers.

Hewitt, D. P. (1979). Tests to confirm quantitative sampling of young fish by the Bagenal buoyant net. *Freshwater Biology* 9, 339-341.

Jeppesen, E., Kristensen, P., Jensen, J. P., Soendergaard, M., Mortensen, E. & Lauridsen, T. (1990). Recovery resilience following a reduction in external phosphorus loading of shallow, Danish lakes: duration, regulating factors and methods for overcoming resilience. *Memorie dell'Istituto italiano di idrobiologia Dott. Marco de Marchi. Milano* 48, 127-148.

Jordan, D. R. & Wortley, J. S. (1985). Sampling strategy related to fish distribution, with particular reference to the Norfolk Broads. *Journal of Fish Biology* 27 (Supplement A), 163-173.

Lagler, K. F. (1978). Capture, sampling and examination of fishes. In *Methods for Assessment of Fish Production in Fresh Waters, 3rd Edition* (Bagenal, T. B., ed.), pp. 7-47. Oxford: Blackwell Scientific Publications.

Maitland, P. S. (1972). A key to the freshwater fishes of the British Isles with notes on their distribution and ecology. *Freshwater Biological Association Scientific Publication No. 27.*

Malley, D. F. & Mills, K. H. (1992). Whole-lake experimentation as a tool to assess ecosystem health, response to stress and recovery: the Experimental Lakes Area experience.

Journal of Aquatic Ecosystem Health 1, 159-174.

Mathis, A. & Smith, R. J. F. (1992). Avoidance of areas marked with a chemical alarm substance by fathead minnows (*Pimephales promelas*) in a natural habitat. *Canadian Journal of Zoology* 70, 1473-1476.

Meijer, M. L., Raat, A. J. P. & Doef, R. W. (1989). Restoration by biomanipulation of Lake Bleiswijkse Zoom (The Netherlands): first results. *Hydrobiological Bulletin* 23, 49-57.

Mills, C.A. (1987). The life history of the minnow *Phoxinus phoxinus* (L.) in a productive stream. *Freshwater Biology* 17, 53-67.

Morin, P. (1984). The impact of fish exclusion on the abundance and species composition of larval odonates: results of short term experiments in a North Carolina farm pond. *Ecology* 65, 53-60.

Moss, B., McGowan, S. & Carvalho, L. (1994). Determination of phytoplankton crops by top-down and bottom-up mechanisms in a group of English lakes, the West Midland Meres. *Limnology and Oceanography* 39, 1020-1029.

Moss, B., McGowan, S., Kilinc, S. & Carvalho, L. (1992). Current limnological condition of a group of West Midland Meres that bear SSSI status. *English Nature Research Reports No. 59.*

Reinertsen, H., Jensen, A., Koksvik, J. I., Langeland, A. & Olsen, Y. (1990). Effects of fish removal on the limnetic ecosystem of a eutrophic lake. *Canadian Journal of Fisheries and Aquatic Sciences* 47, 166-173.

Reynolds, C.S. (1979). The limnology of the eutrophic meres of the Shropshire Cheshire Plain: a review. *Field Study* 5, 95-173.

Reynolds, C.S. (1994). The ecological basis for the successful biomanipulation of aquatic communities. *Archiv fur Hydrobiologie* 130, 1-33.

Smith, P. & Moss, B. (1993). The role of fish in the management of freshwater sites of scientific interest. *English Nature Research Reports No. 111.*

Spindler, T. (1988). The identification of central European cyprinid larvae (Teleostei, Cyprinidae). *Oesterr. Fisch.* 41, 75-79.

Van der Vlugt, J. C., Walker, P. A., Van Der Does, J. & Raat, A. J. P. (1992). Fisheries management as an additional lake restoration measure: biomanipulation scaling-up problems. *Hydrobiologia* 233, 213-224.

Venugopal, M. N. & Winfield, I. J. (1993). The distribution of juvenile fishes in a hypereutrophic pond: can macrophytes potentially offer a refuge for zooplankton? *Journal of Freshwater Ecology* 8, 389-396.

Wigginton, M. (1980). A survey of Shropshire Cheshire and Staffordshire Meres. *Nature Conservancy Council England Field Unit Report No. 1.*

Wigginton, M. & Palmer, M. (1989). Survey of Shropshire and Cheshire Meres 1987. *Nature Conservancy Council England Field Unit Report No. 59.*

Winfield, I. J. & Bean, C. W. (in press). The applications and limitations of new developments in echo-sounding technology in studies of lake fish populations. *Proceedings of the Institute of Fisheries Management 1994 Annual Study Course.*

Winfield, I. J. & Townsend, C. R. (1991). The role of cyprinids in ecosystems. In *Cyprinid Fishes - Systematics, Biology and Exploitation* (Winfield, I. J. & Nelson, J. S., eds), pp. 552-571. London: Chapman & Hall.

Wright, R. M. & Phillips, V. E. (1992). Changes in the aquatic vegetation of two gravel pit lakes after reducing the fish population density. *Aquatic Botany* 43, 43-49.

Youngs, W. D. & Robson, D. S. (1978). Estimation of population number and mortality rates. In *Methods for Assessment of Fish Production in Fresh Waters, 3rd Edition* (Bagenal, T. B., ed.), pp. 137-164. Oxford: Blackwell Scientific Publications.