TOWARDS A QUANTITATIVE BASIS FOR THE MANAGEMENT OF FRESHWATER FISHERIES IN SITES OF NATURE CONSERVATION INTEREST

PHILLIP A. SMITH[1], BRIAN MOSS[2], LAURENCE CARVALHO[3], ADRIAN E. WILLIAMS[4] AND BARRY J. HOWARD[5]

[1]*Applied Environmental Research Centre Ltd, Tey Grove, Elm Lane, Feering, Colchester, Essex, CO5 9ES. Tel: 01376 572582, Fax: 01376 572700*
[2]*The Derby Building, School of Biological Sciences, The University of Liverpool, Liverpool, L69 3BX*
[3]*Environmental Change Research Centre, University College London, 26 Bedford Way, London WC1H 0AP*
[4]*The Jones Building, School of Biological Sciences, The University of Liverpool, Liverpool, L69 3BX*
[5]*Freshwater Fisheries Advisory Services Ltd, 29 Ivry St, Ipswich, Suffolk IP1 3QP*

Corresponding Author: Dr Phillip A. Smith

ABSTRACT

English Nature has identified a number of factors which pose a threat to the conservation status of freshwater SSSIs; included amongst this list is the development of fisheries which contain a high biomass of fish. This contribution provides an overview of the role of coarse fish in affecting the ecology of shallow lakes and illustrates how fish-effects are related to both the species present and total biomass. The collation of data concerning abundance of fish, turbidity, nutrient levels and abundance of algae permitted the development of empirical relationships for shallow lakes. The major trends found were that macrophyte cover (%) was not linearly related to nutrient level, expressed as total P, (regression analysis, p=0.08), but was significantly related to turbidity (regression analysis, p=<0.0001, r^2 = 0.83, n=12). Macrophyte cover (%) was negatively related to fish biomass (regression analysis, p=0.0001, r^2=0.58, n=19). Secchi disc depth was negatively related to fish biomass (regression analysis, p=0.0003, r^2=0.65, n=15). Neither nutrient concentration or abundance of algae, indicated by Chlorphyll *a*, were significantly related to fish biomass (P=0.11 and 0.25 respectively). The implications of this analysis are that a low biomass of fish is associated with clear water and abundant macrophytes whilst waters with a high biomass of fish are associated with turbid conditions and few macrophytes. The analysis suggests that a threshold in fish biomass appears to exist, between 150 and 250 kg ha^{-1} above which a submerged macrophyte community can no longer be sustained. Waters which have conservation interest related to clear water and an abundance of macrophytes should be managed so that they have a fish biomass below this threshold.

KEYWORDS

Fisheries management, intensive fisheries, biodiversity, nature conservation, SSSI

INTRODUCTION

Freshwater sites provide a very important contribution to wildlife conservation in the UK with over 200 SSSIs designated for open water communities. Sustainable management of these sites is therefore important and requires an understanding of factors which may affect site integrity.

Fisheries management has always been viewed as having the potential to damage the features of special interest at SSSIs. Indeed the specific list of potentially damaging operations includes 16a "The introduction of freshwater fishery production and/or management and changes in freshwater fishery production and/or management." Furthermore, English Nature (1997), in its agenda for sustainable management of wildlife and freshwater, identified a number of factors which pose a threat to the conservation status of freshwater SSSIs; included amongst this list is the development of 'intensive fisheries' - i.e. waters which contain a high biomass of fish.

Supporting evidence that fish are a potentially important factor in the management of sites important for nature conservation is provided by an English Nature-funded survey of 96 SSSIs perceived to be subject to eutrophication (Carvalho and Moss 1995). Of these sites, 36 % showed symptoms of eutrophication that could primarily be attributed to excessive nutrient inputs from sewage effluent. However, 23 % sites, showed symptoms of submerged aquatic plant loss and high turbidity (i.e. low water clarity) that could not be attributed to high nutrient concentrations. The sites were all associated with intensive carp and bream fisheries in shallow lakes.

It is the aim of this contribution to raise awareness of the potential for coarse fish communities to potentially affect the nature conservation interest of shallow freshwaters. This will be achieved by first describing the trend for increasing fish biomass in shallow lakes and secondly through the provision of an explanation of the mechanisms by which fish can affect the structure of aquatic communities. The role of fish in affecting the ecology of shallow lakes will be examined through a comparison of studies and the generation of empirical relationships. The general conclusion is that the effects of increasing fish biomass on macrophyte cover and turbidity in some waters may be predictable.

THE TREND FOR INCREASING FISH BIOMASS IN SHALLOW LAKES

In 1994, the National Rivers Authority (now the Environment Agency) conducted a National Angling Survey and estimated that there were 3.3 million anglers aged 12 and over in Great Britain (NRA 1994). The majority of these (i.e. 2.9 million) live in England and Wales and target coarse fish (i.e. cyprinids, percids and other non-salmonids). Taking into account the reported frequency of angling and the estimated number of anglers (NRA 1994), there is an estimated 90 million angling occasions per annum. The survey also reported that 52 % of anglers primarily fished stillwaters and 49 % of anglers preffered day-ticket waters. Furthermore, anglers were willing to pay £5 - £10 for each fishing session. A conservative estimate would conclude that the freshwater day-ticket coarse fishery is potentially worth more than £200 million per annum. As the survey found that the mean distance travelled by anglers was 20 miles, it is clear that the development of a recreational catch and release fishery in the vicinity of urban areas containing large numbers of anglers is a promising commercial venture.

The construction of a new fishery is clearly a potentially lucrative venture, however, it requires investment; vegetation stripping and removal of excess material is costly and newly designed purpose-built fisheries tend to be small in absolute area (i.e. < 1 ha) and to accommodate a large number of anglers they tend to be long, thin and shallow (mean depth < 2 m). As catch rate is an important determinand to the commercial value of the fishery, fish are often stocked at a high density. Absolute figures are not available, but conservative estimates exceed 500 kg ha^{-1}. Regular stocking often takes place to maintain such an elevated biomass. In many of these fisheries carp are the dominantly stocked species. This is not surprising as, of those who expressed a preference, 36 % of anglers preferred carp (NRA 1994). This hardy species can tolerate low dissolved oxygen levels and forage successfully in turbid conditions which contain few invertebrates.

A recent questionnaire survey (Williams, *in. prep.*) involving 31 Angling Club Secretaries, indicated that in developing a successful fishery, both fish species and abundance were important but fish size was less important (Table 1). Waters with unmanaged fish communities, i.e. lacking carp and probably of a low overall fish abundance, may be perceived to be of a much lower quality than heavily-stocked waters. Some fishery managers/angling clubs managing more natural waters may, therefore, respond to this by attempting to increase fish stocks, particularly carp, in shallow lakes. In these circumstances, understanding the effects of increasing fish biomass on the conservation value of the water is an essential pre-requisite to their sustainable management.

Table 1 Relative importance (% of each category) of three fishery aspects when trying to achieve a successful fishery as given by respondents to a 1998 questionnaire (derived from Williams *in prep.*)

	Fish species	Fish abundance	Fish size
Most Important	43	42	27
Middle Importance	38	12	27
Least Important	19	46	46

THE ECOLOGY OF SHALLOW LAKES

The waters in which there is the greatest potential for conflict between coarse fish introductions and nature conservation are shallow lakes where demand for angling is high (Carvalho and Moss 1995). In these lakes fish can play a significant role in determining the biological structure and water quality status of the site.

In some shallow lakes submerged vegetation is abundant, the water is clear and biodiversity is high. Important species include the ribbon-leaved water plantain *Alisma gramineum*, convergent stonewort *Chara connivens*, starry stonewort *Nitellopsis obtusa*, tadpole shrimp, *Triops cancriformis* and freshwater white-clawed crayfish *Austropotamobius pallipes* (Environment Agency 1998). Some waters are also capable of supporting large numbers of wildfowl such as wigeon A*nas penelope* and shoveler *Anas clypeata*. The conservation status may range from being of international importance e.g. the shallow water West Midland Meres which are a candidate Special Area of Conservation to significance at the local level.

In other shallow lakes, however, the water is turbid, submerged vegetation is limited in diversity and abundance (e.g. Cahn 1929, Carvalho and Moss 1995, Wright and Phillips 1992, Howard, *pers. obs.*). There are few species of benthic invertebrates and an alteration to the fish community witha loss of phytophilous species such as tench, rudd and crucian carp. Other changes may include an increase in the density of juvenile / young zooplantivorous species and a decrease in abundance of older fish. The conservation value of these waters is limited (English Nature 1997) and such a state is frequently perceived to be caused by nutrient enrichment and is associated with excessive algal growth. It seems that, except in extreme circumstances, shallow lakes can exist in these two states over a range of nutrient concentrations with each state being prevented from switching to the other by a number of ecological buffers (Scheffer 1989).

Macrophytes can prevent dominance by algae through utilisation of sediment nutrient sources, release of algal suppressants, shedding and replacement of leaves that are heavily shaded by epiphytes and by providing a structural refuge within which algae-eating zooplankton can escape predation by fish. These refuges allow the large zooplankton to coexist with zooplanktivorous fish and hence to control phytoplankton by grazing. In the turbid state, the competitive ability of submerged macrophytes is reduced by shading (either via epiphytes, or resuspended sediment) or competition for nutrients.

The switching from one state to another may involve mechanisms that directly affect plants (cutting, grazing, or reduced light resources) or indirect mechanisms that act through enhancing the phytoplankton community (either through zooplantivory or an increase in nutrient mobilisation). Examples of these switching mechanisms include: herbicide, excessive manual weed cutting, intensive boat traffic, grazing by waterbirds and wind induced turbidity.

Fish also have the potential to cause a switch and can act directly by feeding on plants, uprooting of macrophytes, preventing seedling establishment and through resuspension of sediments. Fish can also act indirectly: nutrient release from sediments during feeding or released in excretion, feeding on zooplankton and removing macrophyte-associated macro-invertebrates. Most attention has focused on the indirect effect of fish feeding on zooplankton, however, the direct effects may in some circumstances be more significant.

EVIDENCE FOR THE ROLE OF FISH

There have been a number of attempts to determine the role of fish in shallow waters. The majority have used small scale enclosures and a number of examples are given in Table 2. These have proved useful in illustrating the potential role of fish, but a synthesis of studies carried out at a larger scale, such as a whole waterbody, explicitly examining fish effects is lacking.

A common the theme to small scale studies is that species differ in their effect on macrophytes. The natural history of the major species of angled fish has been reviewed and related to potential effects in shallow waters (Smith and Moss 1994). A league table was drawn up relating features of the fish to their potentially effects in shallow waters (Table 3). The from least desirable,, when trying to promote clear water and abundant macrophytes, is Common carp, bream and roach. Other species such as tench, rudd and crucian carp are less important whilst the piscivorous perch, eel and pike may promote the clear water state.

Table 2 A selection of small-scale studies demonstrating the potential for fish to affect macrophytes

Study	Major finding
Crivelli (1983)	A strong linear negative correlation between macrophyte abundance and carp density (0 - 726 kg ha^{-1}) over a 71 day enclosure experiment. Suggested mechanism was uprooting rather than sediment suspension.
Hill et al. (1986)	A strong negative relation between stocked biomass of bream and the remaining biomass of macrophytes was observed in enclosure experiments.
Meijer et al. (1990)	In 10 shallow ponds (average fish biomass 466 kg ha^{-1}), underyearling fish (about 80 % of which were carp) were found to decrease water clarity but not affect nutrient levels.
Breukelaar et al. (1994)	Stocking of 16 experimental ponds with bream or carp at a biomass range of 0 - 500 kg ha^{-1} showed that suspended solids were significantly related to fish abundance.
Roberts et al. (1995)	Carp stocked into small enclosures at a biomass of 510 kg ha^{-1} increased turbidity ten fold within 4 days.
Williams (*in prep.*)	Development of macrophytes within replicated enclosures was significantly less when fish density was 200 and 800 kg ha^{-1} when compared to a fishless control.

Table 3 Summary of the characteristics of the most common fish species in shallow waters

Species	**Ecological characteristic**
Common Carp	Disturbs the bottom substrate, when young consumes pelagic zooplankton, physically destroys plants, may occur at a high biomass.
Bream	Disturbs the bottom substrate, may consume pelagic zooplankton, physically destroys plants, may occur at a high biomass.
Roach	Capable of producing a very large number of zooplanktivorous young.
Tench	Disturbs the bottom substrate and may consume periphyte-eating snails.
Rudd	Breeds prolifically and produces many zooplanktivorous young, though adults tend to include macrophytes in their diet.
Crucian Carp	Omnivorous, though seldom occurs in large numbers in the UK.
Perch	Young perch may be zooplanktivorous, but soon switch to eating macroinvertebrates or fish.
Eel	Includes fish and benthic macroinvertebrates in diet.
Pike	Piscivorous and may reduce the density of zooplanktivorous fish.

Other studies have chosen to examine the role of fish at much larger scales. These include whole-lake manipulations spatial comparisons of lakes which are essentially similar, but differ in a single factor such as the abundance of fish. Existing studies on a number of shallow lakes were examined. to provide an overview of the associations between fish abundance, macrophyte cover, water clarity, nutrient level and abundance of algae. These characteristics provide a quantitative framework for comparing different lakes. The validity of using data obtained by workers using different sampling methodologies applied at various times of the year will no doubt be questioned. It was felt, however, that such a comparative method, which involves studies over time and space, has the potential to provide much broader insights than smaller scale studies.

The lakes were chosen on the following criteria:

- UK or similar geographic location
- standing water
- mean depth < 2 m
- fish population biomass estimated
- nutrient data recorded
- water clarity recorded
- algae abundance determined
- macrophyte cover recorded

A limited search of the literature provided information on eleven lakes. These ranged from the fishless Isle of Wight Pond (Surrey), which contained an abundant and diverse aquatic plant community to Bay Pond (Surrey) which had 800 kg ha^{-1} of fish and no aquatic vegetation (Tenner 1996). Also included are lakes studied by The Game Conservancy and ARC (Main Lake and St Peters Lake) (Wright and Phillips 1992), two lakes in Suffolk (Howard 1981 and *in prep.*), and two European shallow waterbodies (Meijer *et al.* 1989 and Gulati 1995). Six of these lakes experienced manipulations of their fish biomass and were represented more than once. The total data set therefore comprised 19 observations of lakes with a fish biomass range of 0 - 800 kg ha^{-1}.

For each study, the fish population was either determined by survey, lake draining or estimated from stocking / anglers' catches. Nutrient (total P), water clarity (Secchi disc depth)and abundance of algae (chlorophyll *a*) data were generally collected between May and October. The mean of data obtained for each study was used in this analysis. Macrophyte cover was obtained by survey between the months of June and September.

Within the subset of lakes examined, the major trends found (Figure 1) were consistent with our current understanding of factors affecting the functioning of shallow waters i.e. lakes can exist in either the macrophyte- or algal-dominated state over a range of nutrients. Not surprisingly, macrophyte cover was found to be associated with water clarity.

The examination of the association of different levels of fish biomass with other parameters within the sub-set of shallow lakes was therefore considered useful.

The major trends, as given in Figure 2 and Table 4, are:

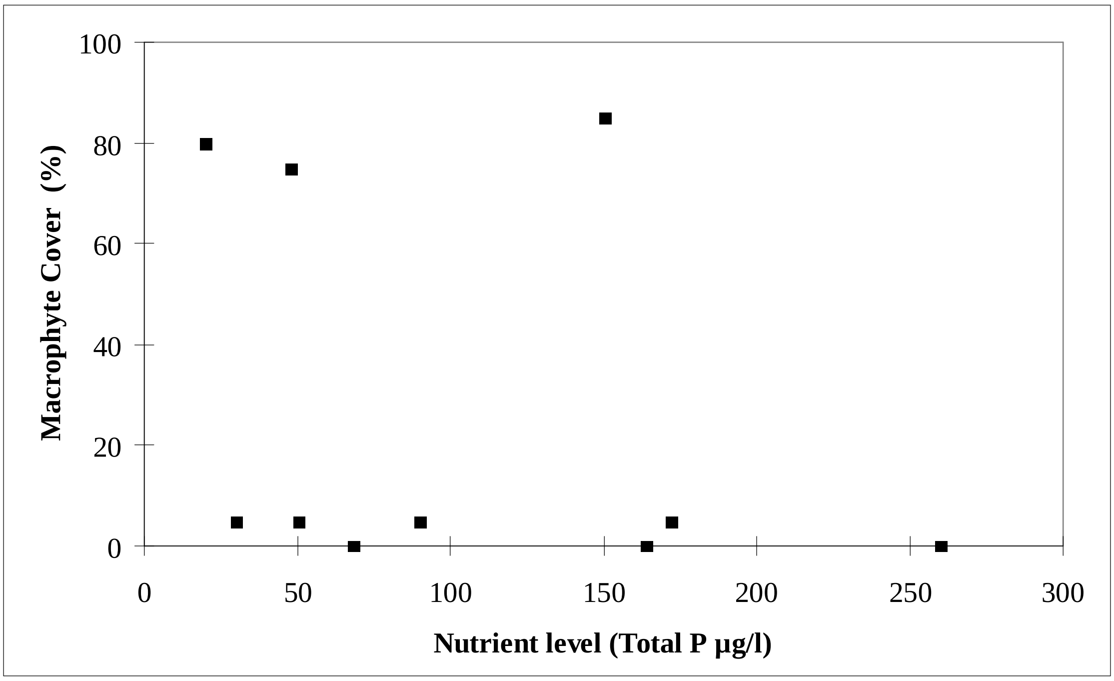
Macrophyte cover	• large cover associated with low fish biomass • small cover associated with high fish biomass
Water clarity	• water clarity decreases as fish biomass increases
Nutrient level	• nutrient level is not linearly associated with fish biomass
Algae	• abundance of algae not linearly associated with fish biomass

Table 4 The relationship between various parameters, as determined by linear regression (y=c+mx) and given in Figure 2

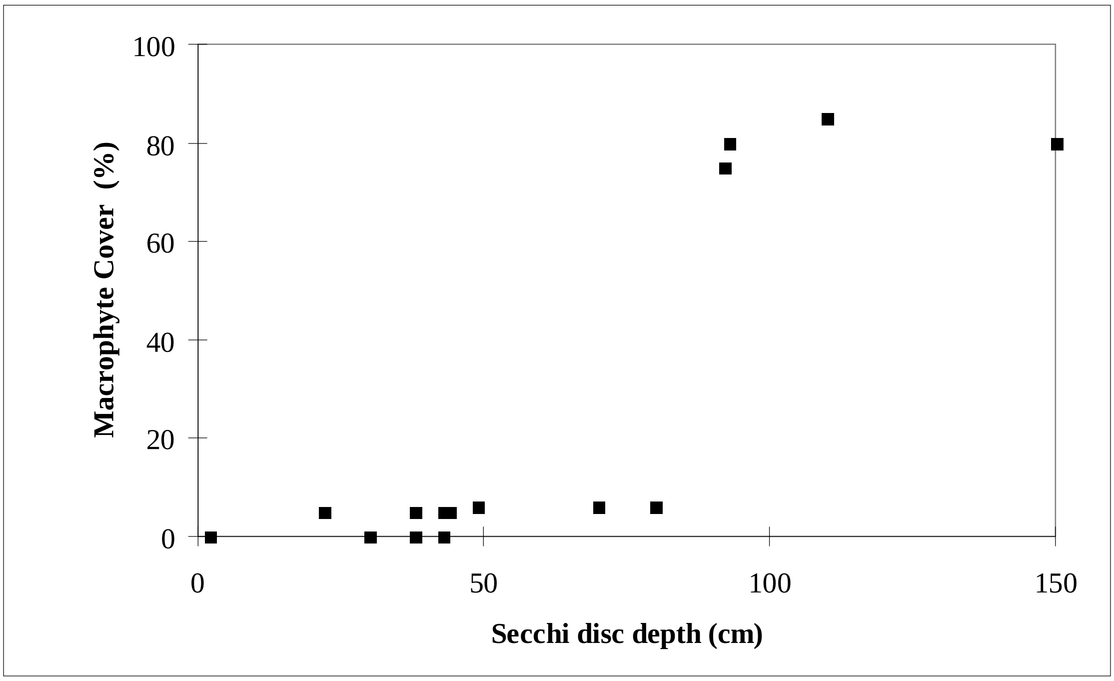
Independent variable	Constant c	Gradient m	Dependent variable	P	r2	n
Macrophyte cover (%)	-	-	Nutrient level	>0.10	-	10
Macrophyte cover (%)	-20	+ 0.81	Secchi depth	<0.001	0.83	12
Macrophyte cover (%)	74	- 0.12	Biomass	<0.001	0.58	19
Secchi depth (cm)	110	- 0.13	Biomass	<0.001	0.65	15
Total P (μgl^{-1})	-	-	Biomass	0.08	-	10
Chlorophyll *a* (mgl^{-1})	-	-	Biomass	>0.10	-	12

Figure 1 Associations between a) macrophyte cover and nutrient level, b) macrophyte cover and turbidity and c) algal abundance and nutrient level for a series of shallow water lakes

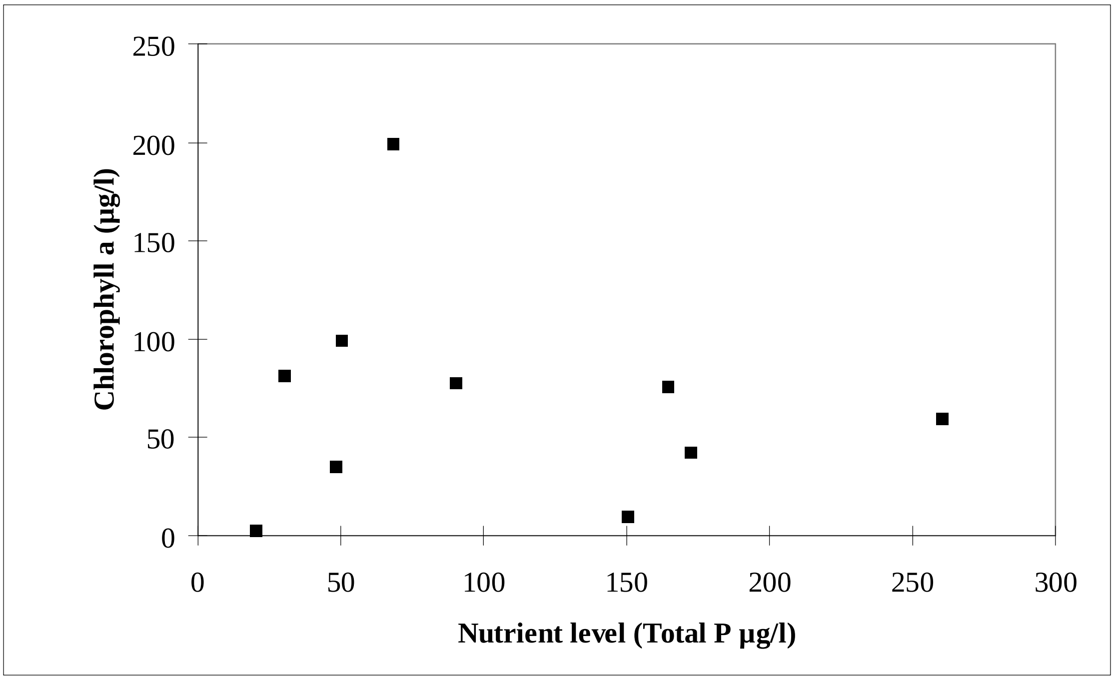
a) macrophyte cover and nutrient level



b) macrophyte cover and turbidity



c) algal abundance and nutrient level



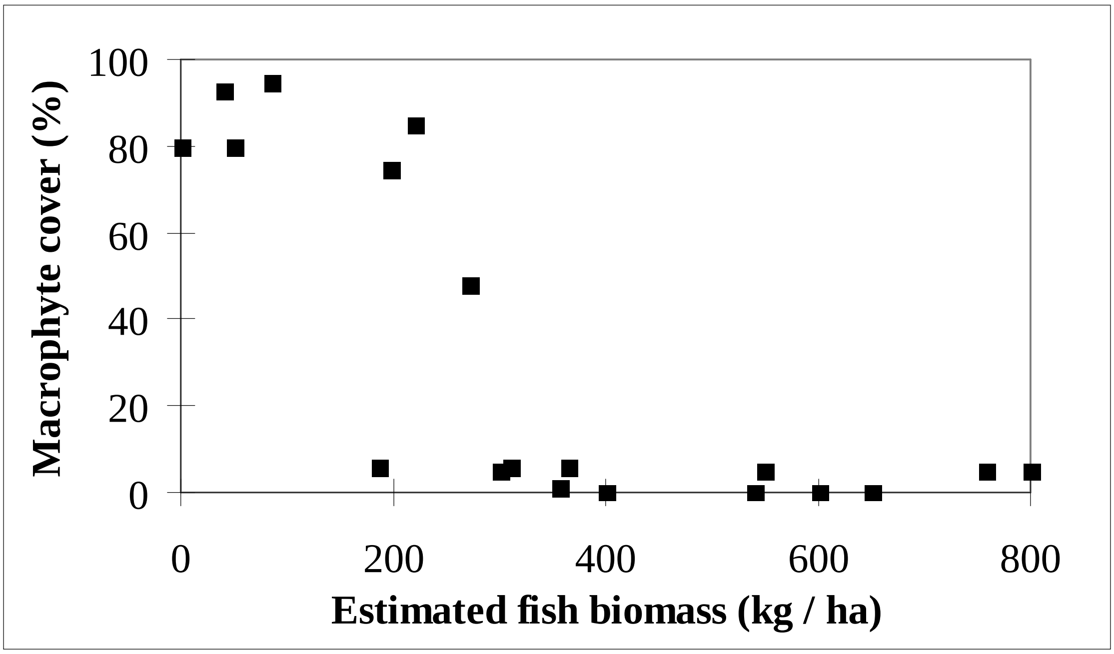
The collation of these observations was not designed to elucidate the relative importance of direct and indirect effects of fish in determining the ecology of shallow lakes - more detailed studies involving suitable controls would be required for that. Furthermore, the study did not attempt to determine the actual cause and effect of any relationship. Indeed the method of using linear regression to determine significance may not be appropriate in this case (Scheffer 1989). Rather, the present study provides a preliminary quantitative basis for estimating the effects of increasing fish abundance within a shallow water. The fundamental basis of this approach is reliant on associations between the key parameters of fish abundance, macrophyte cover, water clarity, nutrient level and abundance of algae. A number of these are likely to be inter-related and research to determining actual cause and effect would considerably advance our understanding of the actual mechanisms involved.

IMPLICATIONS FOR FISHERY MANAGEMENT IN SITES OF NATURE CONSERVATION INTEREST

The concept that the nature conservation interest of UK freshwaters is under threat from a variety of factors including fisheries management has been developed in the previous sections. The trend for intensively stocking shallow waters with fish looks set to continue. Where this occurs in newly created ponds, the issues are more concerned with fish welfare than nature conservation. Increased stocking of naturalised ponds which have inherent nature conservation interest will, no doubt, be considered by fisheries managers. The key issues will relate to what biomass and species composition of fish and what kind of angling is compatible with the nature conservation interest.

Figure 2 Associations between a) macrophyte cover, b) turbidity, c) nutrient level and d) algal abundance and fish biomass for a series of shallow water lakes

a) macrophyte cover



b) turbidity

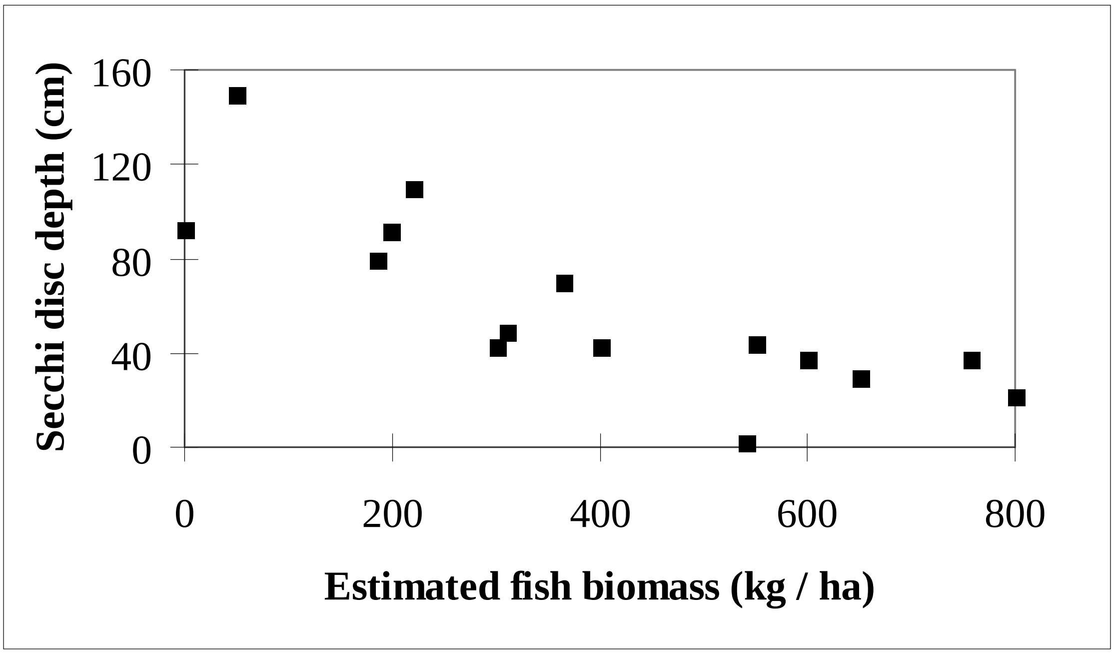
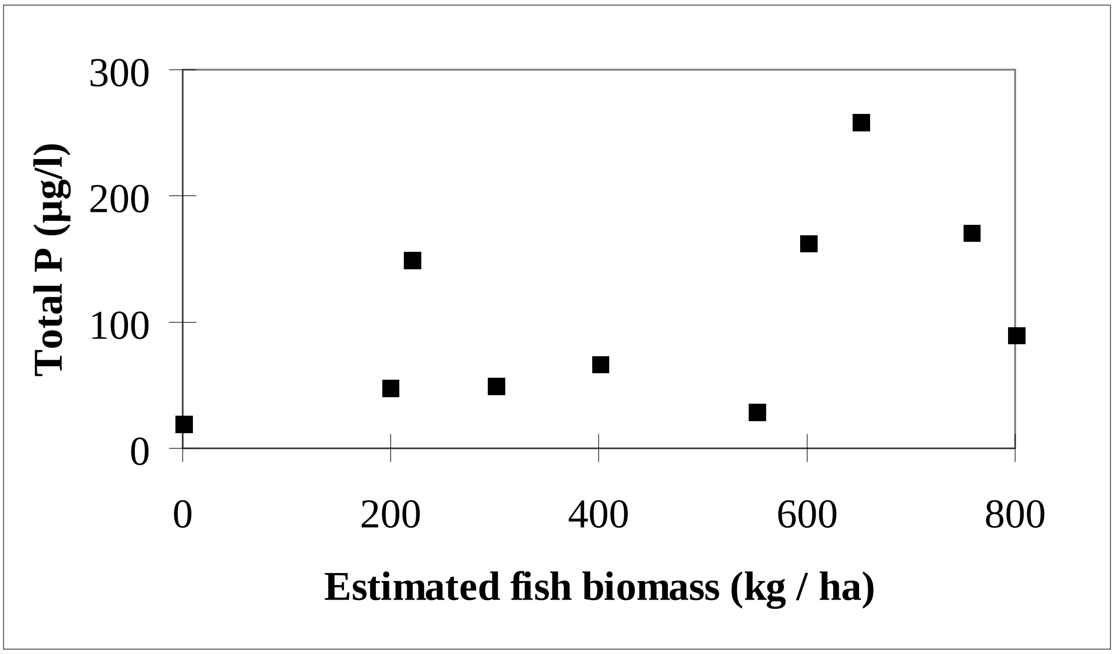
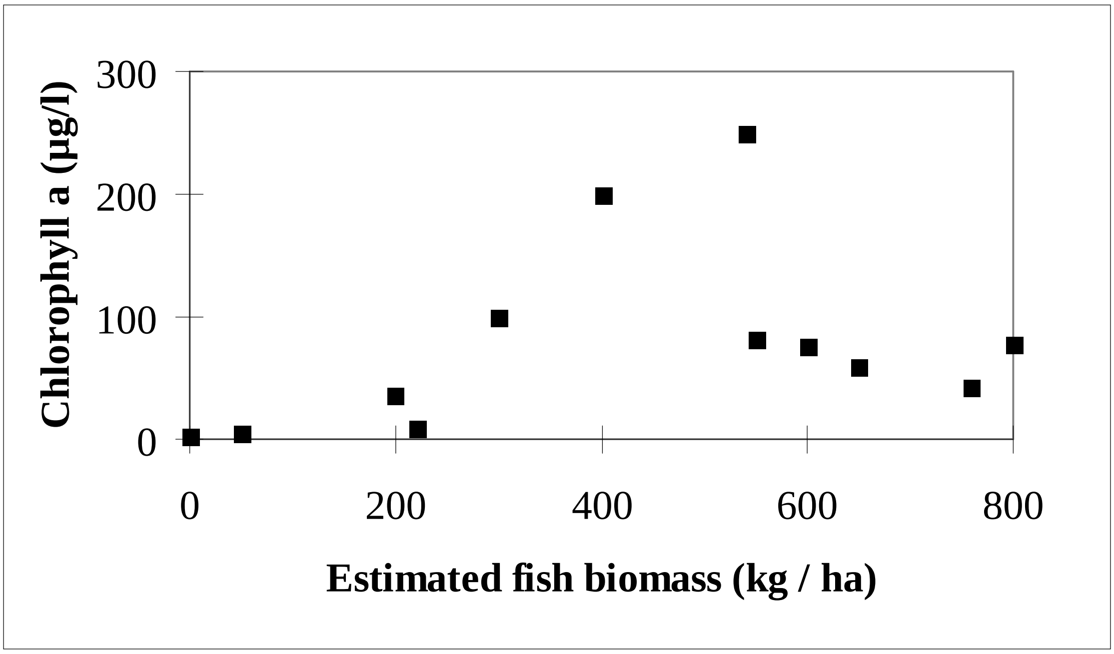


Figure 2 continued....

c) Nutrient level



d) Algal abundance



The major conclusion of this comparative study is that within this subset of lakes, which is considered representative for shallow lakes, biomass of fish, specifically benthivorous species, is negatively associated with macrophyte cover and water clarity. Submerged macrophyte communities being completely absent from sites with an estimated fish biomass of over 300 kg ha^{-1}. The driving causative agent seems to be a decrease in water clarity, probably through an elevation of algae at low fish biomass levels and an increase in suspended solids where a high fish biomass occurs.

This analysis would clearly benefit from the consideration of other studies relating to shallow lakes as well as extending the review to include lakes which are characterised by other features such as depth, substrate, influence of other factors etc. It would also be useful to examine the effects of both fish species and size.

Not withstanding the above, it is possible to draw a number of tentative conclusions regarding shallow lakes:

1) Fish play a potentially important role in determining the ecology of a shallow lake.
2) Effects are related to both species and overall biomass, though on the basis of current information, it is only possible to comment on effects associated with overall biomass.
3) An increase in fish biomass within a clear water shallow lake increases the likelihood that the water will become turbid and macrophyte cover decrease.
4) A threshold in fish biomass appears to exist between 150 and 250 kg ha^{-1} above which a submerged macrophyte community can no longer be sustained.
5) Waters which have conservation interest related to clear water and an abundance of macrophytes should be managed so that they have a fish biomass well below this threshold.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the comments of Dr Iwan Jones on a previous draft of this paper. This analysis was possible though funding by a number of organisations including English Nature and the Applied Environmental Research Centre Ltd.

REFERENCES

Breukelaar, A.W., E.H.R.R. Lammens, J.G.P. Breteler and I. Tatrai (1994) Effects of benthivorous bream (*Abramis brama*) and Carp (*Cyprinus carpio*) on sediment resuspension and concentrations of nutrients and chlorophyll *a*. *Freshwater Biology* **32** 113-121.

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

Carvalho, L. and B. Moss (1995). The current status of a sample of English Sites of Special Scientific Interest subject to eutrophication. *Aquatic conservation: Marine and Freshwater Ecosystems* **5** 191-204.

Crivelli, A. (1983) The destruction of aquatic vegetation by carp. *Hydrobiologia* **106** 37-41.

English Nature (1997) Wildlife and freshwater: an agenda for sustainable management. English Nature, Peterborough, UK.

Environment Agency (1998) Environmental Issues Series: aquatic eutrophication in England and Wales Consultative Report. Environment Agency, Wallingford, Oxon OX10 8BD. Also http://www.environment-agency.gov.uk

Gualati, R. (1995) Manipulations of fish populations for lake recovery from eutrophication in the temperate region. In Guidelines for Lake Management Volume 7: Biomanipulation in Lakes and Reservoirs Management (Eds R. DeBewrnadi and G. Giussani) International Lake Committee Foundation and the United Nations Environment Programme pp53-79. ISBN 4-906356-15-X

Hill, D.R., R. Wright and M. Street, 1996. Survival of mallard ducklings (*Anas platyrhynchos*) and competition with fish for invertebrates on a flooded gravel quarry in England. Ibis **129** 159-167.

Howard, B.J. (1981) Interactions between anglers and coarse fish populations in two gravel-pit lakes. Unpublished Ph.D. Thesis, City of London Polytechnic.

Kitchell, J.F., J.F. Koonce, P.S. Tennis (1975). Phosporous flux through fishes. *Verh. Int. Verein. Limnol.* **19** 2478-2484.

Meijer, M.L., A.J.P. Raat and R.W. Doef (1989) Restoration by biomanipulation of lake Bleiswijkse zoom (The Netherlands): first results. *Hydrobiol. Bull.* **23** 49-57.

Meijer, M.L., E.H.R.R. Lammens, A.J.P. Raat, M.P. Grimm and S.H. Hosper (1990) Impact of cyprinids on zooplankton and algae in ten drainable ponds. *Hydrobiologia* **191** 275-284

Moss, B., J.F. Madgewick and G. Phillips (1996), A guide to the restoration of nutrient-enriched shallow lakes. Broads Authority, Environment Agency and European Community, Norwich.

NRA (1994) National Angling Survey Fisheries Technical Report 5. ISBN 0 11 885841 6 HMSO.

Roberts, J., A. Chick, L. Oswald, and P. Thompson (1995) Effect of carp, *Cyprinus carpio*, an exotic benthivorous fish, on aquatic plants and water quality in experimental ponds. *Austr. J. Mar. Freshwater. Res.* **46** 1171-80.

Scheffer M. (1989) Alernative stable states in eutrophic shallow freshwaters: a minimal model. *Hydrobiol. Bull.* **23** 73-83.

Smith, P.A. and B. Moss (1994) The role of fish in the management of freshwater Sites of Special Scientific Interest. English Nature Contract No. F72-06-38.

Tenner, C. (1996) The impact of carp stocking on freshwater Sites of Special Scientific Interest in Southern England. *Environmental Change Research Centre Research Paper*, **14**, 18 pp. ECRC London

UK Biodiversity Group (1999) Tranche 2 Action Plans. Volume II - terrestrial and freshwater habitats.

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