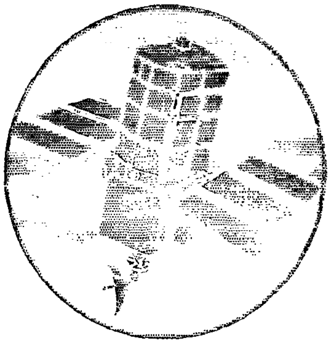
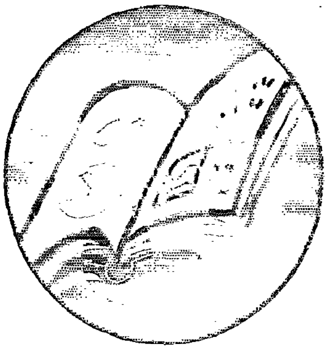
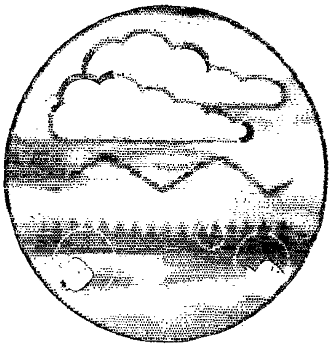
Species Management in Aqautic Habitats
Compendium of Project Outputs - Research and Survey Reports on Non-mollusc Species







Research and Development

Project Record
W1/i640/2/M

ENVIRONMENT AGENCY

Species Management in Aqautic Habitats
Compendium of Project Outputs - Research and Survey Reports on Non-mollusc Species

Project Record
W1/i640/2/M

Species Management in Aquatic Habitats

Compendium of Project Outouts - Research and Survey Reports on Non-mollusc Species

Project Record W1/i640/2/M

C P Mainstone (Editor)

Research Contractor:
WRc plc

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Statement of use

This document contains a series of reports on the distribution and ecological requirements of certain priority species. These can be used to help guide the operational and promotional works of the Agency by providing information on where the species in question should be considered, what the potential impacts may be, and what steps might be suitable for population enhancement. It should be noted that investigations on specific species are often at an early stage (more so for some species than for others) and further research is necessary to clarify appropriate habitat management. Management Guidelines have been drawn up for some species and are included in the Agency's new manual on habitat and species management.

Research contractor

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R&D Project Record W1/i640/2/M

Amendments

Any corrections or proposed amendments to this manual should be made through the regional Agency representative on the Water Resources National Abstraction Licensing Group.

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EXECUTIVE SUMMARY

R&D Project i640 was initiated three years ago to provide information on species of conservation value of particular relevance to the Environment Agency (then the National Rivers Authority), in relation to its activities affecting aquatic environments. A total of 52 stand-alone outputs has been produced by 22 different contributing organisations or experts, many funded in collaboration with English Nature and/or the Countryside Council for Wales.

Outputs comprise Species Action Plans (SAPs), practical management guidelines for Agency staff and third parties, and various research and survey outputs to improve the knowledge base on the status and ecological requirements of priority species. An overview of the work undertaken is provided in R&D Technical Report W161, whilst three Project Records contain all outputs produced during the course of the project (except for two special cases). Project Records W1/i640/1/M and W1/i640/2/M group together all research and survey reports produced with Project i640 involvement: W1/i640/1/M contains reports on priority mollusc species, whilst W1/i640/2/M (this document) contains reports on all other species addressed by Project i640. Project Record W1/i640/3/M contains all SAPs and management guidelines, which are temporary documents and will be updated by the Agency and other relevant bodies as new information comes to light.

KEY WORDS

Priority species, conservation, management, aquatic habitats.

Full list of outputs produced with Project i640 involvement

Species		Output type
Water shrew	*Neomys fodiens*	SAP/MG Research report
Daubenton's bat	*Myotis daubentonii*	SAP/MG Research report
Bats		Research report
Kingfisher	*Alcedo atthis*	MG
Yellow wagtail	*Motacilla flava*	MG
Grey wagtail	*Motacilla cinerea*	MG
Sand martin	*Riparia riparia*	MG
Reed bunting	*Emberiza schoeniclus*	MG
Dipper	*Cinclus cinclus*	MG
Marsh warbler	*Acrocephalus palustris*	MG
Grass snake	*Natrix natrix*	SAP/MG
Common amphibians		SAP/MG
Great crested newt	*Triturus cristatus*	MG
Spined loach	*Cobitis taenia*	SAP Research report 1 MG Research report 2
Brook lamprey	*Lampetra planeri*	SAP
River lamprey	*Lampetra fluviatilis*	SAP
Sea lamprey	*Petromyzon marinus*	SAP
Pearl mussel	*Margaritifera margaritifera*	Survey report - England Research report Survey report - Wales
Shining rams-horn snail	*Segmentina nitida*	{Survey report
Little whirlpool rams-horn snail	*Anisus vorticulus*	{Survey report Research report
Fine-lined pea mussel	*Pisidium tenuilineatum*	SAP Survey report
Compressed river mussel	*Pseudanodonta complanata*	SAP
Glutinous snail	*Myxas glutinosa*	Survey report
Norfolk hawker dragonfly	*Anaciaeshna isosceles*	MG Research
Downy emerald dragonfly	*Cordulia aenea*	MG
Scarce chaser dragonfly	*Libellula fulva*	MG
Southern damselfly	*Coenagrion mercuriale*	MG Research report
Scarce blue-tailed damselfly	*Ishnura pumilio*	MG
Scarce emerald damselfly	*Lestes dryas*	MG
Native crayfish	*Austropotamobius pallipes*	Strategy report Leaflet
Medicinal leech	*Hirudo medicinalis*	SAP
Triangular club-rush	*Schoenoplectus triqueter*	SAP Research report
Loddon pondweed	*Potamogeton nodosus*	MG
Round-headed club-rush	*Scirpus holoschoenus*	MG
Northern spike-rush	*Eleocharis austriaca*	MG
Black poplar	*Populus nigra ssp betulifolia*	MG
Ribbon-leaved water-plantain	*Alisma gramineum*	Research report

MG Management guidelines SAP Species Action Plan

PART 1 MAMMALS

1.1 A field survey of water shrews in Hampshire to assess their population status and the utility of methods for standardised surveying

1.2 The ecology and conservation of Daubenton's bat

1.3 The use of river corridors by bats

A field survey of water shrews (*Neomys fodiens*) in Hampshire to assess their population status and the utility of methods for standardised surveying.

A Report produced under Environment Agency R&D Project 640

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July 1997

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Executive Summary

During the preparation of a Species Action Plan and Management Guidelines for the water shrew (*Neomys fodiens*), the lack of knowledge about its occurrence, population status and habitat requirements has been highlighted. Aiming to address this problem, particularly with the need to produce practical recommendations in the Species Action Plan and Management Guidelines, the Environment Agency agreed to support and fund a brief field survey project of the water shrew within R&D Project 640 (Species management in aquatic habitats, coordinated by WRc). This assistance is gratefully acknowledged by the author.

The aims of the project were: (i) to gain an update on the status of water shrew populations in selected sites; (ii) to assess their occurrence in sites subject to different habitat management schemes; and (iii) to commence the development of simple field-survey techniques to assist future surveys of water shrews by Environment Agency staff and other third parties.

This document reports the results of the field survey carried out during July 1996 at selected sites in the catchment area of the rivers Itchen and Alre in Hampshire. The survey included visual assessment of the habitat quality and impact of management schemes at six sites, together with examination for recent field signs of water shrews. This was followed by a census of water shrew populations by live-trapping and mark-release techniques. The survey sites comprised banks of rivers and commercial water-cress beds subject to different mowing regimes. The potential of hair tubes and bait stations as survey methods for water shrews was assessed by field trials, and recommendations made.

The live-trapping survey showed that water shrew populations at most sites were buoyant. Numbers were greater during July 1996 than at the same sites in the same month in a similar survey in 1982. The occurrence of water shrews at two sites previously occupied and now subject to increased habitat management was not confirmed. However, water shrews were maintaining populations in other sites subject to regular and frequent habitat management, as well as in sites with less rigorous management. Regular vegetation clearance on banks of streams and water-cress beds did not deter habitation by water shrews, but more captures were sustained at sites where vegetation was rarely or occasionally mown compared with those mown frequently. Human disturbance at the sites did not deter habitation by water shrews.

Trials with bait stations successfully provided confirmation of the presence of water shrews in the three sites investigated, and will form the basis for development of an appropriate surveying protocol.

Recommendations are made to increase further our knowledge of the occurrence, population status and habitat requirements of water shrews by means of greater efforts to survey habitats and record the occurrence of this species, with Agency support. To assist in surveys, and enable the participation of Agency staff, local wildlife groups and other third parties, the development of appropriate, easy-to-use and economical surveying techniques should be further researched.

Key words: Water shrew; populations; habitats; survey; live-trapping.

1. INTRODUCTION AND PROJECT DESCRIPTION

The water shrew (*Neomys fodiens*) is one of the least known and least studied of British mammals. Lack of knowledge about its occurrence, population status and habitat requirements is hampering the production of an appropriate Species Action Plan and useful Management Guidelines. Until this situation is systematically addressed, any practical recommendations aimed at its conservation are purely provisional. The aims of the present project were:

1. to gain an update on the status of water shrew populations in sites where they were known to occur in previous years;

2. to assess their occurrence in the sites subject to different habitat management schemes;

3. to commence the development of simple field-survey techniques to assist future surveys of water shrews by Environment Agency staff and other third parties.

Much of our knowledge of the ecology and population dynamics of water shrews comes from a detailed study made over some three years at field sites close to the rivers Itchen and Alre in the Winchester area of Hampshire during the 1980s (see Churchfield 1984a and b). Following visual and trapping surveys of a number of potential sites in Buckinghamshire, Hertfordshire, Oxfordshire and Hampshire, attention was finally concentrated on the Hampshire sites because these sustained the largest populations of water shrews of all the areas investigated. The sites comprised a series of commercially-exploited water-cress beds under slightly different management schemes which supported populations of water shrews throughout the year. This is only one type of habitat used by water shrews, but it provided easy access and favourable working conditions to carry out the live-trapping study, and was a useful starting point for wider investigations.

Although brief visits have been made to a number of the original sites in Hampshire at intervals since 1982 when the study finished, no systematic surveys have been made to assess the continued presence of water shrews, or to estimate their population densities. However, the management practices on several of these sites have been observed to change over recent years, affecting habitat quality for the water shrews. As these sites had supported water shrews over a number of years, it was appropriate and timely to re-survey them in the light of the changes instituted. The results of the survey will assist our understanding of the habitat requirements and tolerances of water shrews which are of direct relevance to management practices (such as river-bank maintenance and vegetation clearance) in freshwater habitats overseen by the Environment Agency. The sites also provide an excellent opportunity to develop and validate surveying techniques for water shrews, including simple field signs which would be applicable to other habitats. A major medium-term aim is to provide written guidelines about practical surveying methods for water shrews requiring the minimum of training and apparatus.

This report provides details of a brief survey of the Hampshire sites carried out in July 1996 to investigate the current status of water shrews and their habitats. July was chosen as the optimum time for the survey since population density of water shrews is high at this time in the breeding season.

2. GENERAL DESCRIPTION OF STUDY SITES

Six sites were investigated for the purpose of this survey. Five of these are old, established water-cress beds which remain under cultivation throughout the year (named Alresford Pond, Bighton, Bishop's Sutton, Itchen Stoke and Tichborne). Previous surveys had found these sites to support water shrews. They comprise a series of beds in which water cress (*Rorippa nasturtium-aquaticum*) is grown under controlled water depths and flow rates. The beds are supplied with water from adjacent streams.

The beds and streams are bounded by grass banks, previously found to support water shrews and other small mammals. The banks are covered predominantly by grasses with additional stands of herbs, mostly nettle (*Urtica dioica*), dock (*Rumex crispus*), butterbur (*Petasites hybridus*), cow parsley (*Anthriscus sylvestris*), dandelion (*Taraxacum officinale*), buttercup (*Ranunculus repens*) and silverweed (*Potentilla anserina*). These banks are subject to different management schemes: some are kept closely mown throughout the year while others are mown only once or twice during the growing season and the vegetation is permitted to grow up freely between mowings. Mowing is carried out by scything or strimming and is mostly confined to the summer growing season. In all cases, the mowings are left *in situ* to become incorporated into the litter layer, providing additional cover for the shrews (and their terrestrial invertebrate prey). The total area occupied by water-cress beds and peripheral banks at each site ranges from 0.75 to 2.5 ha.

A sixth site (named Alresford Weir) was chosen which more closely resembled the natural habitat available to water shrews. This is a little-managed river bank close to water-cress beds which had not previously been surveyed.

All sites are within a three-mile radius of Alresford, Hampshire. Adjacent to the study sites are patches of grass-scrub and reed-bed which are surrounded by pasture and arable land. Site maps are not included in this report, as they are long-term study sites and need to be left free from outside disturbance.

3. METHODS

3.1 Habitat assessment by visual survey of sites

All six sites were visited and a detailed visual survey carried out to assess: (i) the presence of recent field signs of water shrews; and (ii) the habitat quality in the light of management changes since the last survey fourteen years ago. Each site was searched for burrow entrances, scats, faecal middens and food remains of water shrews. Particular attention was paid to the mowing regime employed at each site and the state of the vegetation on the banks.

3.2 Live-trapping survey

Longworth live-traps were set at five sites (Alresford Pond, Bishop's Sutton, Itchen Stoke, Tichborne and Alresford Weir) between 9 and 17 July, 1996. Traps were provided with hay bedding and blowfly pupae as bait. They were placed singly at 3-6 m intervals in selected places on the vegetated banks of the water-cress beds and adjacent streams/rivers. Some were placed close to the water's edge and amongst the cress, but above the surface of the water. Traps were left open for four days and nights at each site and examined at regular intervals throughout to prevent casualties. All captures of small mammals were recorded, along with details of site, habitat and time of day. Water shrews were weighed, sexed, placed in an appropriate age class and individually marked by fur-clipping before release at the point of capture.

3.3 Use of hair tubes and bait stations

The use of hair tubes has been used successfully in a number of surveys of small mammals (e.g. Day 1966, Dickman 1986). They work on the principle that many small mammals readily investigate and enter small holes and potential burrow entrances. Plastic tubing of a diameter large enough to permit the rodent or shrew to pass through it but small enough for the sides of the tube to be brushed by the passing mammal can be used to gather samples of hair caught on sticky tape placed on the inner walls. These hair tubes can be placed strategically in the habitat to be surveyed, and left safely for days or even weeks before being removed for analysis. Identification of the hairs from different species of mammal which have entered the tubes is laborious, and requires specialist knowledge and techniques, but the use of hair tubes has great potential as a non-invasive, harmless, cheap and reliable surveying method. It has not yet been used for detecting the presence of water shrews, but common shrews have been identified successfully by this method.

Preliminary trials to investigate the potential of hair tubes in assessing the presence of water shrews were carried out with double-sided sticky tape applied to the insides of 12 cm lengths of 3.5 cm diameter plastic drainage pipe. Eight hair tubes were placed amongst the vegetation at each of three of the live-trapping sites (Alresford Pond, Tichborne and Itchen Stoke), and left *in situ* for 8 days. They were then collected and examined for the presence of hairs.

Bearing in mind the laborious process of examining and identifying hairs from small mammals, and the specialist microscopical knowledge needed, a possible alternative to hair tubes is the use of bait stations. Water shrews, in common with other shrews, are inquisitive and will readily investigate novel objects in their home ranges, particularly if a food source is detected. The use of specially-designed bait stations which permit entry only by small mammals also has great potential as a cheap and easy field survey method. By providing a suitable food source, these bait stations encourage visiting shrews to enter and linger to feed and defaecate. Scats of water shrews are readily identifiable and distinguishable from those of rodents and other shrew species.

Plastic piping of two types (white pipe of 4.0 cm diameter, and black pipe of 6.5 cm diameter) was cut into 30 cm lengths. One end of each length was covered with nylon net, and a handful of blowfly pupae placed at the covered end of the tube. One tube of each type was placed amongst the vegetation at each of four sampling points in three of the study sites (Alresford Pond, Tichborne and Itchen Stoke). They were left *in situ* for 8 days before being collected. Their contents (including faecal pellets) were decanted into specimen tubes for subsequent microscopical analysis.

4. RESULTS

4.1 Site descriptions and habitat assessment

4.1.1 Alresford Pond

This site comprises approximately 1 ha of water-cress beds with peripheral banks, adjacent to reed-beds and marsh by Alresford Pond. The site is largely intact but subject to more intense habitat management than in previous years. Grass banks surrounding the water-cress beds and adjacent to the supply stream are kept closely mown (to within 4 to 25 cm in height) by strimming every 2-4 weeks during the growing season, and a central grass bank (150 m in length) which was a favoured site for water shrews has been replaced with concrete to permit motorised access. Fresh signs of bank voles were plentiful (burrows, faeces and vegetation clippings). There were some signs of water shrews in the form of old burrow entrances (possibly still in use) on mown banks, and occasional scats amongst rougher grass around the outfall pipes leading to the stream. No food remains were found to denote recently-used feeding sites of water shrews. The beds were currently being re-seeded and were not being cut for cress, so little cover for foraging shrews was available within the beds. Freshwater invertebrates were not very abundant, as is usual in midsummer during the re-seeding period.

4.1.2 Bighton

The extensive area of water-cress beds near Bighton (some 2.5 ha) is highly commercialised and managed. Although banks of vegetation offering habitat for water shrews are still intact around the perimeter of the site, these are kept closely mown (every 2-3 weeks during the growing season). At the time of the survey the vegetation was less than 8 cm in height. The beds are surrounded by agricultural and pasture land. Inspection revealed signs of bank voles but none of water shrews.

4.1.3 Bishop's Sutton

This site comprises approximately 1 ha of water-cress beds together with adjacent river and river bank, and is surrounded by pastureland. It has undergone considerable change since the previous survey. The beds are still commercially managed but, at the time of this survey, they were supporting old, rank, flowering cress ready for re-seeding which provides good cover for foraging water shrews. The greatest changes have been made to the grass banks, particularly bordering the adjacant river, which have been cleared of shrubs and old trees, and the remaining riparian vegetation is closely mown (approximately monthly). At the time of the survey the vegetation was up to 15 cm tall. Despite this, the litter/root layer is intact and offers cover for small mammals. One bank previously favoured by water shrews has been destroyed. Freshwater invertebrates were abundant. There were many signs of bank voles (burrows, faeces, vegetation clippings). Some signs of water shrews were evident, but of doubtful age (no faecal deposits but some prey remains of broken caddis cases and snail shells were found).

4.1.4 Itchen Stoke

This small site (0.75 ha) close to the River Itchen has remained a commercially-exploited site but is currently not over-managed as a habitat. The vegetation on the peripheral banks is thick and rank, up to 1 m in height, and provides plentiful cover for small mammals including water shrews. The cress is at various stages of development within the beds, with some tall, thick, flowering stands providing cover for foraging water shrews. The site is sympathetically managed, the banks are mown rarely (1-2 times per year) and water shrews are reported to be seen occasionally. The site is bounded by rough pasture and hedgerows. Freshwater invertebrates were abundant at the time of the survey. Fresh signs (burrows, faeces, vegetation clippings) of bank voles were evident on the banks, and also occasional scats of water shrews.

4.1.5 Tichborne

This 1 ha site also remains a commercially-exploited site which is currently not over-managed as a habitat. The vegetation on the peripheral banks is mown only 1-2 times per year and, at the time of the survey, was up to 0.75 m tall, providing plentiful cover at all times for small mammals including water shrews. The cress was at various stages of development within the beds, with some tall, thick, flowering stands providing good cover for foraging water shrews. The site is adjacent to water meadows (holding SSSI status) and small areas of unexploited water cress, and it provides an excellent habitat generally for water shrews. Visual survey proved difficult because of the extensive riparian vegetation on the site. No food remains or scats of water shrews were found, but some burrows were located.

4.1.6 Alresford Weir

This 1 ha site beside the River Alre combines managed water-cress beds with an adjacent stretch of pristine shallow river. The visual assessment (and live-trapping survey) concentrated on the river bank as an example of natural habitat for water shrews. It supports rank vegetation of forbs and grasses up to 1 m in height which is mown only 1-2 times per year. No food remains or scats of water shrews were found but burrow entrances of unidentified origin were found, along with faeces of bank voles.

4.2 Live-trapping survey

Based upon the results of the visual surveys, five sites were chosen for the live-trapping survey. These included two sites subject to increased habitat management since the last survey in 1982 (Alresford Pond and Bishop's Sutton) and two sites (Itchen Stoke and Tichborne) subject to 'sympathetic' management which has remained unchanged since the last survey. Previous surveys had shown that all four of these sites had supported water shrews regularly, and visual examination during the present project had revealed signs of these shrews. A fifth site was also chosen as being more representative of typical water shrew habitat, namely river bank at Alresford Weir. This site had not been surveyed in previous years. Although water shrews had not been confirmed by the visual examination, it looked a promising site. The absence of confirmed field signs of water shrews coupled with the judged unsuitability of the habitat lead to the decision not to carry out live-trapping at the Bighton site.

4.2.1 Site occurrence of water shrews

The number of water shrews captured (individuals and total captures) at each site is shown in Table 1. Trapping effort (in terms of the number of traps used) differed between sites, and so results are also provided as numbers of captures per 50 trap nights to permit comparison between sites. An indication of the management scheme in operation at each site is also given.

The trapping survey confirmed the continued presence of water shrews in the three of the four sites surveyed in previous years, and added Alresford Weir to the list of locations inhabited by these shrews. It did not confirm the continued presence of water shrews at Bishop's Sutton. Numbers differed between sites and, with the possible exception of the Bishop's Sutton site, high levels of habitat management did not prevent occupancy by water shrews. The absence of water shrews at Bishop's Sutton, despite it having been a favoured site during previous surveys, was coincident with bank clearance and the increased frequency of mowing.

Table 1 Results of live-trapping for Water shrews, July 1996.

Site	Management scheme	No. individuals captured	Total captures	No. individuals per 50 trap nights	Approx. population density (No. ha^{-1})
Itchen Stoke	M1	11	19	8.6	14
Alresford Weir	M1	2	2	2.8	4
Tichborne	M2	6	20	2.8	6
Alresford Pond	M3	9	13	5.5	9
Bishop's Sutton	M3	0	0	0	0

M1 - Banks mown rarely M2 - Banks mown occasionally M3 - Banks mown frequently

4.2.2 Population structure

The sexes and age categories of the water shrews captured are shown in Table 2. The majority of individuals were juveniles, as expected at this time of year when females are occupied with rearing young and males are wandering widely in search of mates. The presence of both juveniles and breeding adults at most sites indicates viable, ongoing populations. All individuals captured were in good condition, with excellent pelage, body weights in line with the expected, and few external parasites.

4.2.3 Population estimates, and comparisons with previous surveys

Estimates of population density rely upon mark-recapture data. This survey was too brief to provide adequate data of this kind, although individuals were marked. However, tentative estimates of population density, based upon minimum numbers known to be alive and the catchment area subject to trapping, are given in Table 1.

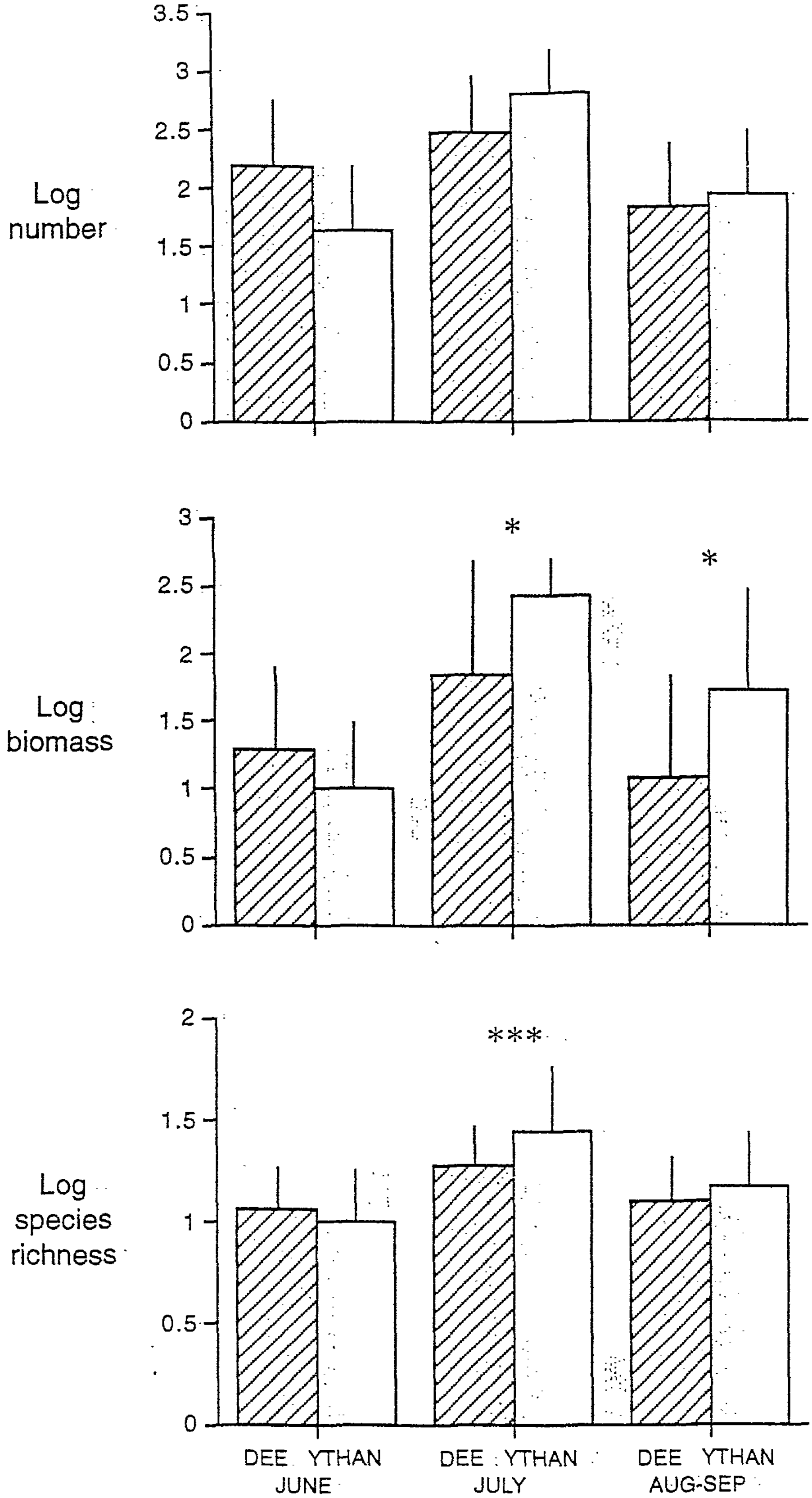

Figure 10 Insect catches (means and SD) at the rivers Dee (hatched) and Ythan (white) obtained on ten evenings during each of three sampling periods (June, July and August/September 1995), expressed as (a) total number of insects per sample, (b) total biomass (mg dry weight) per sample and (c) "species" richness (ie number of "morphospecies") in each sample. The samples were obtained by Johnson-Taylor insect suction traps run at boost speed during 1.5h at dusk and simultaneously at the two rivers. *:p<0.05;***p<0.001.

Table 4 Captures of water shrews at trap sites subject to different mowing regimes.

Site	Rarely mown (1-2 times per year) No. individuals	Rarely mown No./50 trap nights	Rarely mown Total captures	Occasionally mown (once per month) No. individuals	Occasionally mown No./50 trap nights	Occasionally mown Total captures	Frequently mown (twice per month) No. individuals	Frequently mown No./50 trap nights	Frequently mown Total captures
Itchen Stoke	11	5.7	19	-	-	-	-	-	-
Alresford Weir	2	2.8	2	-	-	-	-	-	-
Tichborne	6	2.8	20	-	-	-	-	-	-
Alresford Pond	-	-	-	6	5.0	10	3	2.4	4
Total	**19**	**4.0**	**41**	**6**	**5.0**	**10**	**3**	**2.4**	**4**

These results should be viewed with caution and it should be noted that the study sites were surrounded by potentially suitable water shrew habitat. For example, the Alresford Old Pond was frequently mown but was adjacent to unmanaged reed beds and scrub which may provide a refuge for water shrews. The importance of habitat management to water shrews requires further research, and the role of adjacent areas of unmanaged and/or suboptimal habitat in providing refuges and overflow sites should be included in such an investigation. Such information is required as a basis for developing habitat management schemes for water shrews.

4.2.5 Occurrence of other small mammals

In addition to water shrews, bank voles (*Clethrionomys glareolus*) and wood mice (*Apodemus sylvaticus*) were captured at each of the sites, including Bishop's Sutton where water shrews were absent. Common shrews (*Sorex araneus*) were also numerous at most sites (see Table 5). There were no signs of water voles (*Arvicola terrestris*) in any of the sites. Their absence may be due to the high levels of human disturbance and lack of suitable cover.

Table 5 Total captures (including recaptures*) of common shrews (*Sorex araneus*). bank voles (*Clethrionomys glareolus*) and wood mice (*Apodemus sylvaticus*).

Site	*Sorex araneus*	*Clethrionomys glareolus*	*Apodemus sylvaticus*
Itchen Stoke	5	3	1
Alresford Weir	0	2	2
Tichborne	13	5	5
Alresford Pond	36	6	2
Bishop's Sutton	2	4	2

* These species were not individually marked.

4.3 Use of hair tubes and bait stations

Preliminary trials with hair tubes yielded inconclusive results since the diameter of the tubes appeared to have been too great to collect samples of hair reliably. However, further microscopical analysis is required before recommendations can be made.

In contrast, the bait stations proved very successful. The presence of water shrews at each of the three study areas investigated was confirmed by the positive identification of their scats in the bait stations. Microscopical analyses of the material found in the bait stations yielded rapid and reliable results, with remains of aquatic crustaceans, Plecoptera nymphs, gastropods and ostracods being clearly visible. Of 18 bait stations recovered from the study areas, 82% of them contained scats of water shrews. Ninety percent of the large-diameter black tubes and 75% of the small-diameter white tubes contained water shrew scats.

5. DISCUSSION OF SURVEY METHODS

5.1 Visual assessment

Visual surveys took the form of initial assessment of habitat suitability for water shrews, followed by examination for field signs of shrews (scats, food remains and burrows, see above). The visual surveys carried out were mostly successful in predicting the presence of water shrews which were then confirmed by live-trapping. The exception was Bishop's Sutton where prey remains were the only sign found to indicate water shrews, and none were captured. However, these prey remains were of doubtful age.

Most reliable of the field signs are generally scats, faecal middens and food remains, but all are difficult to find, especially in heavily-vegetated habitats. However, guidelines could be produced on the identification of these field signs and the best places to look for them. Confirmation of water shrew scats can easily and quickly be provided if samples are available. Burrow entrances can also be a useful field sign but can be confused with bank voles' burrows (which are also used by water shrews), and it is often not possible to distinguish between burrows currently in use and abandoned ones.

5.2 Use of hair tubes and bait stations

Further work is necessary to validate the use of hair tubes as a survey method, but their potential has been superceded by the success of the bait stations which have proved to be a better option, providing rapid results. These are easy-to-use and cheap: the cost of large- and small- diameter tubes for bait stations was 67p and 30p each, respectively (plus the cost of bait). The small-diameter white tubing is recommended because its slightly lower success rate (compared with the large-diameter tubing) was offset by its greater visibility (making it easier to recover from the field), the ease with which any scats inside could be seen, and its cheapness. More trials are needed to further validate the use of bait stations in a wider range of habitats, particularly along river- and stream-banks, and to devise a sampling protocol.

A good way forward, to increase the area of survey and develop the protocol, would be to engage volunteers and Agency staff to place the bait stations in suitable areas of habitat and to recover them after approximately two weeks. A preliminary examination of the bait stations for the presence of scats by volunteers would ascertain whether or not they had been used by small mammals. It should be possible for these volunteers, with minimal training, to distinguish scats of small rodents (discrete, cylindrical, mid-brown in colour, and tough and fibrous when crushed between the fingers) from those of shrews (small, blackish in colour and, when crushed gently between the fingers, easily crumble to a granular consistency revealing shiny fragments of arthropod exoskeleton). This does not require the use of a microscope, and can be done in the field. Positive identification of water shrew scats requires more careful microscopic examination but this is a skill which could quite easily be acquired and just needs some practice.

An aid to the identification of typical remains in scats would be an illustrated key which could be prepared by the author (with some financial help towards the costs of engaging an illustrator). In the interim, samples positive for shrew remains could be forwarded to the author for examination. They do not need to be preserved in alcohol or formalin: the chitinous remains in the scats will preserve perfectly well if they are allowed to dry in air. If simply a positive or negative result is required, it should be possible to analyse approximately 15 samples per hour. More detailed analysis (ie. the identification of prey remains) would need more time. The time taken to provide results and the cost per sample would depend upon the number of samples supplied, the frequency of supply and the level of identification required (and hence the allocation of time to complete the assignment). A rough estimate would be in the order of £1.50 per sample.

The bait station survey technique has great potential in assessing the presence of water shrews in a wide variety of habitats and sites. It should be noted that, as with trapping surveys, a negative result cannot be interpreted as confirmed absence of water shrews from the site, but this survey method would certainly assist in the identification of good sites for water shrews. Provided the survey protocol (principally the distances between bait stations) was based upon our knowledge of home-range size of water shrews it could provide a guide to relative (but not absolute) population densities in different sites/habitats.

5.3 Assessment of food resource base

As part of our on-going habitat assessment work we are undertaking a study of inter-site and inter-seasonal differences in prey available to water shrews. Both freshwater and terrestrial invertebrate availability (abundance and biomass) at four different sites in the Alresford study area are being investigated as a research project by a final-year student of Biological Sciences at King's College, London. This should provide useful information about the suitability of sites for water shrews, and contribute to a predictive model of suitable habitat.

6. CONCLUSIONS

1. The live-trapping survey revealed that populations of water shrews in the Itchen and Alre catchment area are buoyant. Captures in July 1996 were greater than those at the same sites in the equivalent month during the last survey in 1982.

2. Water shrews are maintaining populations in areas subject to regular and frequent habitat management, as well as in areas with less rigorous management schemes. The presence of breeding adults as well as juveniles at all sites indicated that these habitats are not populated simply by transient, dispersing individuals.

3. Preliminary results indicated that regular vegetation clearance on banks (without removal of cuttings) did not deter habitation by water shrews, but more individuals were captured at trap sites where vegetation was rarely or occasionally mown compared with those mown closely and frequently. The spatial impact of intensive habitat management on water shrews and the importance of adjacent, unmanaged refuge areas have still to be assessed.

4. Human disturbance (as in cutting, rolling, clearing and re-seeding of water cress, and mowing of banks) does not deter water shrews.

5. The correlation between habitat quality (particularly human disturbance, bank management, pesticide use, water quality and prey resource base) and water shrew numbers and activity remains largely unknown and requires further study.

6. Bait stations have great potential as an easy-to-use and cheap survey method for water shrews.

7. RECOMMENDATIONS

Below are some recommendations which stem from the present project, and which would benefit from involvement by, and support from, the Environment Agency.

1. The present survey has highlighted the lack of information about annual population trends of the water shrew. A population census should be undertaken on a regular basis (every one to two years) in the same sites so that changes in occurrence and status can be monitored and documented.

2. The area of investigation should be enlarged with the aim of instituting a nationwide survey of the occurrence and population trends of the water shrew. Cooperation from local Wildlife Trusts, the Mammal Society and interested individuals would facilitate such a survey.

3. A detailed investigation of the habitat occurrence and requirements of water shrews is urgently required, in order to form a sound foundation for management guidance in the range of habitat types in which it occurs.

4. To assist in the water shrew surveys, and enable the participation of Agency staff, local wildlife groups and other third parties, the development of appropriate, easy-to-use and economical surveying techniques should be researched. Further validation of the use of bait stations as a survey method should be made in a range of habitats, and a sampling protocol devised, with assistance from Agency staff and other third parties. Suitable areas for a pilot study to test and develop this survey method, and assess presence and relative population densities of water shrews, have been identified along the River Chess in Buckinghamshire, River Lea in Hertfordshire and River Itchen in Hampshire. These provide a mixture of natural and man-managed riparian habitats where water shrews were known to occur but which have not been surveyed for several years.

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The ecology and conservation of Daubenton's bat, *Myotis daubentonii*.

A report produced under Environment Agency Project 640

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Executive summary

The primary aim of this project was to develop habitat management guidelines of general applicability to bats using river catchments, but with special reference to Daubenton's bat, *Myotis daubentonii*, because of its particular dependence on water. A review of current knowledge of the ecology of Daubenton's bat was carried out, and in 1996 field studies were conducted to fill some important gaps in our knowledge. Specifically, a Species Action Plan and Management Guidelines for Daubenton's bat were produced, together with guidelines for the integration of bats into Local Environment Agency Plans.

Bat activity (as determined using bat detectors) along the upper reaches of the River Wharfe, North Yorkshire was high, with a mean of 20.1 bat passes per km. This was much higher than the means of 8-10 found during the National Bat Habitat Survey for various land classes including those containing rivers (Walsh and Harris, 1996), the best available comparative data. The mean number of *Myotis* bats per kilometre was 8.9 and that for pipistrelles, *Pipistrellus pipistrellus*, 11.2. Ultrasound analysis suggested that only one recorded *Myotis* bat was a Natterers bat, *M. nattereri*. However, three of the 17 *Myotis* bats caught in harp traps set up directly over the river were this species; the rest Daubenton's bats, *Myotis daubentonii*. Both phonic types (45 and 55 kHz) of pipistrelle (*P. pipistrellus*) used the river, but only five passes were of 55 kHz bats. Incidental recordings of noctule bats, *Nyctalus noctula*, and long-eared bats, *Plecotus*, were made.

Daubenton's bats were predominantly active around areas of river where there were canopy trees on both banks and where the water surface was relatively smooth. Insects were significantly more abundant in the air space immediately above the water when trees were present on at least one bank. The number of insects was also significantly greater over smooth water, relative to cluttered or rapid water. The insects found by sampling were primarily Diptera (flies) (77% by number: Brachycera 44%, Nematocera 22% and Cyclorrapha 6%), Hemiptera (bugs) (9%), and Trichoptera (caddisflies) (7%).

Radio-telemetry revealed that an individual male Daubenton's bats foraged over the same 1.5 km of river for four consecutive nights in July. Another male fitted with a transmitter during September travelled at least 2 km downstream, but its detailed foraging patterns are not known. One male caught and ringed with reflective tape was found foraging 4.5 km downstream.

Two roost sites, in tree holes in old ash/wych elm woodland 0.5 km from the river, were used by a radio-tagged Daubenton's bat. One roost contained at least 13 other bats. Roosts were also found in Kettlewell bridge (minimum of 64 bats) and Skirfare bridge (min. 30 bats), 1.8 km beyond the southern limit of the study site.

97% (n=37) Of the Daubenton's bats caught were males. One female was caught in September at the beginning of the mating season.

1. INTRODUCTION

There are an estimated 110,000 Daubenton's bats in England and Wales (reliability rating 4, 1 highest, 5 least reliable), and its status is described as stable (Harris *et al.,* 1995). Speakman *et al.* (1991) reported a decline in Daubenton's bat in northern Scotland. Reports in other parts of Europe suggest an increase in numbers based on counts in hibernacula (Daan, 1980; Voute *et al.,*1980; Ryber, 1981). However, the latter may reflect the concentration of bats into a few remaining suitable sites rather than a true population increase (Stebbings, 1988).

Daubenton's bat fulfils two of the five criteria set by English Nature to determine which species should receive priority for conservation action. These are that it is listed on Schedule 5 of the Wildlife and Countryside Act, and that it is a native species. It has been given a medium priority for conservation action (Mitchell-Jones, 1996). There is a high priority for status surveys on species which are believed to be declining or for which inadequate data are available. The reliability of the population estimate is low, we know of relatively few nursery colonies and many roost sites are vulnerable. Further research into the status and requirements of breeding populations is therefore necessary, and action needed to protect existing roosts and foraging sites.

The primary aim of this project was to develop habitat management guidelines for Daubenton's bat, *Myotis daubentonii,* which relies heavily on river catchments for roosting and foraging. A review of current knowledge of the ecology and this species was carried out, and field studies were conducted to fill some important gaps in our knowledge. The following documents have been prepared:

1. A review of the ecology and conservation of Daubenton's bat (this document)
2. Species Action Plan for Daubenton's bat.
3. Management Guidelines for Daubenton's bat
4. Guidelines for integrating bats, particularly Daubenton's bat, into Local Environment Agency Plans.

Daubenton's bat is more closely associated with riparian and wetland habitats than any other species of bat in Britain, and is therefore of particular concern to the Environment Agency. It feeds almost exclusively in the 1m air space above water or from the water surface itself (Jones & Rayner, 1988; Kalko & Schnitzler, 1989; Miller & Degn, 1981; Nyholm, 1965; Swift & Racey, 1983; Vaughan, 1997) and roosts close to water (Barrett-Hamilton, 1910-1911; Nyholm, 1965; Speakman *et al.,* 1991). It feeds mainly on flies (Diptera, primarily Nematocera) and caddisflies (Trichoptera) (Nyholm, 1965; Sullivan *et al.,* 1993; Swift & Racey, 1983).

This report summarises the current knowledge of the behaviour and ecology of Daubenton's bats, and findings from a field study carried out in 1996. Ultrasound recording of bats made on timed transects have been used to quantify habitat preferences for Daubenton's bats (and pipistrelles). Radio-telemetry has been used to determine the foraging patterns of individual bats, and the diet and available prey were determined from faecal analysis and insect sampling. The results are discussed in relation to the habitat management and conservation needs of Daubenton's bat, and recommendations are made for future research. A recent review of the use of river corridors by bats by Racey (1996) should also be consulted.

2. STUDY SITE AND METHODS

The study site was a 14 km stretch of upper Wharfedale, in the Yorkshire Dales National Park, between Yockenthwaite (GR SD905791, 270m above sea-level) and Kettlewell (SD970723, 210m) (Figure 1). The dale is a glaciated valley, with a misfit river, the Wharfe, which is bounded primarily by unimproved/semi-improved pasture and hay meadow, and passes through or close to the small villages of Hubberholme, Buckden, Starbotton and Kettlewell. The flat valley floor is rarely more than 1 km wide, and the steep sides rise to moorland over 600 m above sea-level. The entire upper dale is within the Great Scar Limestone area, and the slopes are characterised by stepped rock scars, with deciduous woodland. There are many caves and potholes, and a few disused 19th century lead mines. Much of Upper Wharfedale is owned and managed by the National Trust, there are numerous SSSI sites, and it is within an Environmentally Sensitive Area (Pennine Dales Hay Meadows). The river Wharfe is prone to flooding, and there have been attempts in the past to manage the river, with artificial levees and a gravel trap.

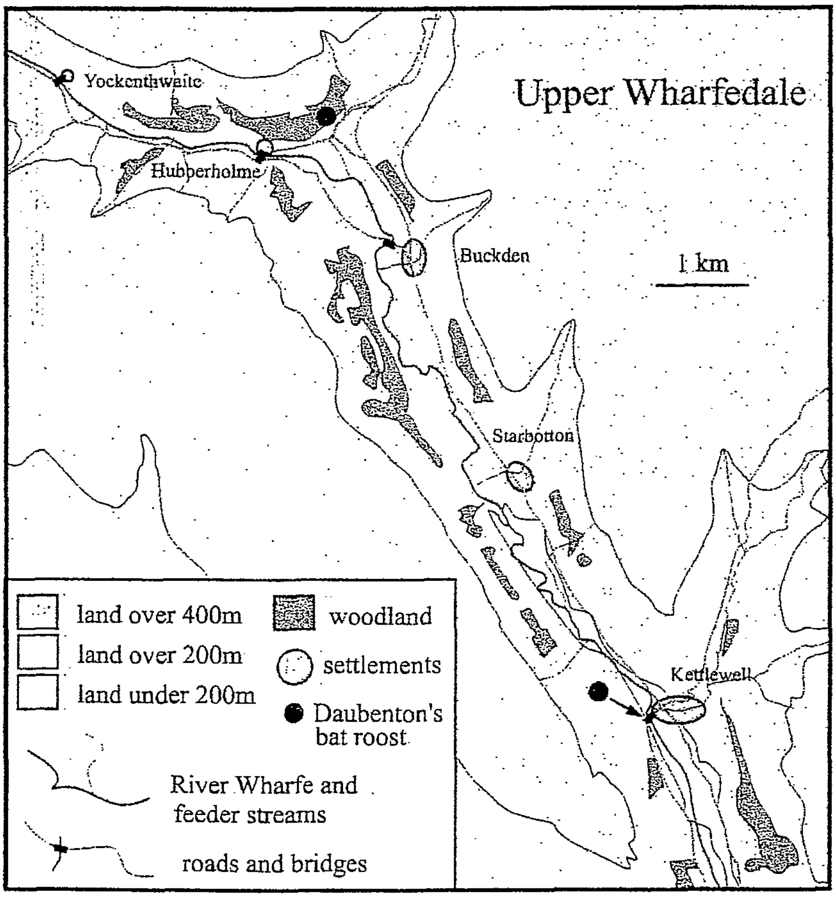


Figure 1 Study site in Upper Wharfedale, Yorkshire Moors National Park.

Transects. The length of the river under study was divided into eight approximately equal transects. In early July, each transect was selected randomly and walked at a constant (~3.5 km h^{-1}) walking pace starting 30 min after sunset. Transects were walked on warm evenings (10-19°C at the start of the transect) without rain or heavy wind.

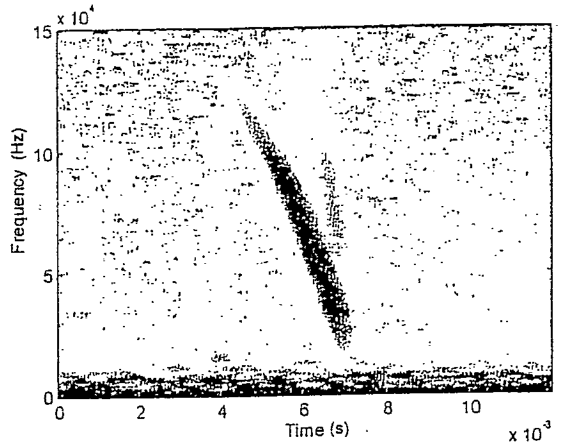
A Pettersson D980 time-expanding ultrasound detector was used to determine the presence of bats by listening to the broadband frequency division facility. Simultaneously, recordings were made of all bats encountered by sampling the received ultrasound at a sampling rate of 450 kHz, and down-loading a 10X time-expanded sequence into a Sony Professional Walkman WM-D6C for later analysis. Dictaphone notes were taken of the positions of bats recorded, and the times at which identifiable distance markers such as walls and bridges were passed. Since the recording tape ran continuously, the time of any bat encountered, as measured by tape position, translated accurately to a position along the transect. When the transect was completed in one direction, it was walked in reverse starting 60 min after sunset. This was to investigate the influence of sampling time on bat distributions and feeding activity. The river and its banks were rarely more than 10 m wide, and never more than 20 m wide, so all bats flying over the water surface or banks were within range of the detector.

Spectrographic analysis of time-expanded recordings was performed with custom written routines for MATLAB on a PC. Spectrograms were constructed of calls using a 512 point Fast Fourier Transform with Hamming window to separate *Pipistrellus* species from the two *Myotis* species known to use the river. Calls from all three species are shown in Figure 2. These are from known bats, released after being captured in a harp trap. Since no other *Myotis* species have yet been found in the dale, it was assumed that all *Myotis* recording not identified as Natterer's bats were Daubenton's bats.

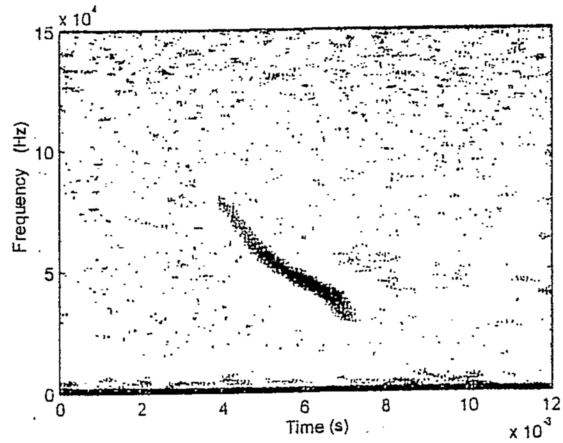
The position of each bat was marked on enlarged sections of the OS 10,000 map of the area. On the same map, the major physical features of the river were marked: the presence of trees (>5 m high with no breaks >5 m in length) on one or both banks, and whether the water surface was smooth, cluttered (had projecting rocks and riffles), or rapid (with white water and heavy ripples). Data were expressed as the total number of bats recorded within a habitat type, divided by the total length of that habitat in km. A χ^2 contingency table was constructed to compare the number of *Myotis* bats and pipistrelle bats recorded in the various habitat combinations. Bonferroni confidence intervals were constructed at the $P < 0.05$ level to determine which habitats were used significantly more or less than in proportion to availability (Neu *et al.*, 1974).

Insect sampling. Insects were sampled by sweep netting between 30 and 120 min after sunset (when Daubenton's bats are feeding) on four nights in August 1996 (14-16°C, little wind, no rain). At each of 4 locations roughly equidistant along the section of river under study, sample sites were chosen over smooth, cluttered and rapid water surfaces, with trees on both banks and without trees. Start times were the same on each night, and the order of sampling each site was rotated. At each site, 20 180° sweeps of the net were made just above the water surface. Insects were then collected with a pooter and stored in alcohol for subsequent classification down to family level (Chinery, 1993).

Myotis nattereri



Myotis daubentonii



***Pipistrellus pipistrellus* (45 kHz phonic type)**

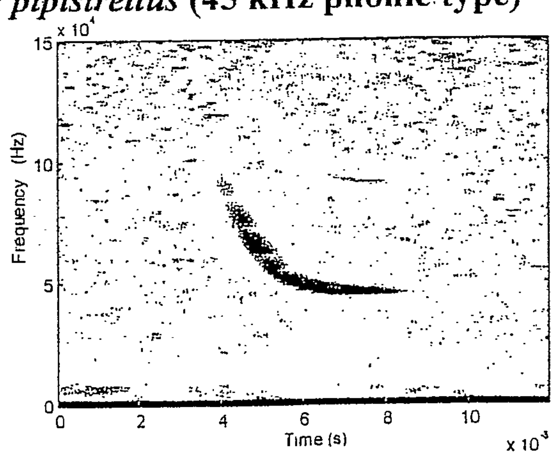


Figure 2 Search phase sonar calls used in species identification

Radio-telemetry. Small (0.44 g) radio transmitters (Holohil, Ontario, Canada) were tested for suitability in July 1996. They are the smallest available, and came onto the market only recently. We therefore felt it essential to field test them before making a major financial commitment. Only bats over 9g were used, to ensure that the transmitter was <5% body mass. Additional transmitters were obtained for use in September. Bats were caught using a harp trap (Austbat, catching area 2.2x2.8 m) erected over the river, where branches of bankside trees restricted the airspace over the water to <3 m in width. All bats caught were ringed using Mammal Society rings. Narrow bands of reflective tape (Scotchlite) were glued to the rings of some bats, which could then be clearly identified when the bats flew through a torch beam. Radio transmitters were glued directly onto the skin, after trimming the fur, using a surgical glue (Skinbond Inc.). Bats were kept in a quiet spot, in a bag, for 1 h before release, after which they were followed continuously until they returned to the roost or were lost.

Faecal analysis. Faeces were collected from underneath roosts in bridges, and from captured bats, which always left faeces in the holding bags. Insect families present in the faeces were determined and a reference collection made of insects captured during the study.

3. RESULTS

Transects. The results are summarised in Table 1, which shows the number of bat passes km^{-1} recorded within each habitat type on the return leg of each transect (60-90 min after sunset). Significantly fewer bats were recorded on the outward leg of each transect, with particularly few Daubenton's bats, reflecting their later emergence from the roost. Data from the outward leg were not used in this analysis, since comparatively few Daubenton's bats were recorded. Only one ultrasound recording proved to be that of a Natterer's bat, all others were assumed to be of Daubenton's bat. Although most parameters of the echolocation calls of the two species showed some overlap, spectrograms from Natterer's bats released from the hand were consistently 'convex up', those from Daubenton's bat 'convex down' (Figure 2). A method for quantifying and confirming this difference is being developed. Three of the 17 *Myotis* bats caught in harp traps set directly over the river were Natterer's bats, all others were Daubenton's bats.

A χ^2 analysis showed that the bats were not randomly distributed between the different habitat types ($P<0.05$ for both Daubenton's bat and pipistrelle). The z statistic was used to calculate 95% Bonferroni confidence intervals, and these results are also shown: '+' signifies a habitat used with greater frequency than expected, and '-' habitats selected against. Other habitats were used in proportion to the length available. With the exception of stretches of river with a cluttered surface and no trees present on either bank, all habitats were well represented (Table 2).

Daubenton's bats showed a clear preference for stretches of river with a smooth water surface and trees on both banks. All but one of the other habitats were used in proportion to availability, but the large variability in the results may have masked more subtle influences. Pipistrelles also showed a clear preference for smooth stretches of river with trees on both banks.

Table 1 Number of bats recorded per km in each habitat category.

M. daubentonii (bat passes km^{-1}) (mean±s.d.)	Trees	Water character		
		smooth	cluttered	rapid
	not present	4.1±2.3 -	7.7±10.9	3.0±1.4
	present on one bank	6.9±4.9	3.2±2.3	4.9±2.8
	present on both banks	24.3±16.7 +	5.4±0.7	4.4±1.7

P. pipistrellus (bat passes km^{-1}) (mean±s.d.)	Trees	Water character		
		smooth	cluttered	rapid
	not present	7.4±0.3	7.7±10.9	12.1±5.7
	present on one bank	12.2±1.4	2.4±1.1 -	5.3±2.1
	present on both banks	17.9±8.8 +	15.7±2.8	7.7±7.4

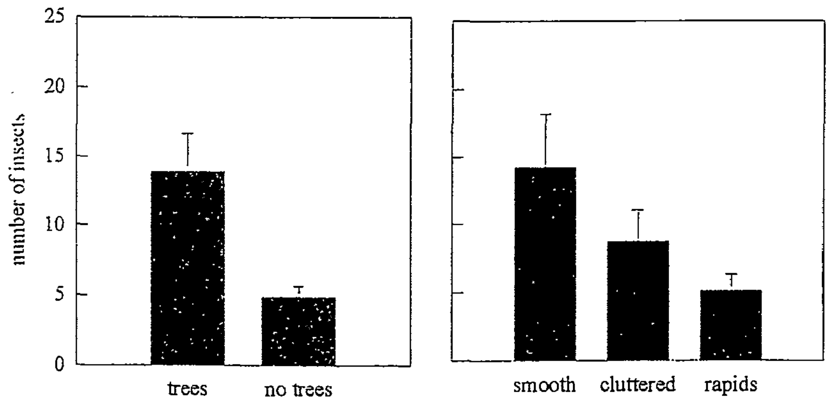
Table 2 Total lengths of each habitat category (in km) within the study area.

Trees	Water character		
	smooth	cluttered	rapid
not present	2.103	0.065	0.498
present on one bank	3.56	0.623	1.03
present on both banks	2.41	1.018	1.24

Insect sampling. The results are summarised in Figure 3. The mean number of insects trapped was significantly greater on stretches of river with trees present on both banks than on tree-less stretches ($P<0.001$), and on stretches with a smooth, relative to a rapid, surface ($P<0.05$) (2 way ANOVA on log transformed data). The number of insects trapped over cluttered water was intermediate to those over smooth and rapid surfaces, but not significantly different from either. The insects found were primarily Diptera (77% by number: Brachycera 44%, Nematocera 22% and Cyclorrapha 6%), Hemiptera (9%), Trichoptera (7%), with small numbers of other groups.

Faecal analysis. A preliminary analysis of faeces from bats caught in harp traps revealed a diet similar in composition to the insects caught in the sweep nets.

Figure 3 Mean number (± SD) of insects trapped in each habitat category.



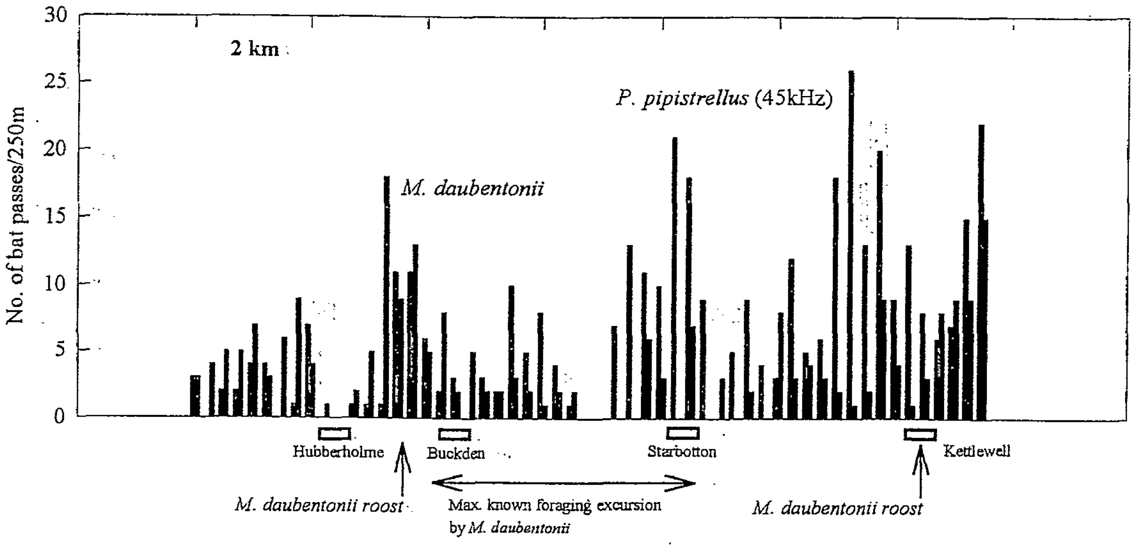
Radio-telemetry. A male Daubenton's bat, trapped and fitted with a transmitter in mid July was followed continuously for four consecutive nights, with visual contact being made at frequent intervals. After release at midnight, the bat foraged almost continuously over a 0.5 km stretch of the river until 4.20 a.m. when it flew directly to a roost in an ash tree 0.5 km from the river (GR SD933787), close to a gill which flows into the river. More than 80% of foraging time was spent flying over a large pool in the river. The bat used a night roost in a bankside tree for 15 min at 3.00 a.m. Over the following three nights the bat emerged around 22.00 and foraged over a total of 1.5 km of the river, apparently commuting between favoured locations, notably the same large pool used on the first night. It returned to roost in one of two ash trees (50 m apart) 0.5 km from the river at around 4.00 a.m. The first tree roost was shared with a minimum of 13 other bats. This bat was recaptured in October, whilst feeding over the river, at the site of initial capture. The transmitter had fallen off, and the fur regrown. After this initial success, more transmitters were purchased, and were delivered in late August. Two male bats were fitted with transmitters in September. Both were lost on the first night, but one was followed over 2 km downstream, after foraging at the capture site for 30 min, before being lost. Since no signals could be picked up over several days of searching, we assume that the bats either left the study area, or roosted in caves during extended periods of cool weather. Telemetry was therefore discontinued.

A bat carrying a ring with a reflective band was seen foraging 5.0 km from its capture site several weeks after being caught and ringed.

Of the 29 Daubenton's bats caught (14 over the river at Buckden, six from Kettlewell bridge, and nine from Skirfare bridge), only one was a female, caught in the harp trap in September, after the maternity period, and at the beginning of the mating season. eight bats caught in a previous year from Kettlewell bridge roost were also males. Small but roughly equal numbers of male and female Natterer's bats and pipistrelles were caught in the harp trap.

Distribution along the dale. Figure 4 shows the total recorded bat passes in 250 m stretches of river along the entire transect. The distribution of pipistrelles (45 kHz) was unimodal, with a significant decline in the number of bats in an upstream direction ($P<0.001$, $r^2 = 0.36$). No major roost sites are known. The distribution of Daubenton's bats was clearly bimodal, the peak of the Hubberholme/Buckden population coinciding with the location of the known tree roosts. The peak activity of the Kettlewell population occured south of the roost, and bats from this roost clearly foraged outside the study area. The observed foraging ranges of Daubenton's bats suggest that there will be some overlap in the home ranges of these two colonies (the area in which an animal travels in pursuit of its routine activities). Bats were ringed at all three known roost locations (Buckden, Kettlewell and Skirfare), and no bats were observed to move roost, suggesting minimum interchange, and therefore relatively isolated colonies. The number of bats at each roost was variable, suggesting the use of alternative roosts, as described by Rieger (1996a).

Figure 4 The total recorded bat passes in 250 m stretches of river along the entire transect



4. DISCUSSION

4.1 Population estimates

Bat activity along the River Wharfe was high, with a mean of 20.1 bat passes per kilometre, considerably higher than the mean of 8-10 bat passes km^{-1} found in various land class categories, including those containing rivers, during the National Bat Habitat Survey (Walsh and Harris, 1996), the best available comparative data. This result suggests that habitat quality is high, in terms of the numbers of bats it can support. If we assume that each pass recorded on the second transect leg is a separate bat, then this 12.5 km stretch of river supported 141 pipistrelles and 112 Daubenton's bats. A ratio close to 1 between the echolocation calls of *Pipistrellus* and *Myotis* species recorded over rivers was also observed by Vaughan *et al.* (1996) in south-west England. Individual Daubenton's bats typically foraged back and forth along a short stretch of river for at least several minutes before moving on (see also Swift and Racey, 1983). Similarly, pipistrelles also tend to forage in a small area for a period before moving. This makes it likely that most bats were recorded only once as the recorder walked along the transect, but the actual number of individual bats may be fewer than the number of passes recorded. Since the transects were done over eight nights, some bats may have been missed since they were feeding elsewhere, so this would lead to an underestimate of numbers. The simplest (but unsupported) assumption is that these two sources of error will cancel each other out. From roost counts, the minimum population of Daubenton's bats was 78, assuming no bats were counted twice. Interchange between roosts could lead to an over- or underestimate of the total population. Given the observed separation of the colonies shown in Figure 4, (and the absence of exchange seen from ringing studies) the level of exchange at any one time was likely to be minimal. Furthermore, Daubenton's bat can use many tree roosts when they are available (Rieger, 1996a;b), switching roosts frequently, as was observed in the current study. Thus, a population of 78 is likely to be an underestimate. Note also that some of the bats from the Kettlewell roost forage south of the study area. Taking all of these factors into account, our best estimate of the population of Daubenton's bat is therefore about 80-110 bats, in two relatively discrete colonies.

The high density of bats over the water raises the possibility that the population may be limited by the area of suitable water for foraging. In some situations the availability of roost sites near such water may also be limiting. It should be noted that over all habitats available, Daubenton's bat densities will be low due to their close association with water, which in terms of surface area is a scarce habitat.

4.2 Foraging habitat preferences

Foraging Daubenton's bats showed a very marked preference for stretches of river with smooth water and tree cover on both banks. Insect abundance, measured by numbers of individuals, was greatest in these areas, in the 1 m of airspace above the water (this study). This is consistent with their known foraging behaviour. Daubenton's bats are known to hunt low over water, typically at a height of less than 1 m (Kalko & Schnitzler, 1989; Miller & Deyn, 1981; Nyholm, 1965) where they feed on insects, frequently taken from the water itself (Swift & Racey, 1983; Jones & Rayner, 1988; Kalko & Schnitzler, 1989). Jones & Rayner (1988) noted that 38% of prey were gaffed from the water surface. Daubenton's bats used most other habitat in proportion to availability.

Habitat preference may be related to the greater abundance of insects observed in the preferred habitats, *and* to the bats'ability to locate prey more easily, using echolocation, in some habitats. The activity of the little brown bat, *Myotis lucifugus*, which fills a similar ecological niche in Canada to Daubenton's bat in this country, was higher over pools than riffles, in the absence of a significant difference in insect abundance (von Frenkell & Barclay, 1987). The more complex echoes from a rippled or cluttered surface probably make insects harder to locate. High frequency noise from rippling water may also interfere with a bat's echolocation (Fenton *et al.*, 1983). Playback of the sound of turbulent water reduced the activity of *M. lucifugus* over smooth water (Mackey and Barclay, 1989). *Myotis lucifugus* foraging close to the water's surface have significantly lower flight costs than those flying higher due to the ground effect (Aldridge, 1989), again increasing foraging efficiency.

Pipistrelles also showed a marked preference for smooth water and tree-lined banks, although it typically forages in the airspace >1 m above the water, and along the edges of the trees and banks.

There was no evidence that the two species excluded each other from particular habitats, but their foraging styles show that there is a considerable degree of spatial separation of their foraging niches on a small scale. There may also be some temporal separation: pipistrelles were only caught soon after dusk in the harp trap, and consistently earlier than Daubenton's bat. This implies that management strategies for one species may not necessarily benefit the other. Vaughan *et al.* (1996) showed that eutrophication of rivers by sewage outfalls led to a reduction in the foraging activity of pipistrelles, but that of Daubenton's bat increased. We clearly need a greater understanding of the autecology of both species.

4.3 Roost sites

The bimodal distribution of Daubenton's bat along the study site, the observed foraging distances, and the lack of roost interchange, suggest that there were two largely separate colonies in the study area, whose home ranges may overlap. One colony is centred around tree holes in an ash/wych elm woodland between Buckden and Hubberholme, the other in Kettlewell bridge. A very striking and important feature is that both colonies appear to be entirely male. A similar, apparently all male colony roosts under the Skirfare bridge (3 km downstream of Kettlewell); the composition of a roost under Grassington bridge (10 km downstream of Kettlewell) is not known. The nearest known maternity colony on the Wharfe is under Otley Bridge (~50 km downstream). The solitary female caught may have moved into the area from further downstream, at the end of the maternity season.

In the foothills of the Canadian Rockies, only males of the ecologically similar *M. lucifugus* are found in summer, the maternity colonies occupying buildings in the lowlands (Barclay, 1991). Barclay suggested that the upland habitat was marginal: the large but brief dusk peak of diptera being unable to meet the energetic demands of pregnant and lactating females, which may double by the time of peak lactation (Kurta *et al.*, 1989). The same argument could be applied *to* Daubenton's bat in Wharfedale, but this does not explain the high bat densities, which suggest high quality habitat. Pregnant and lactating females need to forage every night, males do not (Hamilton and Barclay, 1994). It may be that foraging is rich on some nights, but too few nights to meet the high energetic demands of breeding females. Female Natterer's bat were caught, but they are known to glean for a wider range of prey, and may thus be able to exploit non-volant prey on cold nights.

Speakman *et al.* (1991) suggest that Daubenton's bats do not fully sexually segregate during the summer: of the three roosts they studied one contained males only and the other two contained predominantly females with males present. This is also supported by observations of roost composition in Czechoslovakia (Cerveny & Burger, 1989). Stebbings (1977) suggests that nursery roosts are composed predominantly of females. Of 30 known roosts in North and West Yorkshire, only four are known to hold nursery colonies, two in bridges, one in a tree hole, and one in a building. All nursery roosts contained less than 50 bats (Jones *et al.*, 1996; J.D. Altringham, J. & H. Gardner, unpublished obs.). With the exception of one roost (700 m) all those in Yorkshire are within 400 m of a substantial water course. Nursery roosts were also reported to be close to water by Barrett-Hamilton (1910-1911). Speakman *et al.* (1991) studied Daubenton's bats in Scotland, near to the border of their northern distribution along the rivers Dee and Don. All four roost sites were located immediately adjacent to the major rivers. Two roosts contained less than 10 individuals, one approx. 40 and the other over 100. All 15 nursery roosts found by Nyholm (1965) in Finland were within 200 m of water: ten of these contained less than 15 individuals. Nursery roosts may be in hollow trees (Nyholm, 1965) and in buildings or under bridges (Ryberg, 1947). In Finland 10 of 15 were in trees (Nyholm, 1965).

Night roost have been recorded approximately 1 km away from day roosts, and very close to the main foraging grounds (Ruedi, 1993; this study). The choice of night roost depended on the reproductive status of the females as well as rainfall and temperature (Reudi, 1993).

The major pipistrelle roost sites in Wharfedale have not yet been found. The numbers of foraging pipistrelles increased significantly in a downstream direction, and numbers were still increasing at the downstream limit of the study area.

Daubenton's bats typically hibernate in caves, mines, tunnels and similar structures, often in crevices, and often solitary (Stebbings, 1965; J.D. Altringham, unpublished obs. in Yorkshire Dales). Nyholm (1965) observed them entering hibernacula in October. Krzanowski (1961) suggested that the bats may emerge from hibernation during the winter. Males precede females into hibernacula and depart earlier in spring (Stebbings, 1977).

4.4 Home range

The typical foraging distances of up to 2 km, with sorties to 5 km, recorded in the present study are consistent with published information. *Myotis daubentonii* in Scotland flew up to 2 km to forage, from a roost in woodland (Swift & Racey, 1983). On a lowland canal in England they regularly flew 2 km, often 5 km and occasionally over 10 km, but in the last case not necessarily to feed (Richardson, 1985).

4.5 Prey

In Scotland Daubenton's bats fed largely opportunistically on insects with aquatic larvae, particularly those which rise from the surface of the water during the night (Swift and Racey, 1983). Nematocera (Diptera) and Trichoptera made up about 95% of the diet in summer. Mayflies (Ephemoptera) were taken when they were available, and moths (Lepidoptera) and beetles (Coloeptera) were also found in small numbers, but no non-flying insects were eaten. Nyholm (1965) recorded Diptera, Trichoptera, and butterflies in the diet in Finland. In Ireland, Sullivan *et al.* (1993) reported a diet of roughly equal numbers of Trichoptera and nematoceran Diptera, the majority of the latter being Chironomidae and Ceratopogonidae. Together they constituted 75% of the insects eaten from June to August. Sullivan *et al.* found a greater range of prey than Swift and Racey (1983) with Hemiptera and non-nematoceran Diptera in particular, forming significant components. The presence of spiders (in 27 droppings) and harvestmen (in 11 droppings) suggests that arachnids, and other prey, may have been taken at the roost and could have been common in the interstices of the stone bridge. They found a noticeable rise in food other than Trichoptera and Nematocera in September.

4.6 Conservation and management

We identified some major habitat requirements for Daubenton's bat and the information has been used to prepare a Species Action Plan and Species Management Guidelines (Altringham *et al.*, 1997a,b). Full management recommendations can be found in these documents. Briefly, riparian woodland corridors and other vegetation should be created or maintained to encourage a diversity of insect species. Trees should be maintained or planted on both banks of rivers and static water bodies. To avoid excessive shading, tree density should be low and variable, with frequent small gaps. The key is to provide continuity of riparian woodland between roosting and prime feeding sites. This woodland should contain trees which can be used as day/night roosts. Smooth pools should be encouraged on stretches of river with surrounding riparian vegetation, particularly where trees are present on both sides of the river, since these are primary foraging sites. Old trees should be protected as potential roost sites, perhaps with judicious use of tree surgery. Renovation of bridges and buildings close to rivers should be undertaken carefully to prevent the exclusion or trapping of bats, through blocking of the roost site entrances and destruction of roosts. At all times, the possibility of conflicting requirements for the conservation of different animal and plant species should be considered in drawing up plans. Ideal solutions are likely to involve a mosaic of habitats along a river.

5. CONCLUSIONS RELATING TO METHODOLOGY AND APPLICABILITY OF RESULTS

5.1 Appraisal of project as a method for assessing bat populations and habitat use

Time-expanded recordings of echolocation calls can be used to identify many bat species in flight with some confidence (Vaughan *et al.*, 1997), making it possible to quantify bat activity, and relate this to habitat variation. In this study, population estimates based on river bank transects compared well with those made from roost counts. The distribution of bats along transects gave a clear indication of where roosts might be found, and this was confirmed by radio-telemetry. The technique is sensitive enough to reveal the fine-grained details of bat distribution, is relatively low cost, and with appropriate precautions, can be carried out relatively quickly. We believe the technique can be applied widely to other river systems, and include other species of bat which feed along rivers (see Racey, 1996). With the appearance of low-cost time-expansion detectors and sound analysis packages for microcomputers, we strongly favour their adoption. Heterodyne bat detectors are being increasingly widely used to identify species, but we believe this approach to be unreliable, particularly in inexperienced hands.

5.2 Can the results of this study be applied to all river systems?

We think the answer is yes for upland rivers. However, pregnant and lactating female bats have much higher, and more constant, energy demands than males, and may therefore have different habitat requirements to the predominantly male population of Daubenton's bat present on this upland study site.

5.3 Appraisal of project as a method for assessing habitat quality

The water quality and productivity of a river system determines the diversity and abundance of many vertebrate predators, including fish, amphibians, terrestrial mammals and bats. Bats account for one third of the UK's mammalian species, and are close to the top of the food chain. They are thus potentially important indicators of the health of a particular habitat and the catchment. Bats are relatively easy to detect compared with other vertebrates, their activity can be monitored with relative ease using ultrasound detectors, and several of the major species can be readily identified from time-expanded recordings of their calls. Transect recordings can be made by relatively inexperienced field workers, and even the sound analysis techniques can be learnt quickly.

Daubenton's bat has many of the characteristics required of an 'indicator species' for the quality of the water and riparian vegetation of a river: it has a strong dependence on water, it can be readily monitored, it should respond well to management, and it has some measure of existing legal protection. The abundance of diptera in its diet may make it relatively insensitive to water quality, although reproductive status and season may be complicating factors, and the seasonal dietary requirements of the breeding population need further study.

6. RECOMMENDATIONS FOR FUTURE WORK

Several outstanding questions need to be addressed by future work:

1. The apparent segregation of male and female Daubenton's bat within the dale needs to be confirmed. If such segregation does occur, it is important to determine where and under what conditions it occurs in other populations of this and perhaps other bat species.

2. Habitat (roosting and foraging) and dietary requirements of the breeding females should be studied.

3. Population estimates lower down the river Wharfe and of other river systems should be made. Although the density of Daubenton's bat is high on the river itself, the confinement of the species to riparian sites suggests that it may be relatively uncommon. We still lack a reliable estimate of the national population.

4. Habitat and roost use by colonies and individual bats should be studied in other upland and lowland river valleys to determine how generally applicable our results are.

5. Similar studies of other species which utilise riparian habitats should be undertaken. For example, the UK is believed to be the European stronghold of Natterer's bat, yet we know little about its biology or habitat requirements. A study in progress in southern England (directed by P.A. Racey of Aberdeen University) should help fill the gap.

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Appendix A - Integrating bats into Local Environment Agency Plans

Under Issue: **Loss of Biodiversity**

Most of the species of bat that breed in England and Wales use river corridors and other aquatic habitats. Several of these have shown significant population declines in the last two decades. One species, Daubenton's bat, *Myotis daubentonii*, specialises in feeding over water. When active in summer, it is rarely found far from water: summer roosts are typically in bridges and holes in trees adjacent to water bodies.

The LEAP must take into account the extensive use of river corridors and other water bodies by bats, and the dependence on water bodies of one species, Daubenton's bat, which specialises in foraging over water. Loss of riparian woodland, particularly when adjacent to roost sites, could threaten the local persistence of Daubenton's and other bat species.

Implemental

The Agency would be expected to take the lead in promoting awareness and protection of Daubenton's bat, in liaison with the Bat Conservation Trust who, supported by the DoE, will be monitoring populations of this species in 1997.

In order to protect bats (especially Daubenton's bat) using the catchment, LEAPs would be expected to contain the following:

1. A map of all known roost sites of Daubenton's bat. Survey will be required. Particular attention should be given to bridges, which often constitute roost sites for this species. Bridge repairs must take into account the possible presence of bats in crevices. The Local Authority, EA, County Bat Group and Statutory Nature Conservation Organisation need to liaise.

2. Identification of additional information requirements for each bat species, but especially Daubenton's bat. A particular need is information on the use of tree roosts.

3. Promotion of local action plans for Daubenton's bat (or other species). These should link to action plans for aquatic and woodland habitats.

The use of river corridors by bats

A Report produced under Environment Agency R&D Project I640

on behalf of the Bat Conservation Trust

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1. INTRODUCTION AND OBJECTIVES

The Environment Agency recognises that there is currently a limited understanding of bat behaviour in river corridors upon which to base protection, mitigation and enhancement measures. This study was commissioned under R&D Project i640 to determine the limits of existing knowledge and to investigate ways in which bat behaviour and requirements might be clarified in a cost-effective manner.

The pricipal aims of the study were to:

1. review available information/knowledge on the relationship of bats to rivers/river corridors for species indigenous to England and Wales;

2. review survey techniques suitable for use in an assessment of the importance of rivers to bats (in England and Wales);

3. undertake a feasibility study of a national river-corridor-based survey of England and Wales.

In relation to Objective 1, the aim of the review was: to consider the distribution of bat roosts in relation to rivers and other water bodies; to examine the evidence that some bat species forage preferentially along rivers; and to consider what resources are provided by the rivers for the bats. Recent studies on the effects of eutrophication on bats were also considered. The review was principally based on information obtained in Britain and included published and unpublished results obtained by the author and colleagues on five rivers in Scotland: the Dee, Don, Ythan, Spey and Tay. The conclusions of these studies together with those selected from mainland Europe and N. America are thought to apply equally to rivers in England and Wales or point to the need for similar research in these countries.

To assist the non-specialist reader a check-list of bat species found in England and Wales is provided (Table 1).

Work on Objective 3 was to include costed options considering:

- reference to DoE-funded work (and possibilities for collaborative input);

- use of key reference or indicator catchments (with an indication of selection criteria for catchments

Table 1 Bat species recorded in the UK, their distribution and conservation status (modified from Hutson, 1993a)

	Species	Distribution		Status	IUCN status
		England	Wales		
1.	Greater horseshoe bat *(Rhinolophus ferrumequinum)*	+	+	rare	E
2.	Lesser horseshoe bat *(Rhinolophus hipposideros)*	+	+	rare	E
3.	Daubenton's bat *(Myotis daubentonii)*	+	+	common	NT
4.	Brandt's bat *(Myotis brandtii)*	+	+	scarce	V
5.	Whiskered bat *(Myotis mystacinus)*	+	+	scarce	V
6.	Natterer's bat *(Myotis nattereri)*	+	+	frequent	V
7.	Bechstein's bat *(Myotis bechsteinii)*	+		rare	R
8.	Pipistrelle bat *(Pipistrellus pipistrellus)*	+	+	common	NT
9.	Serotine *(Eptesicus serotinus)*	+	+	frequent	V
10.	Noctule bat *(Nyctalus noctula)*	+	+	frequent	V
11.	Leisler's bat *(Nyctalus leisleri)*	+		rare	V
12.	Barbastelle bat *(Barbastella barbastellus)*	+	+	rare	R
13.	Brown long-eared bat *(Plecotus auritus)*	+	+	common	NT
14.	Grey long-eared bat *(Plecotus austriacus)*	+		rare	R
	Regular migrant				
15.	Nathusius's pipistrelle bat *(Pipistrellus nathusii)*	Migrant rare			NT

E (Endangered) = species in danger of extinction and whose survival is unlikely if those factors responsible continue to operate;

V (Vulnerable) = species believed likely to move into the "Endangered" category in the near future if those factors responsible continue to operate;

R (Rare) = species with a small population that is not at present "Endangered" or "Vulnerable" but is at risk;

NT (Not Threatened) = species either widespread and common in at least part of its range, or with no evidence of serious threats to its populations.

2. ARE BAT ROOSTS CONCENTRATED IN RIVER VALLEYS?

2.1 Roosts in buildings

Over the last twenty years, data have been collected of the locations of bat roosts in north-east Scotland (ca. 57ºN), where four bat species commonly occur (Speakman, Racey, Catto, Webb, Swift, and Burnett 1991). The pipistrelle (*Pipistrellus pipistrellus*) is the commonest species and accounted for 147 of 184 bat roosts known in 1989, located close to the Rivers Dee and Don from source to sea (Fig. 1). Thirty four of the roosts were occupied by brown long-eared bats *Plecotus auritus*, most of which were concentrated along a well-wooded stretch of the River Dee (Entwistle, 1994). Seven roosts of Daubenton's bats (*Myotis daubentonii*) were located, mostly adjacent to rivers. Only two roosts of Natterer's bat *Myotis nattereri* have been found in north-east Scotland, also close to rivers, although in Tayside, Swift (1995) found 11 roosts of this species either close to rivers or in river valleys. A similar analysis of roost distribution was conducted by the Durham Bat Group, and revealed an association between bat roosts and the rivers Derwent, Wear and Tees (Fig. 2).

The mean distance between the roosts in north-east Scotland and water (rivers and lochs) was about 300 m (Park, 1988) (Fig. 3). In Northumberland at ca 54ºN (1985), the majority of roosts of six bat species were located within 100m of freshwater (Table 2 and Fig. 4). Although such roost distribution suggest an association between bats and rivers, some caution is required in the interpretation of roost distribution. Bats are highly synanthropic and during summer, most temperate zone species roosts in buildings, behind soffits or weather boarding, in cavity walls and roof voids (Hutson, 1993b). Buildings are often concentrated in river valleys so that the observed distribution of roosts is hardly surprising. Furthermore, a study of roost site selection (Entwistle, Racey and Speakman, 1997) and foraging behaviour (Entwistle, Racey and Speakman, 1996) of brown long-eared bats has revealed their preference for large houses more than 100 years old with complex roof voids containing several compartments and with immediately adjacent deciduous woodlands in which the bats forage. The abundance of such houses in river valleys explains the observed pattern of roost distribution and there is no evidence that the distribution of brown long-eared bats is related to the proximity of rivers themselves. The association between roosts of Natterer's bats and river valleys may also be explained by the presence of woodland in these valleys where this species, like the brown long-eared, gleans at least part of its prey from foliage.

Stronger inferences may be made however about the association between roosts of other bat species and rivers by comparing the incidence of such roosts in buildings situated in river valleys and those elsewhere. A survey conducted by Pritchard and Murphy (1987) of the buildings in Glen Lyon and Glen Rannoch, in Perthshire, Scotland, (ca 56ºN), is unique in this respect. The area is lightly wooded, the majority of the buildings are of stone, with slate roofs over rough pine underboarding, and modern housing development is minimal. Three hundred and sixty of the 450 buildings present were inspected and bats had roosted in 82, 61 of which were occupied in the year of the survey. Of the dwelling houses occupied by humans, 26% were also used by bats. The incidence of bat roosts (1 in 6 buildings) is far higher than in areas of countryside without river valleys (Fig.1) and points to an association between the roosts of some bat species and rivers.

2.2 Roosts in bridges

In recent years, considerable attention has been paid to bats roosting in bridges, out ofconcern that repointing work was entombing bats that had taken up residence (Mitchell-Jones, 1989). Roberts

(1989) surveyed 306 bridges in North Yorkshire and considered that 78, almost all of which were built of stone, contained potential roost sites. Roosting was confirmed by the discovery of bats or their faeces, in a third of these. Many of these bridges had been built in stages, and had been widened, sometimes twice, to meet increased traffic demand, and the commonest roosting site identified by Roberts (1989) was in the gaps between the stages on the underside of bridges. The commonest bat species roosting in these bridges was Daubenton's (Table 3), and Roberts (1989) concluded that bridges were the most important roost site for this species in North Yorkshire.

Table 2 Distance (m) between bat roosts and fresh water in Northumberland. Data collected by the Northumberland Bat Group (1985)

	m	N
Pipistrelle	141 ± 116	18
Brown long eared	178 ± 187	10
Whiskered/Brandt's	105 ± 53	4
Natterer's	140 ± 162	3
Daubenton's	50	1
Noctule	25	1

Table 3 Bat species roosting in N. Yorkshire bridges (Roberts 1989)

Species	Summer roosts	Winter roosts
Daubenton's	16	3
Natterer's	5	2
Noctule	1	1
Brown long-eared	-	1
Unidentified	6	-

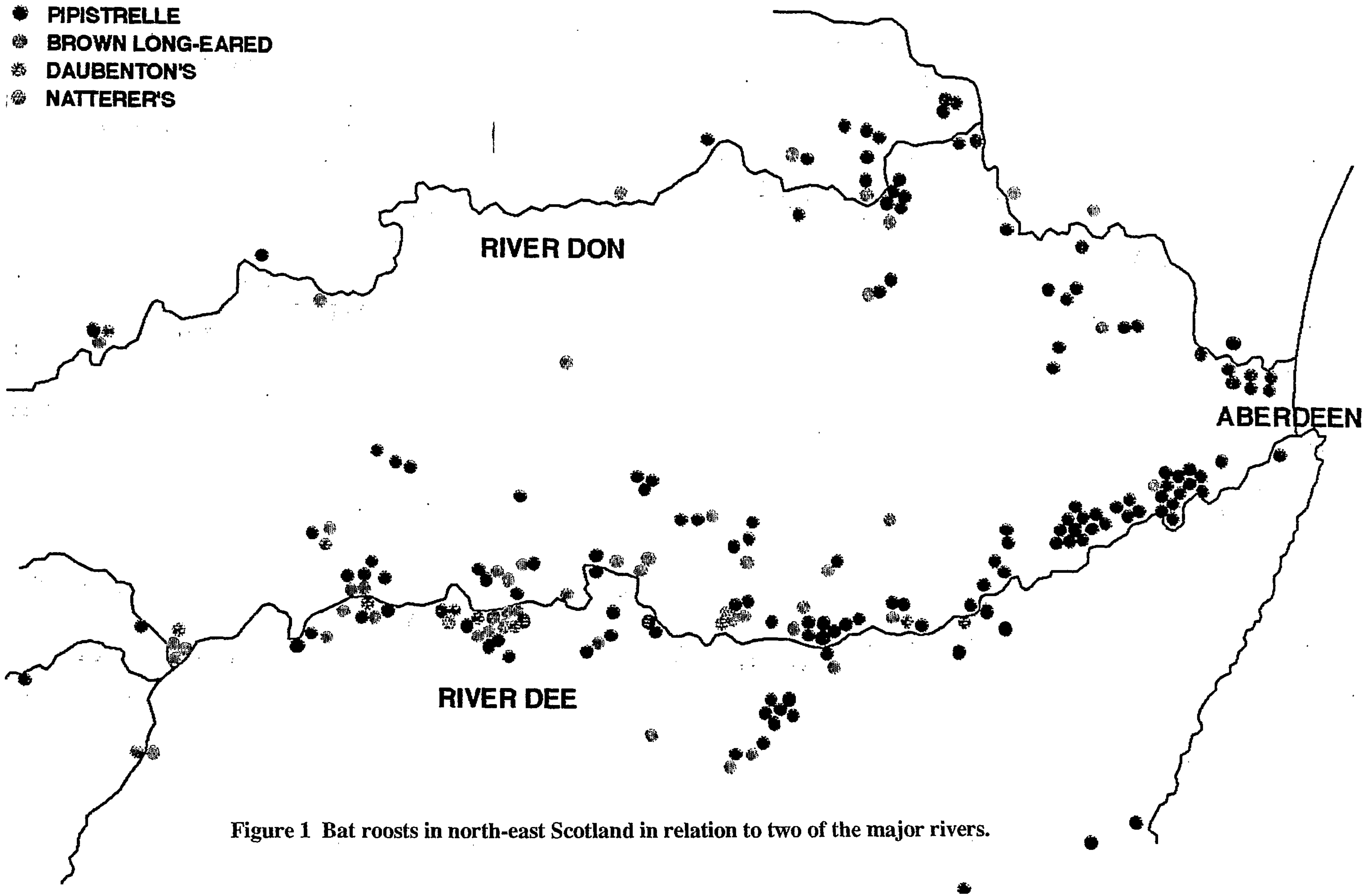

Figure 1 Bat roosts in north-east Scotland in relation to two of the major rivers.

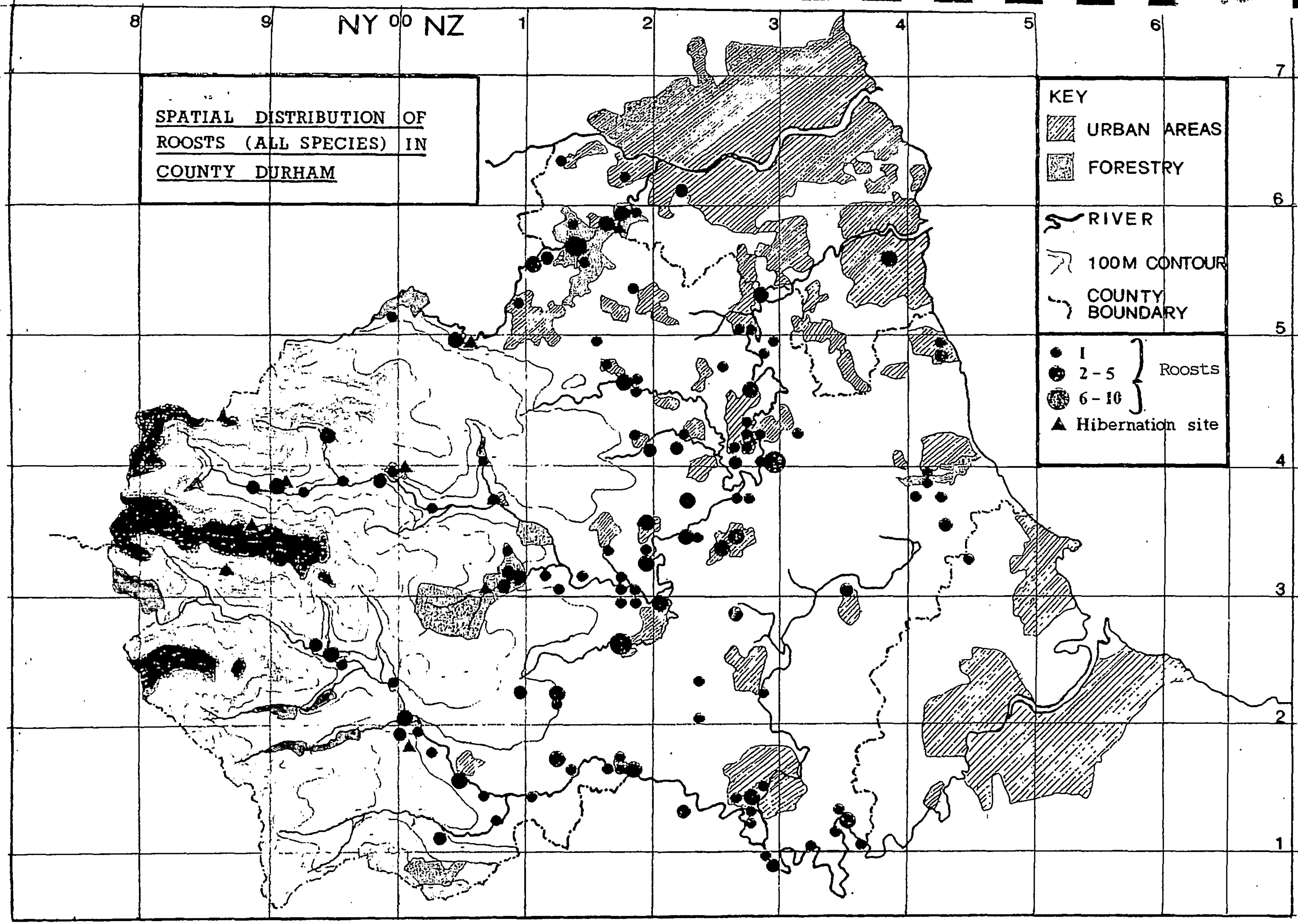

Figure 2 The distribution of bat roosts in relation to rivers in County Durham, UK (from Sargent, 1991).

Durham Bat Group
from Sargent, 1991

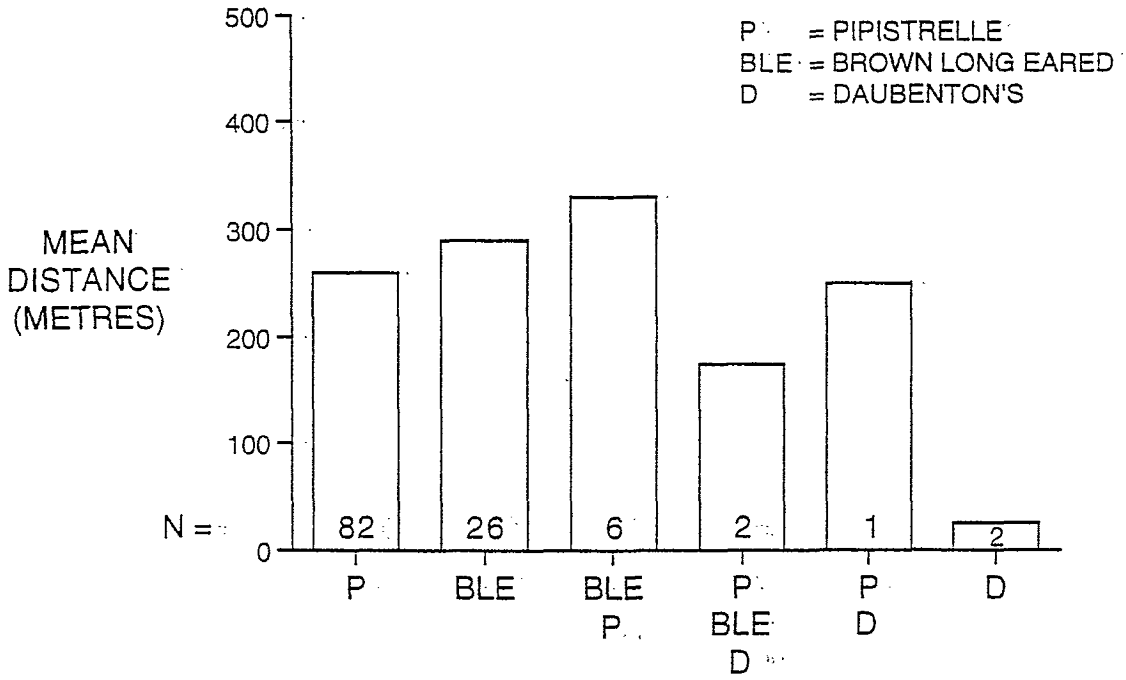

Figure 3 The mean distance of bat roosts in houses in north-east Scotland to the nearest water body shown on ordnance survey maps (from Park 1988). Nine houses contained roosts of more than one bat species.

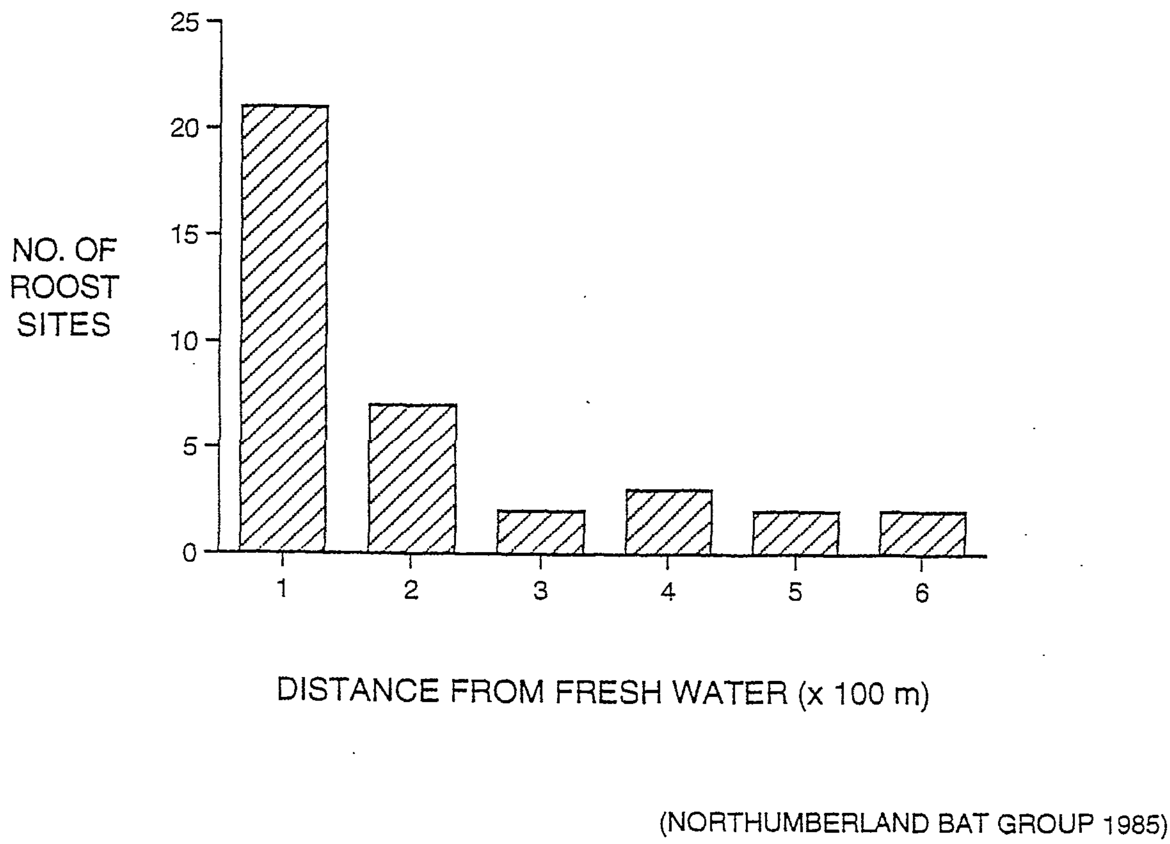

Figure 4 The distance between bat roosts and fresh water in Northumberland (Northumberland Bat Group 1985).

A similar survey was carried out by Smiddy (1991) in the west of Ireland, where 14% of 366 bridges contained roosting bats, 11% showed evidence of roosting, 26% had suitable roosting sites but no evidence of occupancy and the remainder were considered unsuitable for bats. Daubenton's bat was again the commonest species encountered (Table 4) although the numbers of individuals in each bridge was low. These are likely to have been males or non-reproductive females, since reproducing females form large nursery colonies during pregnancy and lactation (Speakman, 1991).

Table 4 Bat species roosting in bridges in Cork and Waterford (Smiddy 1991)

Species	Bridges n	Bats/Roost (mean)	Bats/Bridge (mean)
Daubenton's	38	1.39	1.76
Brown long-eared	8	2.76	3.0
Natterer's	4	1	1
Whiskered	3	1	1
Pipistrelle	3	1-2	1-2

In a survey of canal bridges and tunnels in England and Wales, Richards (1992) reported a total of 45 Daubenton's bats in eight bridges and five tunnels, the largest colony consisting of 19 bats in a bridge. In contrast, a survey of 90 bridges in Fife (Fife Bat Group, 1988) revealed no bats and only two individual Daubenton's were found in a survey of 72 bridges in north-east Scotland (Speakman *et al.* 1991).

The most extensive survey was carried out recently in Cumbria where bats roosted in 320 (12.5%) of 2555 bridges, 1039 (41%) of which had suitable crevices but no signs of roosting bats (Billington and Norman, 1997). Daubenton's was again the most frequently identified species, and was found in 92 bridges (3.6%). Natterer's bat was recorded in 25 (1%) (Table 5). Roosts were more frequently recorded in bridges over water courses than other bridge types, and such bridges were strongly associated with slow flowing water and deciduous trees.

2.3 Roosts in trees

Bats are thought to have evolved in association with trees and several European species such as noctules (Racey, 1991), Daubenton's bats (Childs and Aldhous, 1995) Natterer's (P Smith pers comm) and pipistrelles (F. Mathieson pers comm) roost in holes in trees in the UK, as well as in buildings. In Switzerland, 50 roosts of Daubenton's bats were located in 1.5km^2 of woodland, mainly in beech and oak trees (Rieger, 1996). A study currently in progress in the valley of the River Wye has revealed that this species makes extensive use of bat boxes installed close to the river (J. Messenger, pers. comm.). A radiotracking study of Daubenton's bats foraging over the River Rhine in Switzerland enabled 67 roosts to be located, 60 of which were in trees (Rieger and Alder, 1994).

Table 5 Number of roosts in bridges in Cumbria by species

Species	Number of roosts	% of total roosts
Daubenton's bat	92	27.8
Natterer's bat	25	7.6
Whiskered/Brandt's bat	4	1.2
Brown long-eared bat	4	1.2
Pipistrelle sp.	4	1.2
Pipistrelle 45kHz	2	0.6
Pipistrelle 55kHz	3	0.9
Bat sp	196	59.4
Total	**330**	**100**

3. DO BATS FORAGE PREFERENTIALLY IN RIVER VALLEYS?

3.1 Autecological studies

In a study of Daubenton's bat *Myotis daubentonii* in the valley of the River Spey, in the Highlands of Scotland (250 m. a.s.l.) bats foraged almost entirely over or adjacent to the river over riparian vegetation (Swift and Racey, 1983). They also foraged over pools and drainage ditches which connected pools and river.

In a parallel study of the foraging behaviour of pipistrelles in the lowland agricultural valley of the River Don (100m a.s.l.), with a range of land uses, marked individuals followed the river, feeding over water and within 100m of the river in areas where there were trees and thick undergrowth (Racey and Swift, 1985). The only bats seen further from the river were over two large ponds, about 600m from the river. No bats were sighted where the river passed through open fields with no riparian trees nor were they seen in or near coniferous plantations on the valley sides. In an upland area in Perthshire, Scotland (350-750m a.s.l.) containing a stretch of the river Blackwater and its catchment, pipistrelles foraged over all areas containing deciduous trees and water, including the river itself and a small loch, and were not observed in open fields or moorland (Racey and Swift, 1985).

Similar results were found by Sargent (1991) in County Durham. Daubenton's bats fed almost exclusively over rivers and showed a significant preference for wide rivers with calm water and adjacent deciduous woodland. Pipistrelles also favoured wide rivers but showed no preference for the presence of calm or turbulent water or for a particular level of bankside tree cover. Pipistrelle activity was also recorded around deciduous trees and hedges away from the river. Whiskered bats selected narrower rivers wtih abundant bankside vegetation up to 5m high.

From these initial studies, it was not clear whether pipistrelles feeding in riparian situations were associated with the vegetation, mainly riparian trees, or with the water itself or with a combination of the two. This question was addressed by Rydell, Bushby, Cosgrove and Racey (1994) who studied eighty four sites in the valleys of the Rivers Dee and Ythan on 19 nights between June to August, representing the principal foraging habitats available in the two valleys - woodland, open farmland, ponds and rivers. The Dee is the larger of the two rivers with a catchment of 2100 km^2. It is fed mainly by mountain streams, and woodland occurs along 40% of its banks. In contrast, the Ythan is a much smaller river, with a catchment of 690 km^2 consisting mainly of farmland. It is entirely treeless for much of its length, with woodland occurring along only 15% of its banks. The Dee is oligotrophic (Jenkins 1985) whereas the Ythan is eutrophic (Macdonald, Edwards, Pugh and Balls 1995). Each of the woodland and farmland sites was 100-1000m from the river and each was half a hectare in size, and 100m of river or pond bank were surveyed. Each site was visited once and monitored using a bat detector for fifteen minutes, sometime between one hour after sunset and midnight, avoiding the dusk period, since the time at which bats start to feed varies with species. The occurrence of pipistrelles and Daubenton's bats differed significantly between woodlands, open farmlands, ponds and rivers (Fig. 5). Pipistrelles were observed in every river and pond site, but also occurred frequently in woodlands away from water, and occasionally in open farmland. Daubenton's bats were observed in most river and pond sites, but were observed only once in woodland and never in open farmland. Brown long-eared bats were observed only in woodland, and drinking from a pond. The number of bat species detected in each site differed significantly between the sampled habitats and the modal number of species was two over water, one in woodland, and none in farmland (Rydell *et al.* 1994).

If the distribution of bats along the rivers was affected by the presence of riparian woodland, more bats would be expected over the river Dee where the riparian woodlands are more extensive than over the river Ythan which is bordered mainly by treeless farmland. However, the abundance of foraging pipistrelles and Daubenton's bats did not differ significantly between the two (Fig. 6), and Rydell *et al.* (1994) concluded that the river itself is more attractive to foraging bats than riparian vegetation. The fact that Daubenton's bats forage extensively over canals in England (PW Richardson pers comm) also suggests that the waterway itself is more important than the riparian vegetation.

The habitat preferences of European bats may vary with latitude. In a comparative study of Daubenton's and whiskered bats in Finland (ca 60ºN), Nyholm (1965) showed that both species foraged in woodland during the first half of the summer, where they were less conspicuous to avian predators, before moving to open hunting areas which, for both species, included ponds, rivers and lakes as well as meadows. More recently, Taake (1984) reported the preference of whiskered bats for habitats containing flowing water and riparian vegetation. Sixty-nine percent of sightings were within 200m of ditches, brooks and small rivers with flowing water. Similar observations were made by PW Richardson (pers comm) in Northamptonshire where whiskered bats forage over dense willow and alder scrub on the edges of all types of water body. In Bialowieza primeval forest in eastern Poland (52°N), Rachwald (1992) recorded the highest activity of the noctule bat over a river, and Kronwitter (1988) reported the most frequently used foraging habitat of noctules radiotracked in Germany was over a lake. Similarly in Northamptonshire, PW Richardson (pers comm) observed noctules feeding over all water bodies, often following the line of rivers and canals and turning at features such as bridges and telegraph poles. This raises the question of the extent to which bats use linear landscape features such as rivers for navigation as well as sources of food (Limpens and Kapteyn, 1991; Limpens, Helmer, Van Winden and Mostert 1989).

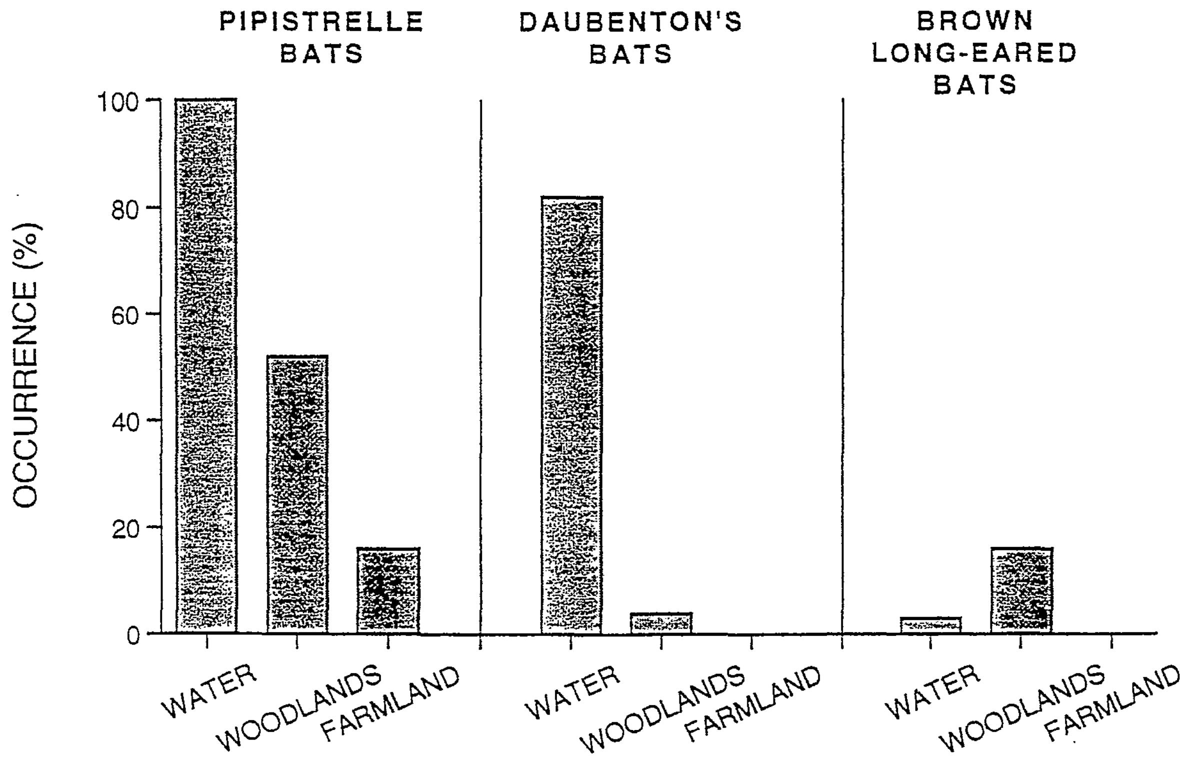

Figure 5 Frequency of occurrence (%) of common pipistrelles, Daubenton's and brown long eared bats in 0.5 ha sites located over water (N=40), in woodlands (N=25) and in open farmland (N=19). Each site was monitored for 15 min using a bat detector (Rydell *et al.*, 1994). Reproduced by courtesy of the publishers of Folia Zoologica.

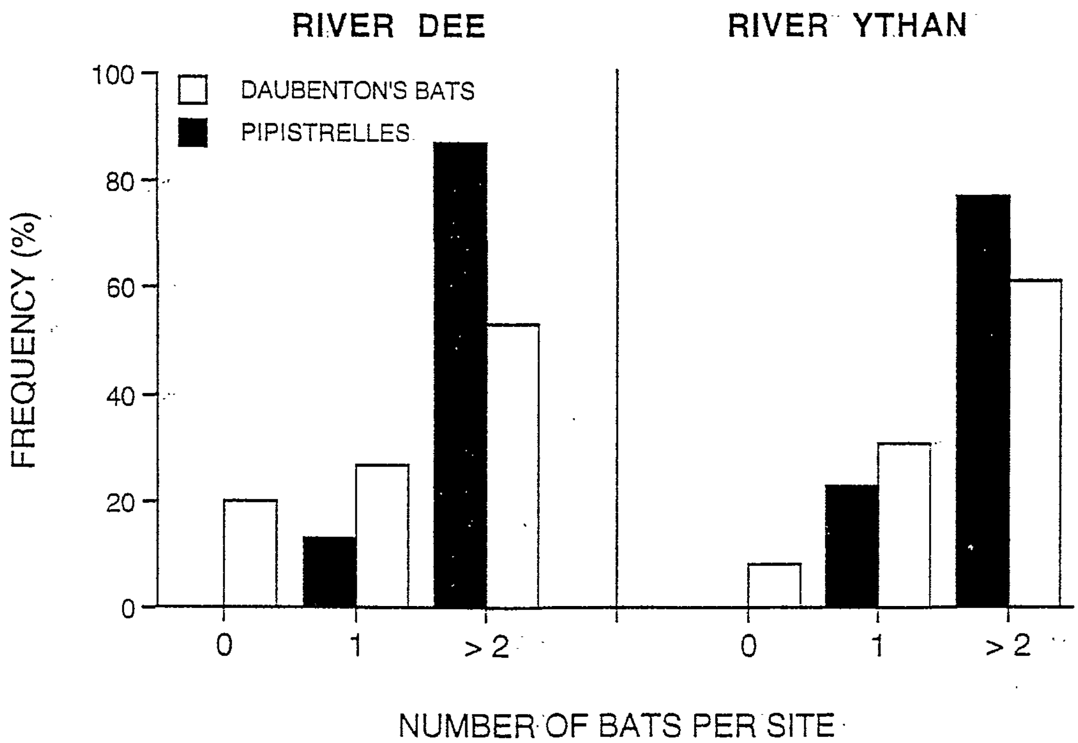

Figure 6 The minimum number of common pipistrelles (black) and Daubenton's bat (white) encountered in each 0.5 ha site over the River Dee (N=15) and the River Ythan (N=13). Each site was monitored for 15 min using a bat detector (Rydell *et al.*, 1994). Reproduced by courtesy of the publishers of Folia Zoologica.

Radiotracking studies have revealed that the distance bats travel between their day roost and their foraging sites is related to body size (Fenton 1997). For the bats present in the UK and foraging mainly over rivers, this distance is likely to vary between 0-2km.

3.2 The UK National Bat Habitat Survey

The scale of the studies reviewed in the previous section was expanded during The National Bat Habitat Survey which adopted a random stratified sampling system (Magurran 1988) based on a land classification which assigns every 1-km square in Britain to one of 32 land classes (Walsh and Harris 1996 a, b, Walsh, Harris and Hutson 1995). Squares in each land class have a similar climate, physiogeography and pattern of land use (Bunce, Barr and Whitaker 1981 a, b, 1983). Within each land class a sample of 1-km squares was selected at random, to avoid observer bias in the selection of sites and ensure a standard sampling effort in different landscape types. Field work was carried out over three consecutive summers from 1990 to 1992, and involved professional and amateur bat biologists, the latter drawn mainly from Britain's 90 bat groups. Each volunteer was allocated one or more 1-km squares and walked a transect in each square four times during predetermined periods in summer, avoiding nights when weather conditions were unfavourable to bats. They carried tuneable bat detectors (mainly QMC Mini 2) set at 45 khz to maximise the range of species encountered, and noted the total number of bat passes and feeding buzzes in each square and within each habitat type. The more experienced surveyors were able to identify some bats to species or species groups by tuning the bat detector to their echolocation calls and from their flight characteristics. Analysis of the data revealed relationships between bat activity and habitat variables within and across the 32 land classes, which for the purposes of the analysis were combined into seven major groups - three arable, two pastoral, marginal upland and upland. Avoidance or selection of habitat types was examined by constructing Bonferroni confidence intervals around the observed use of each habitat type (Neu, Byers and Peek 1974), and regression analyses were employed to evaluate habitats of critical importance in determining high bat activity in each land class group.

Nine hundred and ten 1-km squares of the 1030 surveyed provided data suitable for analysis, and involved 2700 hours of search effort with 30,000 bat passes recorded in the 9000km walked. Twenty four percent of bat passes were identified to a particular species or species group, and 71.0% of these were *Pipistrellus pipistrellus,* 17.0% *Myotis* spp., 7.6% *Nyctalus noctula,* 2.7% *Plecotus* spp, and 1.7% *Eptesicus serotinus.* Since a similar proportion of the unidentified bat passes were probably *P. pipistrellus* (the most abundant bat in the UK, Harris, Morris, Wray and Yalden, 1995), the habitat preferences apply to *P. pipistrellus* in particular.

The incidence of bat passes was strongly related to land class, with the greatest bat activity occurring in pastoral land classes. Across all land class groups, bats tended to forage selectively in edge and linear habitats and avoided more open and intensively managed habitat types. They showed a far stronger preference for all water bodies and woodland edge than for any other habitat type, emphasising the importance of these habitats as key foraging sites. Linear vegetation corridors, particularly tree-lined hedgerows and covered ditches were also selected by bats, emphasising the importance of landscape connectivity.

Bats foraged preferentially in habitats which were comparatively rare within each land class group. For example the percentage availability in each land class group of the preferred habitats of woodland edge, treelines, hedgerows and water bodies ranged from 14 to 31%, with a mean of 25%. In contrast the availability of habitats which were consistently avoided (stone walls, moorland, arable and most grassland categories) ranged from 40 to 54% with a mean of 47%. Optimum habitats tend to be at the perimeters of other habitat types or linear strips, and so in comparison with contiguous blocks of pasture or arable land, for instance, their area is proportionally smaller. Water bodies generally represent less than 1% of the available habitat, and broadleaved woodland edge ranges from 3-4%. Because the selection patterns were consistent between individual land classes, the results of Walsh and Harris' (1996 a) analysis can be summarised by habitat type rather than by land class (Table 6) and reveal the importance of all water bodies for foraging bats.

Analysis of habitat factors affecting high bat activity resulted in equations with high predictive power and of particular value in forecasting the effects of changes in landuse on bats. Although vespertilionids use a diversity of habitats, these regression models identify riparian and woodland habitats as particularly important.

The only woodland category that was avoided by bats was coniferous plantations in upland landscapes which often occur in large blocks (Walsh and Harris 1996a). However in a study of a coastal Scots (*Pinus sylvestris*) and lodgepole pine (*P. contorta*) plantations in north east Scotland, Neville (1986) showed that bat foraging activity was concentrated over ponds and watercourses, even when insect biomass was low. In a similar study of mixed lowland woodland in England, with a range of habitat types, greatest bat activity occurred over ponds and woodland rides and more species (pipistrelles, Daubenton's, noctules and Leisler's) were found over ponds than over other habitat types (Walsh and Mayle 1991).

4. WHAT RESOURCES ARE AVAILABLE TO BATS FORAGING OVER RIVERS AND OTHER WATER BODIES?

4.1 Food

In a comprehensive review of the diets of British bats, Vaughan (1997) concluded that Daubenton's, Leisler's and pipistrelle bats eat mainly aquatic Diptera and may therefore be expected to forage close to freshwater habitats. By analysing the faeces of Daubenton's and pipistrelle bats, and also sampling the insects available to the latter species with a suction trap, Swift and Racey (1983) and Swift, Racey and Avery (1985) showed that in north-east Scotland both species fed mainly on Trichoptera and Nematocera throughout pregnancy and lactation (Fig. 7), and the composition of pipistrelle diet reflected the availability of these insects over a wide range of abundances. Although Ephemeroptera and Neuroptera accounted for a small proportion of the diet in both bat species, in the case of pipistrelles they were significantly over-represented indicating that when they occurred they were selected. In contrast, Coleoptera and Lepidoptera were significantly under-represented (Racey, Swift and Avery, 1985).

The close similarity between the diets of pipistrelles and Daubenton's bats was further emphasised by Sullivan, Shiel, McAney and Fairley (1993) by analyzing faeces collected from roosts in Eire. Trichoptera, Ephemeroptera and several nematoceran families (Chironomidae and Culicidae) have aquatic larval stages and others (such as Ceratopogonidae and Psychodidae) are found in damp situations. Although pipistrelles take flying prey (Kalko, 1995), Daubenton's bats frequently break the water surface and Jones and Rayner (1988) and Kalko and Schnitzler (1989) using photographic methods, revealed that they often use their feet to gaff prey from the water surface. Sullivan *et al.* (1993) showed that Leisler's bat feeds mainly on Trichoptera and nematoceran and cyclorrhaphan Diptera and Gloor, Stutz and Ziswiler (1995) revealed that the noctule also feeds on Trichoptera and several dipteran families including Chironomidae and Anisopodidae which swarm over water.

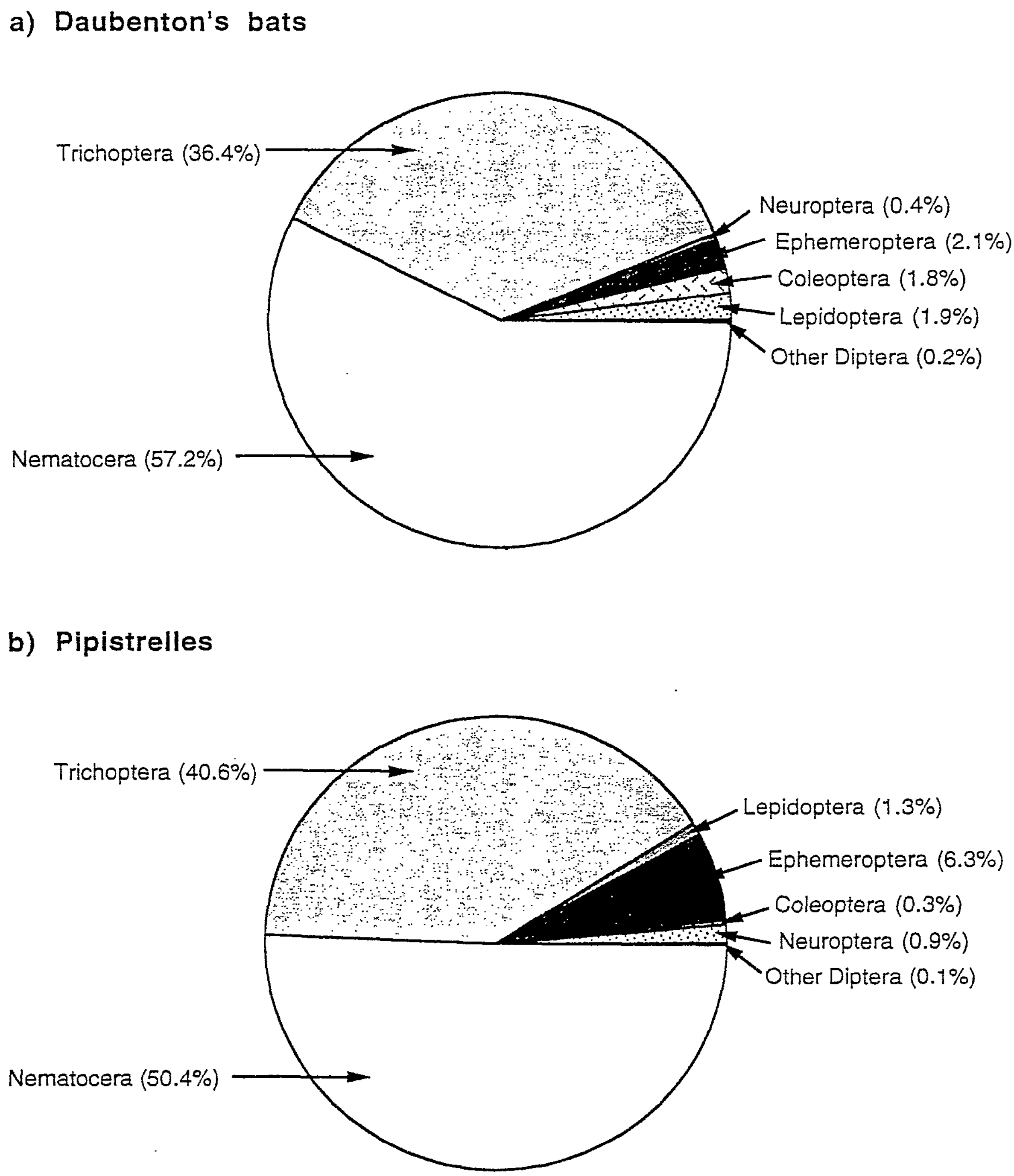

Figure 7 The diet of Daubentons and pipistrelle bats (from Swift 1981) established by faecal analysis. Daubenton's faeces were collected in roosts from May to August and the results are expressed as percentage frequency. Faeces were collected from mist-netted from July to mid August pipistrelles and the results are derived from the actual numbers of insect fragments recovered.

Table 6 Summary of habitats significantly selected by bats in Britain, used in proportion to availability or avoided in 19 discrete land classes. (Walsh and Harris, 1996 a)

Selected in all land classes	Selected in some land classes, never avoided	Selected in some and avoided in other land classes	Avoided in some land classes, never selected	Avoided in all land classes
Treeline	Hedgerow	**Open ditch**	Improved grassland	Arable
Broadleaved woodland edge	**Stream**	**Covered ditch**	Semi-improved grassland	Moorland
Lake and reservoir	Coniferous woodland edge	Stone wall	Lowland unimproved grassland	Upland unimproved grassland
	Mixed woodland edge	Coniferous woodland opening		
	Broadleaved woodland opening	Scrub		
	Mixed woodland opening	Parkland		
	Felled woodland	Urban land		
	River and canal			
	Pond			

Taake (1992) compared the incidence of insects in faeces of bats hunting over ponds and ditches in forests in the N.W. German lowlands with those in a light trap and concluded that the most important prey taxa for the sibling species *Myotis brandti* and *M.mystacinus* were non-aquatic insects such as tipulids. Similarly *M. nattereri* fed on Brachycera, although *M. daubentonii* fed mainly on Chironomidae.

In N. America, the little brown bat *Myotis lucifugus* occupies a similar niche to Daubenton's bat and forages low over water on aerial prey, especially chironomids (Barclay, 1991). In one of the few studies where insect availability, determined by sticky traps, was compared in different habitats, Barclay (1991) showed that the over-water insect mass was significantly greater than that found along paths or in the neighbouring forest in the Kananaskis valley, Alberta.

4.2 Drinking water

Bats spend up to 20 h a day in their roosts during summer, and in hot weather, may become dehydrated. At a relative humidity of less than 20%, Webb, Speakman and Racey (1995) showed that resting brown long-eared and Daubenton's bats could lose over 30% of their body mass per day through evaporation. Evaporative water loss will increase during flight and the need to drink on emergence from the roost may be one of the factors determining the proximity of roost sites to water. Access to water may be even more important during winter and Speakman and Racey (1989) have suggested that the primary function of winter emergence flights is to drink.

4.3 Mates

Since the density of bats foraging along rivers is comparatively high compared with other habitat types, mating opportunities may arise in such situations during autumn when females first come into oestrus. To investigate this possibility, the activity and behaviour of pipistrelle bats was monitored by Rydell *et* al., (1994) at 42 different sites on three rivers - the Dee, the Don and the Ythan during nights in September and October coinciding with the mating season of this species (Racey, 1974). At each site, two observers, each with a bat detector, monitored bat activity under or immediately adjacent to a bridge, and simultaneously over open water 200 - 250 m away from the bridge. Bat passes and attempted prey captures (feeding buzzes) were counted for 10 minutes each with the detector set at 50 kHz and the detector was then retuned to 20 kHz and mating calls were detected for a further 10 minutes. Although significantly more bat passes were detected near the bridges than over open water away from the bridges, there was no significant difference in the incidence of feeding buzzes at bridges, compared with open water.

These results indicate that the bats' feeding activities were not concentrated near bridges, but that some other activity was. Pipistrelle mating calls were significantly more frequent near the bridges than over open water away from the bridges, indicating that bridges may be used as mating stations by pipistrelles. In this way, males may be able to attract or intercept females foraging over rivers, and at the same time have access to food in the immediate vicinity of the territory. In a subsequent study in which calls were analysed sonagraphically, Russ (1995) recorded a high incidence of mating calls and territorial song flights in the vicinity of bridges.

5. FACTORS AFFECTING THE ATTRACTIVENESS OF RIVERS TO BATS

5.1 Eutrophication

Eutrophication refers to nutrient enrichment and its effects on water bodies (Harper, 1992) and despite its widespread occurrence in the second half of this century there have been few studies of its consequences for foraging bats.

In a major study of habitat use in the province of Uppland, Sweden (59ºN), de Jong (1994) found that relatively open deciduous forests and adjacent shallow eutrophic lakes were the only habitats attracting large numbers and high diversity of bats during early summer, as a result of the high chironomid productivity (de Jong and Ahlén 1991). Bats foraged in more diverse habitats later in summer, although lakes, wetland and deciduous forest remained important.

Vaughan, Jones and Harris (1996) monitored bat activity and feeding rates at sites matched for vegetation and land use upstream and downstream from 19 sewage outfalls in south west England at the same time each night. The two phonic types of the pipistrelle, in one of which most of the energy of the echolocation call is at 45 kHz and the other at 55 kHz (Jones and van Parijs 1993), were recorded separately. Bat species of the genus *Myotis* are more difficult to separate using bat detectors and were referred only to genus. Overall bat activity, as measured by passes, was reduced downstream of sewage outfalls by 11% (Fig. 8a) whereas feeding buzzes were reduced by 28% (Fig. 8b). Both phonic types of pipistrelles were less active at downstream than at upstream sites, and there was clear evidence that the 45 kHz pipistrelle concentrated its feeding at upstream sites. Bats of the genus *Myotis* on the other hand foraged at higher rates downstream from sewage outfalls than upstream (Fig. 8c). However, no attempt was made to sample insects and the results are not consistent with Vaughan's (1997) review of the diets of the species concerned, which showed them to be very similar. It would be expected that changes in water quality affecting bats through their food supply, would affect both species in the same way. Nevertheless, Vaughan *et. al.* (1996) concluded that for the conservation of pipistrelles, the maintenance of high standards of water quality may be important, but that Daubenton's bat may benefit from eutrophication.

This is of particular interest in view of Kokurewicz's (1995) hypothesis that increases in numbers of chironomids resulting from eutrophication and canalization of waterways has resulted in the rise in numbers of hibernating Daubenton's bats in several countries in mainland Europe (Barta *et al.*, 1981; Cervený and Bürger, 1990; Daan, 1980; Harrje, 1994; Voûte *et al.*, 1980; Weinrich and Oude Voshaar, 1992). This runs counter to the general trend of declining bat numbers throughout Europe (Stebbings, 1988) which has been the subject of widespread concern and has led to The Agreement on the Conservation of Bats in Europe (Hutson, 1991).

An opportunity to test Kokurewicz's hypothesis arose in north-east Scotland where the Dee is oligotrophic (Jenkins, 1985), but the Ythan has experienced significant increases in nitrate levels over the last 30 years (North East River Purification Board, 1993; Macdonald *et al.* 1995) and has been considered for designation as a nitrate sensitive area under the EU Nitrate Directive. Racey, Rydell, Swift and Brodie (1998) made pairwise comparisons of bats and insects at ten sampling sites on the Dee and Ythan for three periods of ten nights each during pregnancy, lactation and post lactation. Bat detectors were tuned to 55 khz and 45 khz for five minutes each and counts made of the number of passes of 55 khz and 45 khz pipistrelle phonic types respectively and then to 35 khz for five minutes to count passes of Daubenton's bats. This procedure was then repeated to give a total of 30 min recording each night.

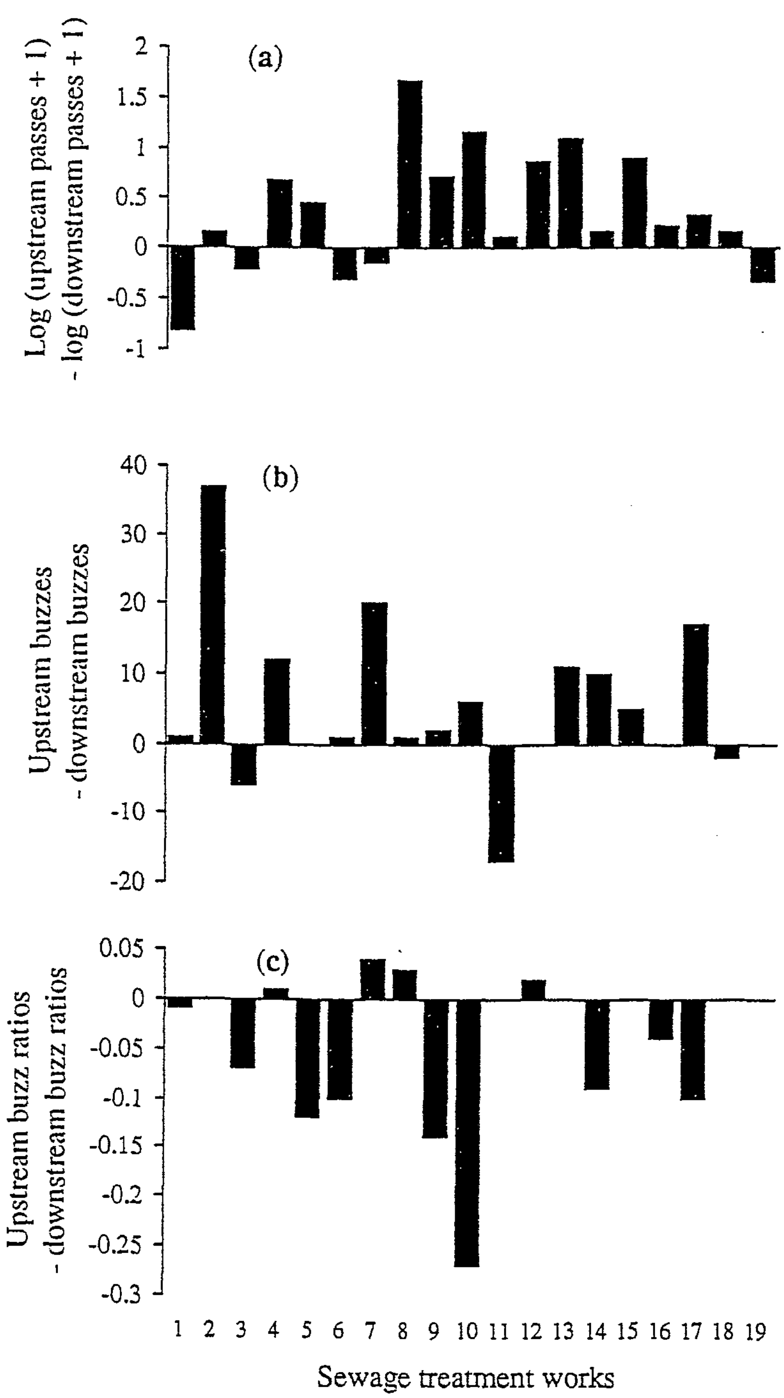

Figure 8 a) Bat passes and b) feeding buzzes of all bats (mainly pipistrelles and *Myotis* spp) and c) feeding buzzes of *Myotis* spp. upstream and downstream of sewage treatment works (Vaughan *et al*, 1996). Negative values indicate that bat activity was higher at the downstream site than at upstream site. Bats were significantly less active (a) upstream than downstream ($t=2.553$; $p<0.05$) and made significantly more attempts at prey capture (b) at upstream than at downstream sites ($z= -2.019$; $p<0.05$). *Myotis* spp. made significantly more attempts at prey capture per unit of flight activity in downstream than at upstream sites. Reproduced by courtesy of the publishers of Biological Conservation.

There was no significant difference in the number of passes of Daubenton's bats between the two rivers during any of the three sampling periods. The activity of both phonic types of pipistrelles was significantly lower over the Ythan than over the Dee in June, but no such difference was recorded between the two rivers in the two subsequent sampling periods (Fig. 9).

The numbers of flying insects caught in suction traps were not significantly different between the two rivers in any of the three sampling periods, although for July as well as for August/September, the insect biomass was significantly higher over the Ythan than over the Dee (Fig. 10). Even more significant is the fact that the diversity of flying insects, as measured by the total number of morphospecies identified from each evening's samples was significantly higher over the Ythan than over the Dee in the July sampling period (Figs 10 and 11).

No clear differences in bat activity or insect numbers between the two rivers emerged from this study and thirteen of the eighteen pairwise comparisons were not statistically different. The smaller of the two rivers, the Ythan, supported just as many bats and insects as the much larger Dee, a finding which supports Kokurewicz's (1995) hypothesis that eutrophication may have beneficial effects on Daubenton's bat. However it is likely that pipistrelles would respond similarly to changes in water quality because they use the same feeding sites and eat the same insects as Daubenton's bats.

Eutrophication can result in the production of algal blooms (Harper, 1992) and there is a single report of the effects of such blooms on bats (Pybus, Hobson and Onderka, 1986). Five hundred dead bats were counted on a lake in Alberta during August, and mortality was estimated at twice that number. A toxic alkaloid (*Anabaena* Very Fast Death Factor) produced by the blue green alga *A. flos-aquae* was extracted from the green slime on the carcasses of six *Myotis* spp. and one hoary bat (*Lasiurus cinereus*).

5.2 Turbulent water

Von Frenkell and Barclay (1987) showed that the little brown bat, *Myotis lucifugus*, feeding low over water, concentrated its activity over calm areas (ponds and stream pools) and avoided areas of turbulence or riffles. Differences in insect abundance, as measured by sticky traps, was not responsible for this preference. It was hypothesised that high frequency sounds produced by running water may mask the weaker echoes of echolocation calls and thus reduce prey detection efficiency. Greater levels of surface roughness (or clutter) may also increase the difficulty of detecting or capturing insects near the water surface by acting as an obstacle to flight and by producing extraneous background echoes that must be discriminated from prey echoes. In subsequent experiments, Mackey and Barclay (1989), showed that both artificial clutter and playbacks of the sound of turbulent water reduced the activity of *M. lucifugus*, while the activity of the big brown bat, *Eptesicus fuscus*, which feeds higher over the water surface, was reduced by playbacks but not by artificial clutter. In the only British study of this subject, Sargent (1991) recorded significantly higher activity levels of Daubenton's bats over pools than riffles, indicating that surface prey capture from disturbed water is difficult. There was no such difference in the activity levels of pipistrelle bats.

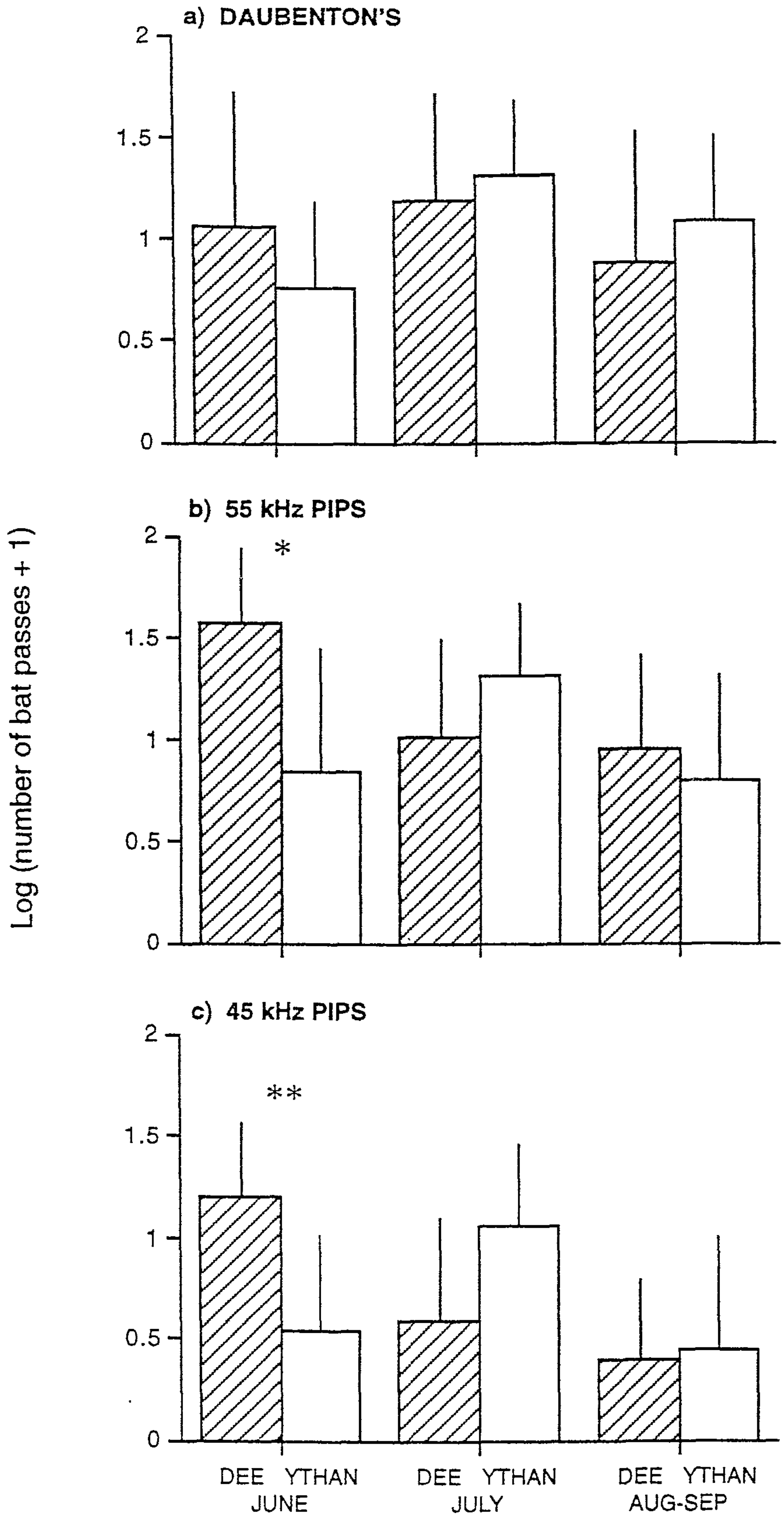

Figure 9 Bat passes (means and SD) recorded during ten 30min samples at the rivers Dee (hatched) and Ythan (white) during each of three sampling periods (June, July and August/September 1995). Three bat species were monitored using Petterson ultrasonic detectors: (a) *Myotis daubentonii*, (b) 55 kHz *Pipistrellus pipistrellus* and (c) 45 kHz *P. pipistrellus*. The counts were made simultaneously at the two rivers. *:p<0.02;p<0.01.**

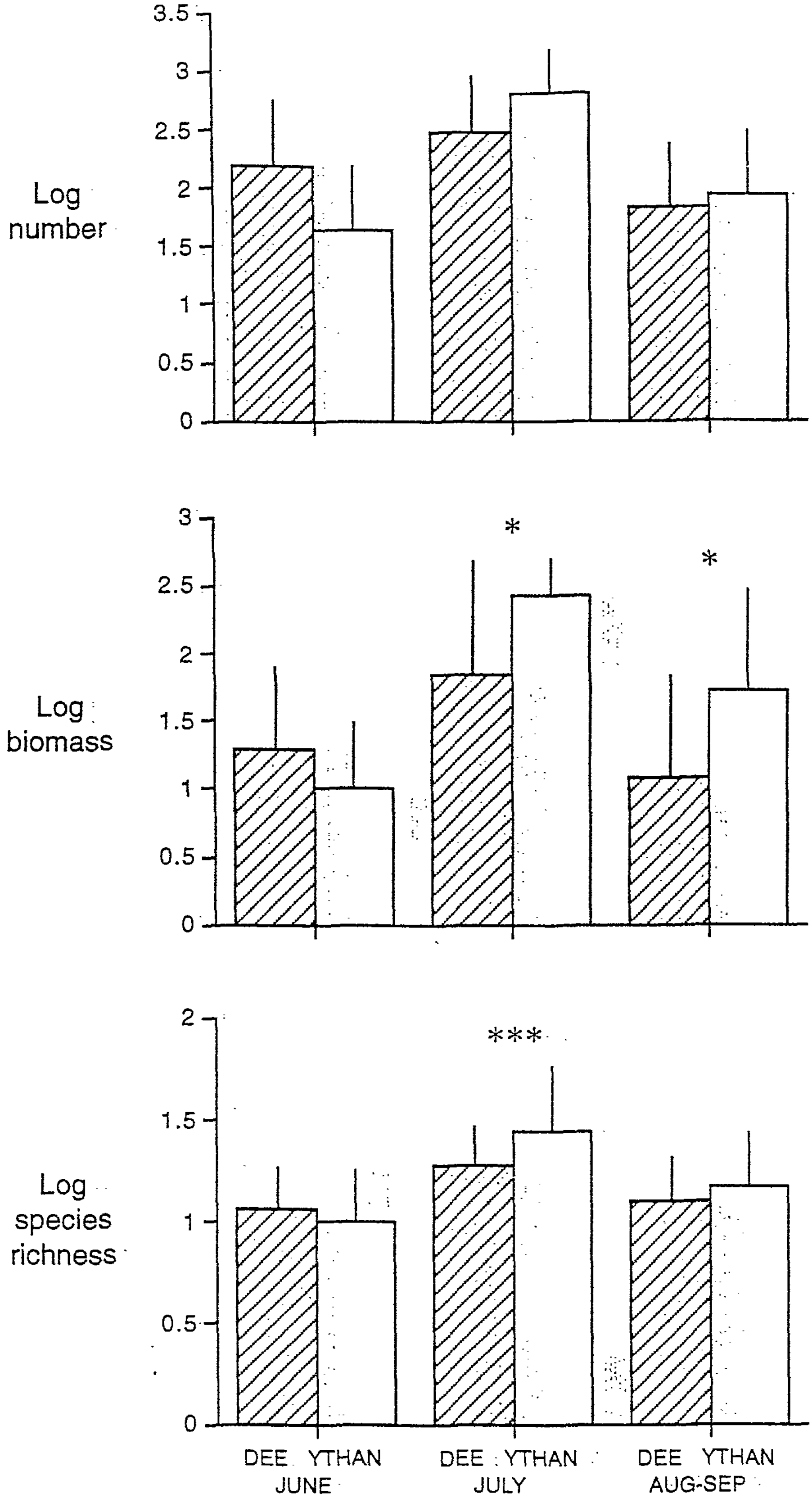

Figure 10 Insect catches (means and SD) at the rivers Dee (hatched) and Ythan (white) obtained on ten evenings during each of three sampling periods (June, July and August/September 1995), expressed as (a) total number of insects per sample, (b) total biomass (mg dry weight) per sample and (c) "species" richness (ie number of "morphospecies") in each sample. The samples were obtained by Johnson-Taylor insect suction traps run at boost speed during 1.5h at dusk and simultaneously at the two rivers. *:p<0.05;***p<0.001.

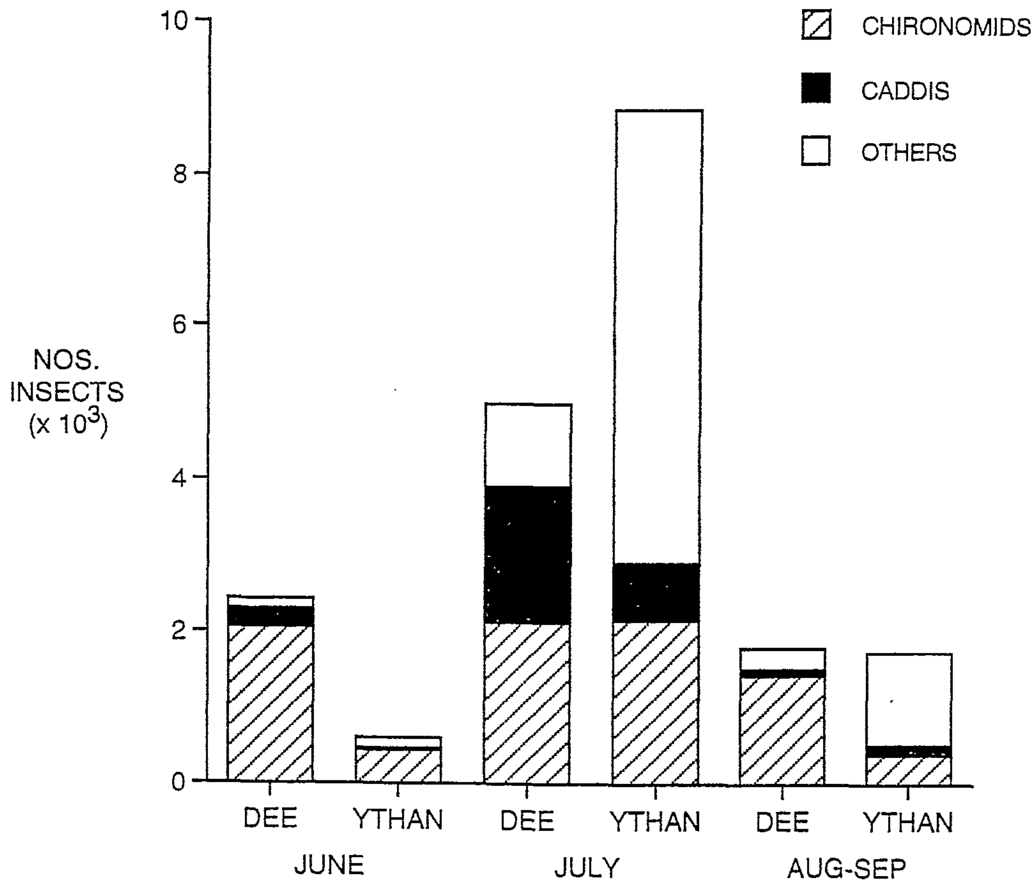

Figure 11 Total number of insects trapped over each of the two rivers (Dee and Ythan) during each sampling period (June, July and August/September). The hatched sections of the bars represent chironomids (Diptera: Chironomidae), the black sections are caddis flies (Trichoptera) and the white sections are all other insects (from Racey *et al*, 1998).

6. CONCLUSIONS

1. Bat roosts are concentrated in buildings and bridges in river valleys, and their incidence in buildings can be as high as 1 in 6. It is likely that bats also roost in cavities in riparian trees.

2. Proximity to a source of drinking water may be as important as proximity to a source of food in determining roost location.

3. A series of small-scale studies have established that Daubenton's bats forage almost exclusively, and pipistrelles frequently, over rivers and other water bodies. Noctules often feed over water and whiskered bats feed in vegetation close to water. For pipistrelles and Daubenton's bats, the rivers themselves seem to be more attractive to foraging bats than the riparian vegetation.

4. On a nationwide scale, the UK Bat Habitat Survey has established the importance of all water bodies for foraging bats.

5. The high density of bats over rivers results in mating opportunities in autumn, and mating activity of pipistrelles appears to be concentrated around bridges.

6. Daubenton's bats and pipistrelles feed mainly on Trichoptera and Nematocera, although Ephemeroptera and Neuroptera account for a small proportion of the diet of both species. Noctules and Leisler's bats also feed on Trichoptera and Nematocera. Most of the insect taxa on which these bats feed have aquatic larval stages and others are found in damp situations.

7. In the only study of bat activity in relation to sewage treatment works, more pipistrelles appear to feed upstream of outfalls than downstream, and the converse is true for Daubenton's bat.

8. In the only study of bat and insect activity in relation to nutrient status, a small eutrophic river supported as many pipistrelles and Daubenton's bats and insects as a large oligotrophic one.

7. FUTURE WORK

1. The association between bat roosts and river valleys has been documented in few catchments in the northern half of the UK. More information is probably available in the roost records of the ninety amateur bat groups in the UK and in the bat roost data base in English Nature and is in need of collation and analysis. Further work on the distribution of bat roosts is needed in relation to river systems in southern England and all river corridor surveys should include inspection of trees and bridges for signs of bats.

2. The lack of information on the extent to which bats use riparian trees as roosts in England and Wales points to the need for radiotracking studies, particularly of Daubenton's bats.

3. At present, no clear relationship has been established between the use of bats make of rivers and water quality. Further work is required on rivers in General Quality Assessment classes 1 to 4 in England and Wales to determine the extent to which nutrient enrichment and pollution affect bats through their insect prey.

4. Many of the data on bats foraging over rivers and water bodies relate to Daubenton's and pipistrelles, and further studies are required to establish the importance of rivers in England and Wales to less common species such as noctules, Leisler's, whiskered and Brandt's bat.

5. Automated surveys of bat activity across the width of river corridors are now required to determine the relative importance of the water body and the adjacent habitat. These should be supplemented by identification of the species concerned by experienced personnel.

6. The provision of artificial roosts (bat boxes) in river corridors is likely to benefit bat populations.

8. REVIEW OF SURVEY TECHNIQUES SUITABLE FOR USE IN AN ASSESSMENT OF THE IMPORTANCE OF RIVERS TO BATS IN ENGLAND AND WALES

The basic tool of bat surveyors is the ultrasonic receiver or bat detector, now available in a wide range of models and prices (Waters and Walsh, 1994). The fact that the first national survey of preferred bat habitat has been carried out in the UK, using mainly QMC Mini 2 detectors demonstrates the capability of the voluntary sector in this respect. During this survey, observers walked transects designed to cross a diversity of habitat types, four times each summer for three years. Such a methodology is not directly applicable to rivers, which have been surveyed by a single surveyor walking transects along river bank paths throughout the night and throughout the summer to reveal temporary and seasonal changes in bat activity (Swift, 1981; Racey, Speakman and Swift, 1987), or by surveyors working synchronously in pairs on the same river (Rydell *et al.,* 1994; Vaughan *et al* 1996) or on different rivers (Racey *et al* 1998) in a series of hypothesis-testing investigations. The use of simultaneous surveys by more than one surveyor is important because it allows more powerful statistical comparisons to be made between different rivers or between different sections of the same river. Such comparisons remain meaningful even if unfavourable weather conditions depress the number of flying insects and bats on any particular night.

This approach can be adopted for surveys of particular catchments by encouraging a bat group to survey a river using the methodology established by Racey *et al* (1998). Observers would be stationed along the river bank at pre-arranged survey stations and would count the passes of pipistrelle and Daubenton's bats either commuting or searching for insects for a predetermined period of time. The procedure could then be repeated to count feeding buzzes.

Since the National Bat Habitat Survey, The Bat Conservation Trust has organised a series of bat detector workshops throughout the UK and the capabilities of the voluntary sector for species identification has improved. Although bats of the genus *Myotis* are not easy to separate using a bat detector, the characteristic straight flight of Daubenton's bat, low over the water, occasionally breaking the surface as it gaffs prey (Jones and Rayner, 1988) provides an additional visual cue to aid species identification. Such a survey is considered to be well within the capabilities of the voluntary sector. PW Richardson (pers comm) has already organised a similar survey using members of the Northants Bat Group stationed at intervals along a canal in studies of the foraging behaviour of Daubenton's bat. Surveys of rivers should be carried out during the return of bats to their summer roosts (late April, early May), pregnancy (early June), lactation (mid July) and post-lactation juvenile growth (late August/early September).

Automatic recording of bats using a cheap detector, a noise-activated pocket tape recorder and a speaking clock housed in a waterproof box (total cost ca £200) has been used recently in a study of bat activity over ponds (Mackie, 1996). Such equipment is suitable for use on a river bank and can enable an individual surveyor to accumulate data from several recording stations. Its disadvantage is that transcription of the information on the tapes is time consuming and tedious. However, in 1997 an automatic recording system was developed in Aberdeen by NC Downs and PA Racey consisting of a cheap detector, an analogue to digital converter, and a data logger (total cost ca £400) which can be downloaded onto a computer. This will be used for river corridor surveys in 1998 and 1999. Species identification, which must be one of aims of future surveys, is however not possible using these automated recording systems. More sophisticated and expensive detectors such as the Australian 'Anabat' system have been used for automatic recording with species identification (L. Duvergé, pers comm), but the computer analysis required for the latter is, in general, beyond the capabilities of the voluntary sector.

9. FEASIBILITY STUDY OF A NATIONAL RIVER-CORRIDOR-BASED SURVEY OF ENGLAND AND WALES

The feasibility study for such a survey has already been completed in The National Bat Habitat Survey. In addition, the capability of The Bat Conservation Trust for mobilising the voluntary sector for such surveys has been demonstrated by the DoE-funded Bats in Churches Survey of England and Wales (Sargent, 1995). As detailed in the foregoing review, bat detector techniques have already been applied to investigations of the activity of bats over a range of rivers, most of which have been in Scotland. It is now timely and appropriate to initiate a survey of rivers in England and Wales, with the aim of establishing whether conclusions about the importance of rivers to bats in Scotland apply equally at more southerly latitudes in the UK. The National Bat Habitat Survey demonstrated the importance of following a formal sampling framework. By structuring a river-corridor-based survey to include rivers with a wide range of nutrient enrichments and pollution burdens, the extent to which pipistrelle and Daubenton's bats are affected by these processes could be inferred.

10. COSTED OPTIONS

10.1 Survey of major river systems in England and Wales

Both the National Bat Habitat Survey and The Bats in Churches Survey cost ca £30K pa for three years. This met the salary and national insurance of a project coordinator, office costs, overheads and volunteer expenses. An effective inducement to bat groups to participate in such surveys is the provision of an additional bat detector, and depending on the discount that can be negotiated for volume sales, this can be achieved for all groups in England and Wales at a cost of ca £10k.

A one year survey would therefore cost ca £40k, increasing by ca £30k for each additional year. Past experience suggests that such surveys are most effective when carried out over three years, at a total cost of ca £100k.

10.2 Survey of selected rivers

The scale of the survey could be reduced by selecting rivers for which EA either already has extensive data from river corridor surveys, such as:

- rivers with increasing nutrient enrichment from source to sea
- rivers with increasing pollution burdens from source to sea
- rivers with contrasting corridor vegetation (e.g. wooded vs arable)
- rivers with contrasting management practices (e.g. recently dredged vs undredged)
- rivers subject to pronounced seasonal changes in flow

However, a project coordinator would still be required and since this represents the major cost, the percentage reduction in the overall cost of the survey would not be significant.

10.3 Small scale survey of selected catchments in areas with best organised bat groups

Some bat groups are contracted for consultancy work through BCT (which provides appropriate insurance cover). It is possible that a survey could be designed to make use of selected bat groups if their geographical location coincides with the rivers of interest to EA. Such a restricted survey could be coordinated by BCT's conservation officer and an approximate cost of £15k.

10.4 Relationship to the national bat monitoring programme

The principal aims of the the National Bat Monitoring Programme (funded by the DETR) are to establish and authenticate methods for monitoring bats in summer roosts, foraging areas and hibernacula and to carry out such monitoring in order to establish changes in bat populations. This will allow the UK to meet the obligations of the Agreement on the Conservation of Bats in Europe and the E.C. Species and Habitats Directive.

The following species have been selected for attention:

- Greater horseshoe bat
- Lesser horseshoe bat
- Pipistrelle
- Daubenton's bat
- Natterer's bat
- Serotine
- Noctule

The National Bat Monitoring Programme project overlaps with that proposed for EA consideration in monitoring Daubenton's, pipistrelle and noctule bats in their foraging areas and the DETR is keen that the results of the project should benefit as large a user community as possible. Through the officer responsible for the project, Mr Trevor Salmon, the Department convened a meeting of the user community during 1996. However a survey to establish the importance of river systems to foraging bats in England and Wales, and the effects of eutrophication, pollution and management of the water and its adjacent habitat has different objectives and should therefore be designed differently to a monitoring project designed to establish changes in bat populations.

In the meantime however, the National Bat Monitoring Programme has initiated a project on Daubenton's bat which was surveyed on 251 waterway sites in 1997, the majority of which were in England and Wales. Although the abundance of bats was consistently lower along canals compared to rivers, the data has not yet been analysed statistically. The survey will be extended in 1998.

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PART 2 FISH

2.1 The habitat and management requirements of spined loach

2.2 Survey of selected sites and habitats for spined loach (in draft)

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The habitat and management requirements of spined loach (*Cobitis taenia*)

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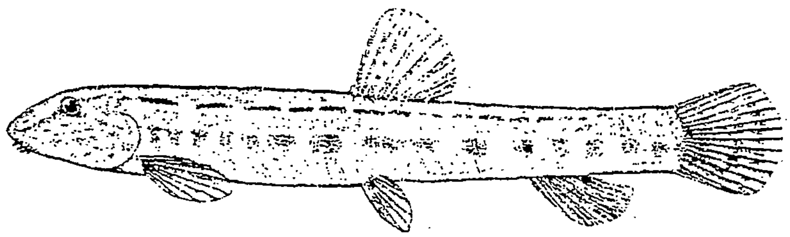


April 1997

Executive summary

Background information

Spined loach (*Cobitis taenia*) is listed under Annex II of the EC Directive on the conservation of natural habitats and flora and fauna. Member countries have the duty to ensure the favourable conservation status of the species through conservation of viable populations within Special Areas of Conservation (SAC's). However, this does not conserve the species in a wider context.

The conservation strategy for spined loach in the UK is therefore based on:

- Implementing the EC directive through the establishment of SAC's. Developing sufficient understanding to enable this process to occur is the principal target of English Nature, one of the partners of the current project.

- The conservation, and if possible, promotion spined loach in all waters in which it occurs. This to be achieved through production of a set of operational guidelines for those organisations undertaking management of waterways primarily for flood defence and drainage. This is the principal concern of the other project partner, the Environment Agency.

For these aims to be achieved, specific information on the distribution and habitat preferences and factors determining the size and viability of populations, particularly the role of habitat management are required. This to be placed within the context of a general understanding of the ecology (especially feeding and reproductive strategies) and population dynamics of the species.

Distribution

From the 180 records of spined loach gathered from a variety of sources during the project, it is clear that the species is naturally restricted to the Great Ouse and Trent (and connected Witham) catchments. This results from a combination of the patterns of colonisation from ancestral riverine connections prior to the severance of the land bridge at the end of the last ice age some 10 000 year ago, and the lack of subsequent dispersal through human means. Spined loach does, however, occur widely within its restricted range and is found in a number of different types of waterbody such as streams, rivers, drains and gravel pits.

Habitat preferences

From a review of available literature, analysis of routine Agency data and specific fieldwork, it appears that the optimal habitat of spined loach consists of a sandy substrate with patchy, dense macrophytes. Spined loach is restricted to fine sediments by its specialised feeding mechanism in which it pumps fine material through its buccal cavity, from which it extracts food particles with mucous. Although spined loach may tolerate silt or mud, a preference for sand may be linked to the presence of a wider range and abundance of its specific (0.2 - 0.75 mm in size), animal and plant food. It is also possible that sand is a more appropriate spawning substrate, perhaps leading to better egg survival. Both these factors may be linked to oxygen levels within the substrate.

Due to its small size, spined loach is thought to be vulnerable to predation from a variety of vertebrate (including piscivorous and omnivorous fish) and even invertebrate predators. Dense macrophytes (and other structures such as filamentous algae) may offer refuges against predation. This is offset against a need for unhindered access to the sediment to feed, probably at night. Consequently, a heterogeneous habitat comprised of dense patchy macrophytes interspersed with open sediment is required. This may be found in a variety of situations from streams to large lakes, which accounts for its occurrence within a range of different types of waterbody. However, on balance, the optimal habitat may be more abundant in natural streams and rivers, where spined loach evolved. This does however, require clarification.

Key issues of a conservation strategy

Spined loach displays a tendency to occur as morphologically and/or genetically distinct forms within the *Cobitis taenia* complex. The lengthy time scale of reproductive isolation both from the source stock in Continental Europe and also between stocks in different catchments within the UK, results in the possibility of endemic races, subspecies or even species being present. SAC selection must take this into account. However, in the absence of detailed information on genotypes, required to make a considered decision, the pragmatic option is to set up SAC's within at least the Great Ouse and Trent catchments. Moreover, as the connection between the Trent and Witham system is restricted to the Fossdyke, and thus mixing of populations may be limited, it may also be prudent to also establish at least one SAC within the Witham.

The conservation of viable populations both in protected areas and in all waterways it occurs, may be challenging. This is because spined loach is thought to be highly vulnerable to anthropogenic influences in any one season. This results from its dependence on annual recruitment, and the constraints of a specialised feeding mechanism and vulnerability to predation resulting in specific habitat requirements. Factors such as habitat changes resulting from management and perhaps stocking of other fish (potential competitors or predators), particularly where they impact upon larval/juvenile survival, may reduce the viability of the population, ultimately leading to local extinction.

Conservation within the Ouse Washes cSAC

Spined loach has been confirmed to be widely distributed in the Ouse Washes candidate SAC (cSAC), which incorporates 19 km of the Counterdrain/Old Bedford river (outer river) and Old Bedford/River Delph (inner river). The Ouse Washes cSAC is therefore likely to meet its objective of conserving a viable population of spined loach within one of its population centres. However, there are considerable differences in the current ability of outer and inner rivers to support spined loach, with the outer river supporting a denser population, with a high proportion of underyearlings. This is related to the presence of macrophytes and a suitable sediment.

Several issues that may compromise the ability of the site to support spined loach and ultimately jeopardise its conservation value are thought to include; nutrient loading and the resultant loss of macrophytes, loading of fine anoxic sediments, and the presence of large stocks of coarse fish. Future work to safeguard and if possible, improve the status of the cSAC and the site as a whole is recommended.

Preliminary management guidelines

Although sufficiently detailed information to determine a management prescription for spined loach is not yet available, a number of precautionary general and more specific guidelines are provided. In general, in any system containing important populations of spined loach, action should be taken to reduce eutrophication, excessive loading of fine sediments, excessive stocking of benthivorous fish and any wholesale management of river and stream channels (e.g. channelisation) that causes a significant reduction in habitat diversity.

Specific guidelines stem from the short-lived nature of spined loach and its reliance on annual recruitment to maintain populations. This suggests that the effects of various management practices used by the Environment Agency and other organisations, such as dredging, weed-cutting and channel profiling, may be considerable. Reduction in the frequency of management, leaving unmanaged refuge areas and alternatives to routine management are discussed.

Future monitoring and research requirements

It is recommended that the principal components of a future programme of research and monitoring include:

- Determining the taxonomic status of spined loach in the UK, through molecular studies.
- Determining the distribution and status of spined loach in the Trent & Witham and Great Ouse catchments with the view to establishing further SAC's.
- Undertaking a survey of spined loach in a number of habitats, particularly streams, in order to provide information on what constitutes a 'good and viable' population. This should also assess the value of the stream habitat and determine the likely impact of modification of streams upon spined loach populations.
- Conducting specific medium term (at least one year) research on the habitat requirements, especially of juveniles, and population dynamics of spined loach. This to be conducted in two study sites; one in a stream/river with sandy substrate and the other in a large drainage channels, with a more silty substrate.
- Determining the effects of different water quality criteria (e.g. salinity) upon spined loach, within a range likely to be encountered in natural habitats. Conducting laboratory eco-toxicological tests is considered to be the most cost-effective approach.
- Monitoring the impact of routine management practices such as channelization, dredging and weed-cutting. Study sites in both streams and large drainage channels are required. A scientifically rigorous experimental design, using replicates and a range of treatments incorporating controls, is recommended.

An assessment of sampling methods concluded that specific methods, including the use of the hand trawl (in large rivers and drainage channels) and point-abundance sampling by electrofishing (in streams) are required to sample spined loach effectively. These should be used in all aspects of future research on, and monitoring of, the species. It is also recommended that these methods, where appropriate, be incorporated into routine Agency sampling of waters within the known distribution of spined loach.

Contents

Background information

The spined loach (*Cobitis taenia*) has an extremely wide distribution across Europe and Asia as far as Japan. It is known from a wide variety of slow-flowing or still water bodies including rivers, streams, drains, canals, ditches and large and small lakes. Even with such a wide range and potentially broad ecological niche, it is generally regarded as threatened, if not rare in Europe (Lelek 1980), and is protected by law in Belgium and the Netherlands (Bervoets *et al.* 1990, OVB 1994). In accordance with its status, spined loach is listed under Appendix 3 of the Bern Convention and has recently been included under Annex II of the EC Directive on the conservation of natural habitats and flora and fauna. Member countries have the duty to ensure the favourable conservation status of the species through conservation of viable populations within Special Areas of Conservation (SAC's).

The current project is a collaborative effort between English Nature (EN) and the Environment Agency (Agency) (see *Project Management* below). Meeting the EC Directive forms the ultimate overall requirement of the project from an EN perspective, whilst the emphasis for the EA is focused on clarifying the distribution and status of the species and developing management guidelines that can be applied where it occurs. Until now, the assessment of the species' status had been constrained by the lack of commercial or obvious ecological/management value. Combined with its small size (<12 cm) and benthic habits (Fig. 1), which has generally precluded its sampling by standard fish stock assessment techniques, the spined loach has remained poorly studied.

Thus there is some uncertainty as to whether spined loach is a minor and/or rare component of the fish fauna, limited by specific habitat requirements, or is simply under-recorded. In the UK, it was thought to be patchily distributed within a range encompassing eastern England into the Midlands (Maitland 1972, Mann 1995). Within this range, one site, the Ouse Washes, is a candidate SAC (cSAC). Selection of this site was, however, hampered by the lack of detailed information on the distribution and habitat requirements of spined loach. Further, with a lack of comparable data from other sites, the value of the Ouse Washes as an SAC, in that it should conserve a good and viable population, remains uncertain. The selection of further SAC's hinges on more detailed knowledge of the limits of the distribution of spined loach and, at the very least, confirmation of its presence at previously identified locations. Maintenance of favourable conservation status within protected areas and in all waters in which it occurs, relies on detailed knowledge of the species' habitat requirements and adoption of best management practice. The latter is likely to be constrained by the needs of other functions such as land drainage or flood defence of property, as the distribution of the species is centred on a rather intensively managed landscape.

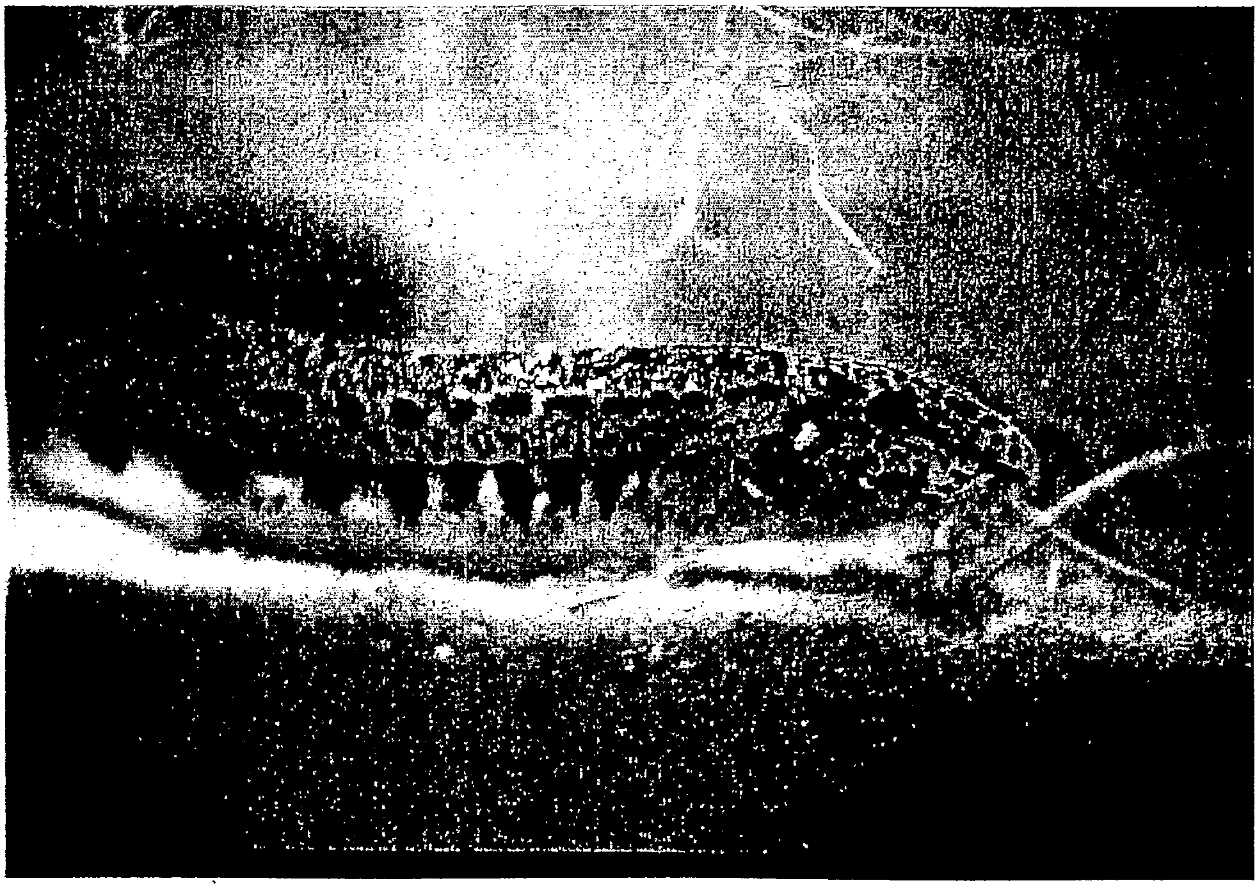


Figure 1. Profile of the spined loach. Note the distinctive body patterning, shape of the head and mouthparts and the indistinct barbels.

Project management

The managers of the project were Mary Gibson (freshwater ecologist) for EN and Andrew Heaton (Regional Conservation Officer for Severn-Trent) for the Environment Agency (hereafter known as the Agency). The Agency provided funds through R & D project 640, 'Species management in aquatic habitats, with EN managing the resulting contract.

Two meetings were held during the course of the project: one at its inception (23rd October 1996) and one to present the findings of the draft report (29th January 1997). A number of representatives from both organisations and from the Royal Society for the Protection of Birds (RSPB)(a major landowner at the Ouse Washes), were present at one or other meeting. These included Mike Evans (Agency), Richard Hall (Agency), Roger Handford (Agency), Neil Lambert (RSPB), and Matt Shardlow (RSPB).

Aims

The current project had five broad aims (see project brief-Appendix 1):

- To review and consolidate all existing information on the distribution of spined loach in England, so as to provide a clearer picture, than currently exists, of its distribution.
- To identify habitat requirements.
- To identify and where possible quantify the key factors/issues which will need to be addressed if favourable conservation of the spined loach is to be achieved across the range of habitats in which it is found.
- To produce management guidelines which will raise awareness relevant to conserving the spined loach and enable operational staff to ensure that management of those sites where spined loach occurs, is undertaken sympathetically. This refers especially to weed and silt control.
- To identify those aspects of ecology and distribution where further research or review is needed.

General information gathering

As it was known that spined loach has been poorly studied (Mann 1995), it was desirable to develop an understanding on all known aspects of its behaviour and ecology in order to fulfil the aims of the project. Consequently, during the search of the scientific literature using Bath Information Data Services (BIDS) at the University of East Anglia (UEA) and Aquatic Sciences and Fisheries Abstracts (ASFA) at the Ministry of Agriculture, Fisheries and Food (MAFF) laboratories at Lowestoft, general key words were used. These were '*Cobitis taenia*' in combination with 'ecology & biology', 'behaviour', 'spawning', 'feeding', 'food' and 'distribution' from 1978-1996. The current literature search extended a previous one using ASFA conducted by EN (M. Gibson, EN, *pers comm.*).

The literature search through ASFA provided 30 relevant references (Appendix 2) whereas BIDS supplied only 8. These are used where appropriate as background information or in the discussion of a particular point throughout the report.

Report structure

For ease of reference this report is divided into 5 sections, in accordance with the aims of the project:

- A. Distribution of spined loach in the UK.
- B. Habitat requirements of spined loach.
- C. Key issues of a conservation strategy for spined loach.
- D. The conservation of spined loach in the Ouse Washes cSAC
- E. Preliminary management guidelines.
- F. Further monitoring and research requirements.

Sections such as the habitat requirements used a combination of literature information supplemented by re-analysis of previously gathered data as well as original research. Within each section, where appropriate, the following is provided: brief background information, an outline of the methods used to gather information and presentation and discussion of the results.

A. Distribution of spined loach in the UK

Background information

As outlined earlier (see *Background information* above), spined loach was thought to occupy a range encompassing eastern England into the Midlands (Maitland 1972, Mann 1995). However, this required confirmation. The production of a distribution map showing all records of spined loach, to update and improve that produced by Maitland (1972) was thought to be a valuable output of the current project.

Methods

Records of spined loach were gathered from the following sources:

- Contact with all fisheries departments of the Agency both within the known range of spined loach (described by Maitland 1972) and in surrounding areas.
- Species Action Plan for spined loach by Mann (1995).
- Contact with a variety of organisations potentially holding records, recommended by the project board, including the Biological Records Centre (BRC), Natural History Museum and the RSPB.
- Consultation with Dr. Peter Maitland, author of the key to British Freshwater Fish (1972), which features a distribution map of spined loach.
- Contact with other individuals that have recorded the presence of spined loach. For example, Dr. Nick Giles, workers in the group of Dr. John Reynolds at the University of East Anglia (UEA) and Dr. Franklyn Perring.

A complete list of the names and addresses of all contacts is provided in Appendix 3. All records were entered into a database and a distribution map produced using the DMAP software package (A. Morton, Dept. Biology, Imperial College, London).

Results & Discussion

A total of 180 records were collected from 76 ten kilometre squares (Fig. 2). Spined loach is recorded from the counties of Bedfordshire, Buckinghamshire, Cambridgeshire, Derbyshire, Humberside, Leicestershire, Lincolnshire, Norfolk, Northamptonshire, Nottinghamshire, Staffordshire, Suffolk and Warwickshire (Appendix 4). A total of 75% of the records were recent (post 1990). The importance of recent records is also reflected by the range data, with only 30% of the 76 10k squares in which spined loach is now recorded, containing records prior to 1990. Overall it is suggested that these patterns indicate a increased tendency to record spined loach, particularly in standard fisheries surveys, rather than any increase in range, frequency of occurrence or abundance of the species. It is also thought that an increase in recording stems from a general increased awareness of so-called minor species (small species with no commercial interest), such as spined loach. An improvement in sampling techniques geared to smaller fish, may also have had a role.

It is clear that the distribution of the species is centred on three east-flowing river systems and their associated waterways; the Great Ouse, the Trent and the Witham (Fig. 2). The latter two river systems are connected through the Fossdyke, an artificial channel dating from Roman times. The fish fauna of east-flowing rivers is generally perceived to have originated from the continental Rhine system, prior to the separation of the land bridge between mainland Britain and continental Europe some 10 000 years ago at the end of the last ice age (see Wheeler. 1977).

Theories on the source of colonists, timing of colonisation and subsequent dispersal of fishes in relation to the land bridge are generally impaired by the lack of good fossil data, which itself is often restricted to bones of species exploited by humans and associated with sites of habitation. The lack of value of spined loach as a food fish and the simple fact that archaeologists use sieves with a mesh unlikely to retain the bones of small species (D. Brinkhuizen, Groningen University *pers comm.*) means that records of spined loach are scant (none known in the UK; none in the Netherlands - Brinkhuizen, 1979; and 1 in Belgium - van Neer & Ervynck 1994). Consequently, a working theory on the factors affecting the historical distribution of spined loach can only be derived from consideration of the evidence for the origin and development of, and likely prevailing ecological conditions within, the rivers in which it does or does not occur.

For example, the current presence of spined loach in the Rhine and its tributaries (e.g. the Ijssel) in the Netherlands (H. de Nie, Wageningen University, *pers comm.*) suggests that it should occur in the Thames (see above). Although there are some unconfirmed records (Maitland 1972, Phillips & Rix 1985), recent fisheries surveys (e.g. by statutory bodies such as the Environment Agency) do not substantiate them. Further, Wheeler (1977) considers a number of species indigenous to east-flowing rivers such as spined loach, silver bream (*Blicca bjoerkna*), burbot (*Lota lota*) (and maybe even barbel (*Barbus barbus*) -A. Wheeler, Natural History Museum, London, *pers comm.*) are also not native to the Thames (Wheeler 1977).

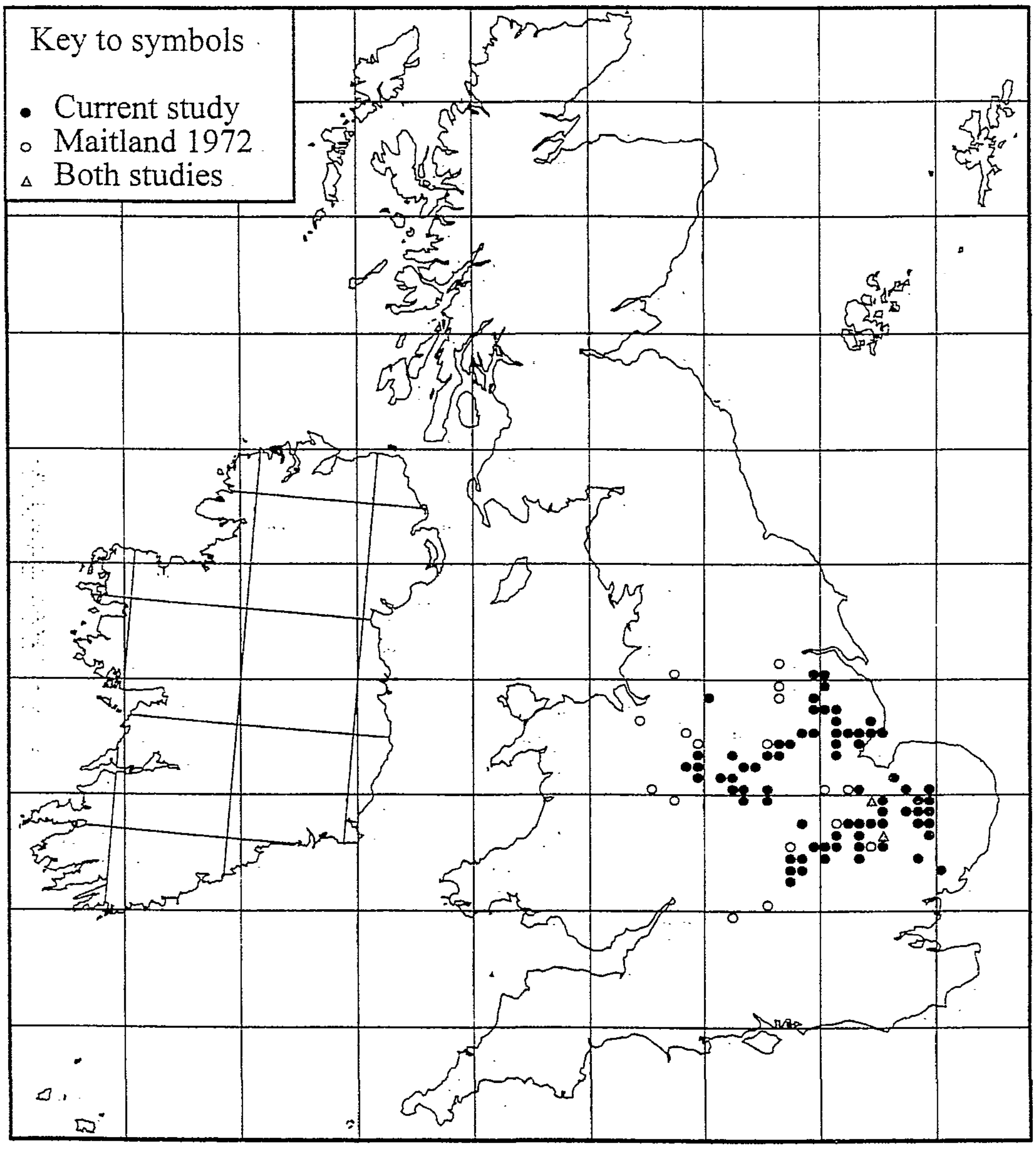
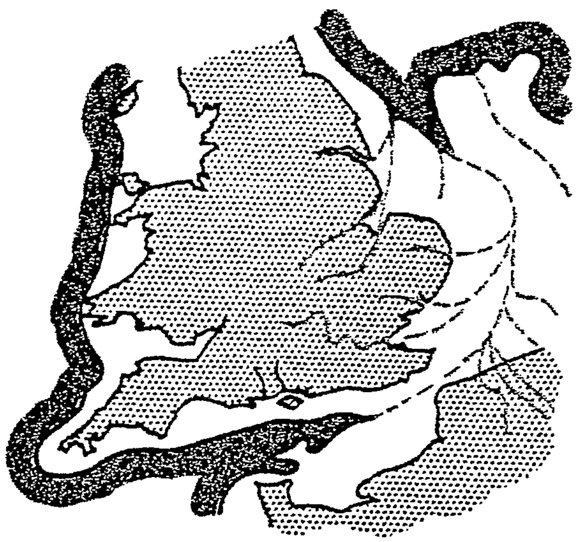


Figure 2. The distribution of spined loach (based on 10 km squares) in the UK, incorporating all records gathered in the current study and by Maitland (1972).

a)



b)

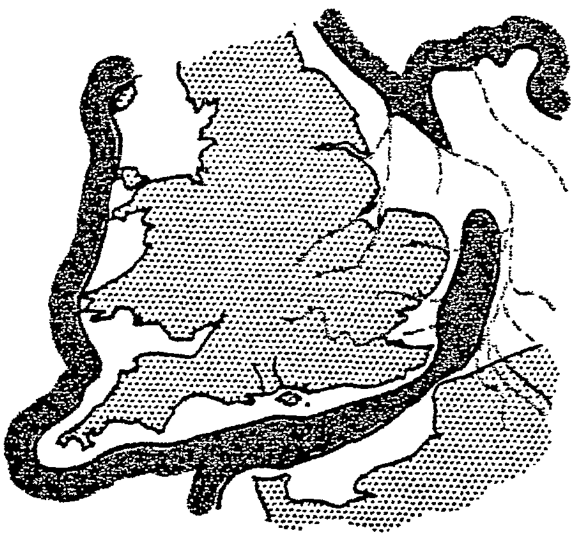


Figure 3. Sketch maps showing the probable position of the ancient rivers of 'dogger-land' immediately after the last ice age. The pattern of sea level rise from a) 9000 to b) 8700 years ago in relation to the current positions of Britain and mainland Europe is shown. Incorporating information from Varley (1967) and D.Brinkhuizen, Groningen University, *pers comm.*

The ultimate reason for the lack of spined loach in the Thames, may stem from the possibility that the principal east-flowing rivers were not confluent with each other but broadly divided into two groups; the Yorkshire Ouse, Trent and Great Ouse in one, and the Thames and southern East Anglian rivers (Yare, Stour etc.) in the other (Varley 1967, P. Gibbard, Cambridge University, *pers comm.*) (Fig. 3). Although there is good evidence that the latter group was confluent with the Rhine in the late Devensian (albeit through a different alignment through the Dover Strait), the former, Great Ouse group may not have been directly so (P. Gibbard, Cambridge University, *pers comm.*), although connection by overland flow cannot be ruled out. The two groups of rivers were therefore subject to different patterns of colonisation by fish, as both the ice receded northwards and the land bridge was eroded from the Dover Strait in the south. The more southerly rivers in the Thames group being isolated earlier than the northerly Great Ouse group (D. Brinkhuizen, Groningen University, *pers comm.*) (Fig. 3).

Spined loach (and the other species noted above) may thus have been in the process of colonising all rivers where ecological conditions were becoming more suitable after the retreat of ice and/or the amelioration of glacial floodwater conditions. It may be that there was insufficient time for the species to colonise the upper reaches of the Thames group (or perhaps these were still unsuitable e.g. too cold for effective recruitment in the case of barbel- Wheeler 1977) before the lower reaches were inundated by the rising sea level. Colonisation by spined loach may thus have been impeded by its generally sedentary nature (D. Brinkhuizen, Groningen University, *pers comm.*). A further several hundred years would have been available for spined loach to colonise the Great Ouse, Trent and Yorkshire Ouse systems. The (apparent) absence from the Yorkshire Ouse and connected rivers may be explained by the prevailing ecological conditions being unsuitable in this system, being the most northerly of catchments of the Great Ouse group and thus the most likely to retain an influence of receding ice and glacial meltwater.

The distribution of spined loach thus appears to have stayed virtually unchanged over the last 10 000 years. Some natural colonisation has occurred. For example, spined loach has been recorded from several gravel pits (e.g. Little Paxton and Great Linford) dug in the floodplain of the Great Ouse. A similar pattern has been observed in several large shallow lakes in the Netherlands with a riverine connection (Perrow & Jowitt 1996, Witteven & Bos unpubl. data). However, in contrast to many other species, spined loach are unlikely to be subject to accidental or deliberate introduction, one of the principal methods of dispersal for fishes (Wheeler 1977). This is primarily because they are of no commercial or angling interest and are unlikely to be used as livebait for larger predatory species. The latter has led to the introduction of other small species into a variety of water bodies (e.g. ruffe *Gymnocephalus cernuus* in Loch Lomond- Maitland & Campbell, 1992).

There is some possibility however of spined loach being transferred during fish rescue operations from polluted waterways, but as these are often conducted within or between neighbouring catchments this is unlikely to be a major supply of colonists to new areas. Indeed, the only outlying population recorded in the current study was that in the Essex Stour. This seems to have resulted from a water bypass scheme which draws water from the Cut-off channel, part of the Great Ouse system.

The outlying populations recorded by Maitland (1972) including one in the catchment of the Thames in Oxfordshire and one in the north-west near Manchester (Fig. 1), cannot now be verified (P. Maitland, consultant & BRC *pers comm.*). In the unlikely event of introduction (see above), we can only conclude that these records are a case of mistaken identity, perhaps resulting from confusion with stone loach (*Barbatula barbatulus*).

Conclusions

Spined loach is naturally restricted to the Great Ouse and Trent/Witham catchments. This results from a combination of the patterns of colonisation from ancestral riverine connections prior to the severance of the land bridge at the end of the last ice age, and the lack of subsequent dispersal through human means. It appears to be widely distributed within these river systems. An increase in the number of records in recent years, is reflective of an increased likelihood of recording the species, particularly in routine fisheries surveys conducted by the Agency and its predecessors. Consequently, there is no evidence of a change in range, frequency of occurrence or abundance in recent years. Several old records suggesting a wider distribution can no longer be verified and are suggested to be a case of mistaken identity.

B. Habitat preferences of spined loach

Background information

Spined loach has been recorded from a wide variety of water bodies including rivers, streams, drains, canals, ditches and large and small lakes. This suggests it has a broad ecological niche. However, it is also possible that the species has a narrow ecological niche which may be satisfied within a number of habitats. It is also possible that selection for different micro-habitats occurs within different types of waterbody. Unravelling these preferences is obviously critical if appropriate management is to be undertaken in different situations, to conserve or promote spined loach populations.

Methods

A four-pronged approach was adopted. First, any literature on habitat preferences was gathered. As this was limited to a few papers in a narrow range of habitats, it was thought that more insight could be gained into likely habitat relationships through an understanding of the general biology, in particular the feeding and reproductive strategies, of the species. Particular requirements in these critical aspects, may then indicate factors limiting the distribution and abundance of spined loach. This was achieved through a search of available literature in the manner described earlier (see *General information* above).

Second, the association between spined loach and other fish species was determined using a large data set derived from routine Agency fisheries surveys in Central area of Anglian region, in the catchment of the Great Ouse, at the heart of the known distribution of spined loach (see *Distribution of spined loach in the UK* above). Association of spined loach with any species/communities with known preferences (e.g. those associated with macrophytes - de Nie 1987), may have implied particular habitat preferences.

Third, the watercourses (or sections of large rivers where these change greatly in type along their course) within the catchment of the Great Ouse (see above), from which spined loach was recorded during routine fisheries surveys, were used in a simple analysis of the likelihood of spined loach occurring within each gross category of waterbody.

Fourth, a more direct approach to determining habitat preferences was undertaken by analysis of three data sets:

- Routine fisheries and river corridor surveys (RCS) from 24 watercourses (or sections of large rivers where these change greatly in type along their course) within Central area of Anglian region (see above).

- Recent surveys undertaken by ECON in the large Lake Veluwe, in the Netherlands as part of a larger study on the interactions between fish and macrophytes (Perrow & Jowitt 1996).

- Specific monitoring of the Ouse Washes candidate SAC (cSAC), as the fieldwork component of the current project.

Habitat implications of associations between spined loach and other fish species

Associations between different fish species were determined by hierarchical cluster analysis (Norusis/SPSS 1993) using presence or absence data from the 345 sites within 51 watercourses within the Great Ouse catchment. This mirrored the successful approach previously adopted by Penczak *et al.* (1991) at 233 sites in 13 drainage basins in Lincolnshire and South Humberside.

A potential caveat of the approach however, is that the techniques used - electrofishing and seine-netting - during routine surveys, were used to sample species important to the fishery. Therefore, spined loach is something of a by-catch. However, as considerable effort was expended at each site (e.g. several runs with electrofishing and several seine nets hauls), it was thought that if spined loach was present in any numbers, at least one individual would be captured.

Frequency of occurrence of spined loach within different types of watercourse

Spined loach has been recorded from 25 watercourses (or sections of large rivers where these change greatly in type along their course) within the catchment of the Great Ouse (see above), during routine fisheries surveys. These were divided into several categories: small rivers or streams, large rivers, drainage channels and canals. The frequency of occurrence of spined loach, within the variable number of sites sampled, during the most recent survey in which it occurred, was determined in each watercourse. A general comparison of the likelihood of sampling spined loach within different types of waterbody was made by determining the mean frequency of occurrence.

Habitat associations derived from routine fisheries and RCS surveys

From the data set outlined above (*Habitat implications of associations between spined loach and other fish species*), 24 watercourses, for which recent (1990-95) habitat data from river corridor surveys (RCS) was available, were selected. The basic approach was to test for differences in habitat variables between the 14 watercourses in which spined loach had been recently recorded (1990 onwards) and the 10 in which it had not. Although the same caveat of spined loach being unrecorded by the sampling techniques adopted (see above) still applies, the chances of sampling spined loach were further increased, by up to 19 sites being sampled within any one watercourse.

Eight habitat variables were determined from RCS data (Table 1). For variables that could be quantified, the mean values from 5 RCS sections, selected in a stratified random manner, were used. Other variables from the same RCS sections were expressed in a semi-quantitative way. For example, the number out of the 5 sites in which a particular substrate type was recorded, was used. Plant abundance, on the other hand, normally expressed as the DAFOR scale, was converted to a simple 1-5 scale and the average score used. The mean value (from all reference stations within each river or section) of three routinely taken water quality variables was also used (Table 1). Student-*t* tests were used to test for differences between watercourses with or without spined loach.

Table 1.
Habitat and water quality variables collected from RCS data, for comparison of sites in which spined loach was present or absent.

Type	*Variable*
Channel characteristics	width depth bank slope
Substrate	sand gravel silt
Macrophytes	submerged/floating littoral emergent
Water quality	BOD 90%ile ammonia 90%ile dissolved oxygen 90%ile

Habitat relationships in Lake Veluwe

Although spined loach is not typically associated with stillwaters in the UK, it is known to occur in several lake systems adjacent to rivers (e.g. Great Linford lakes-Giles 1992). Analysis of the data available from Lake Veluwe was thus potentially relevant to these populations. Moreover, it was plausible that spined loach could associate with the same or similar microhabitat in a number of apparently diverse habitats. As the study in Veluwe had the potential to provide specific detail on microhabitat distribution, with information on diurnal and seasonal patterns from a large number of fish, full analysis of the data set was justified.

Lake Veluwe, a large (3400 ha), shallow lake in the Netherlands is undergoing restoration at the present time and, in the year of study, 1996, was dominated by macrophytes, particularly *Chara* spp. The purpose of the study was to investigate the distribution patterns of fish in relation to macrophytes. Fish were sampled during June-October inclusive, by point-abundance sampling (PAS) (see Copp & Penáz 1988, Copp & Garner 1995), using high frequency (600 Hz) pulsed DC (rectangular wave at 300V with a variable duty cycle of 0-50%) electrofishing equipment, (Electracatch WFC11-12 volt powered by a 1.9 KVa generator) from a 3 m fibreglass dinghy. This was 'push' rowed by one operator, with a second operator electrofishing from the stern. For further details of the sampling technique see Perrow *et al.* (1996a).

During each monthly sampling occasion, samples were taken day (from 10-1100 hrs) and night (starting one hour after dusk) with an interval of approximately 30 hours. Fifty points were sampled along fixed transects (which were identified between occasions using GPS equipment) in each of five habitat zones:

- The littoral zone dominated by reed, *Phragmites australis.*
- The *Potamogeton* spp. and *Myriophyllum* spp. dominated zone, 75 m from the shore.
- Within the centre of *Chara* spp. meadows in the middle of the lake (around 200 m from the shore).
- Along the transition zone between *Chara* and open water, which also has a number of macrophyte species including *Potamogeton perfoliatus* and *Alisma* spp.
- In open water bordering the boat channel.

During PAS the boat was rowed along the transect and points were sampled at regular intervals, after the equivalent (depending on weather conditions) of 10 oar strokes. At each point, the anode was rapidly immersed, and any stunned fish seen were captured by a lightweight fibreglass hand net. Even where no fish were seen, the net was swept quickly through the stunned area to avoid sampling bias created by differences in visibility within habitats and between sampling occasions. The effective sampling radius of 1.3 m^2 was calculated by determining the distance from the anode at which the voltage gradient was reduced to 0.12V, the level at which inhibited swimming occurs (Copp & Penáz 1988). Any spined loach captured were measured to the nearest mm before being returned unharmed. With a known sampling area, the density (n m^{-2}) of spined loach could be calculated. One-way ANOVA was used to test for differences in the density of spined loach between the various habitats on each sampling occasion (both day and night).

In addition, during June and July, a further transect across the width of the lake encompassing all habitats (see above), was explored. In this case, the electrofishing gear was kept on, whilst the boat was propelled forward. The position of capture for each loach was marked and several environmental measures taken. These were:

- The height of vegetation (cm).
- % cover of vegetation and hence bare sediment within a metre diameter of the capture.
- Estimated distance to the nearest bare patch (cm).

The same transect was then followed, recording only environmental variables, within a corresponding sample area, at intervals of 20 oar strokes. A similar number of samples were taken on all occasions. For example, 32 and 45 spined loach were captured and a corresponding number of habitat samples taken, on the first transect, in June and July, respectively. In comparison, 31 and 34 sets of habitat samples were taken on the second transect of each respective sampling occasion. Student-*t* tests were used to test for differences between variables at locations occupied by spined loach and those determined in a systematic manner.

Habitat preferences in the Ouse washes

The habitat preferences of spined loach within the Ouse washes cSAC were assessed during sampling to determine their status and distribution within the system (see *Key issues of a conservation strategy for spined loach* below). The cSAC is comprised of an approximately 19 km length of the Counterdrain/Old Bedford River and the Old Bedford/River Delph (Fig.'s 4 & 5). For ease of reference throughout this document, and following the nomenclature used by the RSPB, the Old Bedford/Delph will be referred to as the inner river and the Counterdrain/Old Bedford River as the outer river.

Within the sampling strategy adopted (see *Key issues of a conservation strategy for spined loach*), it was possible to evaluate the habitat preferences of spined loach at two levels:

- A comparison between populations of spined loach according to the gross habitat characteristics of the outer and inner rivers.

- Determination of the relationship between spined loach density and particular habitat variables within each river.

The basis for the comparison between outer and inner rivers came from RCS data held by the Agency. The outer river contains abundant submerged macrophytes (*Elodea canadensis*, *Myriophyllum spicatum*, *Potamogeton natans* & *P. lucens* as well as filamentous algae), over a silt/gravel substrate with imperceptible flow. The inner river on the other hand is wider (and therefore has a proportionally smaller littoral zone), has higher turbidity and consequently fewer macrophytes. The difference between these two adjacent systems separated by the Middle Level barrier bank stems from their different water supplies; the inner river being ultimately supplied by the Hundred Foot river as overspill through Earith sluice in winter, whilst the outer river is isolated from this water by Middle Level barrier bank, and principally drains water from arable land. At a critical level, the excess is pumped into the inner river via the pumping station at Welches Dam.

Following trials between different sampling methods (see *Further monitoring and research requirements*) the hand trawl was selected as the most appropriate technique (Fig. 6). This was originally designed to catch shrimps in shallow coastal waters by Dr. Bob James (UEA). It consists of a tubular aluminium D' frame of 75 cm x 25 cm height mounted on aluminium runners (0.7 m in length) which allow the trawl to be pulled or pushed (when a long metal handle is attached) across the sediment surface. A 'tickler' chain attached across the front of the runners is designed to disturb the fish (or shrimps) buried in the sediment, which leads to their capture within the 1.2 m long x 2.5 mm mesh tapering net attached to the frame.

Ten trawl samples were taken at each 6 sites in both outer and inner rivers within a five day period (17th-25th February 1997). Sites were spaced at approximately 3 km intervals along the length of the washes controlled by the RSPB from Earith in the south-west to Welney in the north-east (Fig. 4). Trawls were taken in the outer river, the equipment moved over the Middle Level barrier bank (Fig. 5) and then used in the inner river. During each haul, the trawl was dropped into to the water from a small (3 m) dinghy rowed to the opposite bank. Trawls were thus undertaken across the width of the channel or at a slight angle where the channel was narrow (c. 5 m). Mean trawl length was 8.17 m in the outer river and 9.17 m in the inner river. The density of loach (n m^{-2}) was determined simply by dividing the number captured by the area sampled (length of trawl in m x 0.75 m width). This was compared between the outer and inner rivers as well as between sites within a river, using a MANOVA nested design (Norusis/SPSS 1993).

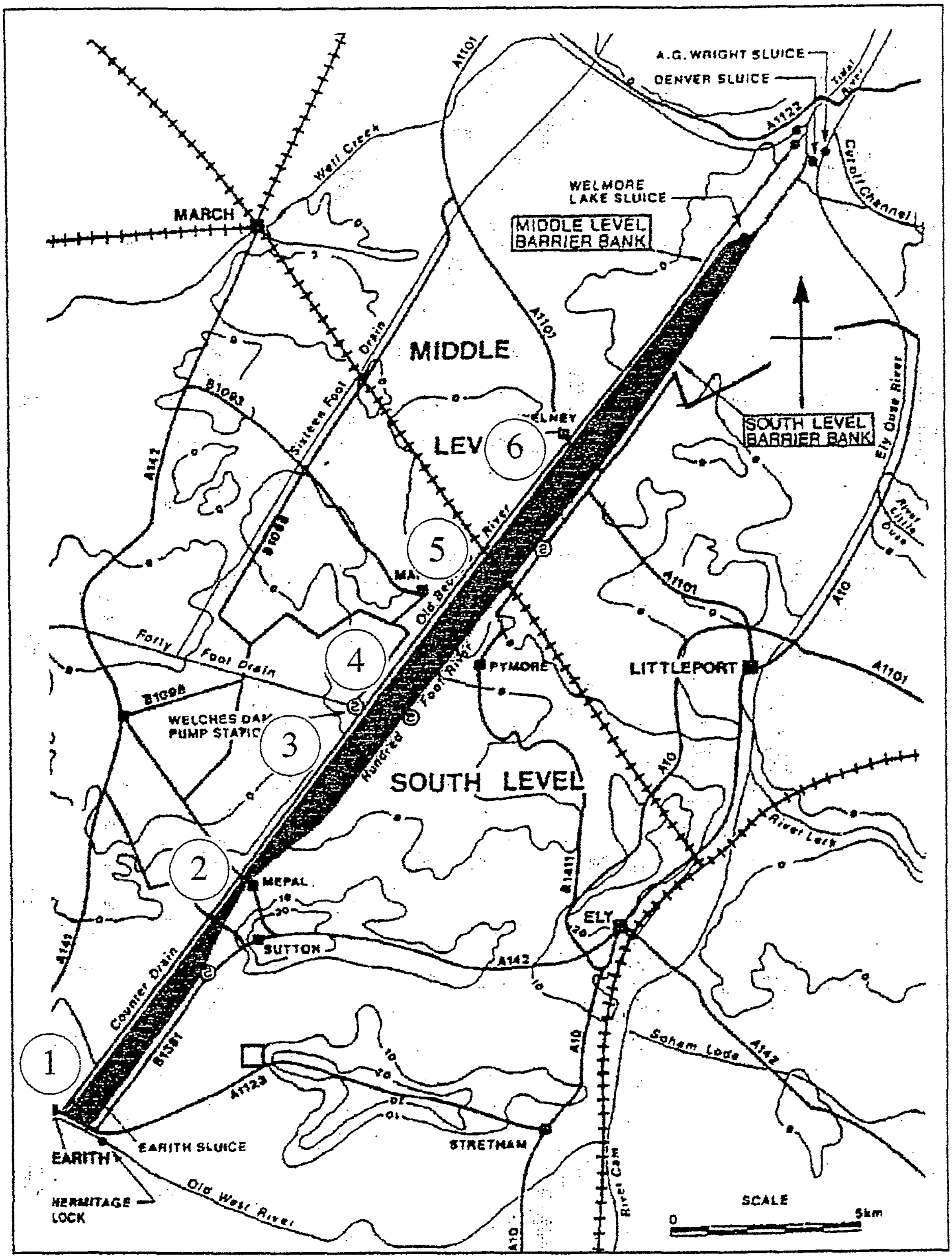


Figure 4. Map showing the extent of the cSAC incorporating the inner and outer river (red lines) and the current SSSI excluding the cSAC (green area). The sites sampled for spined loach during the current study are indicated (1-6).

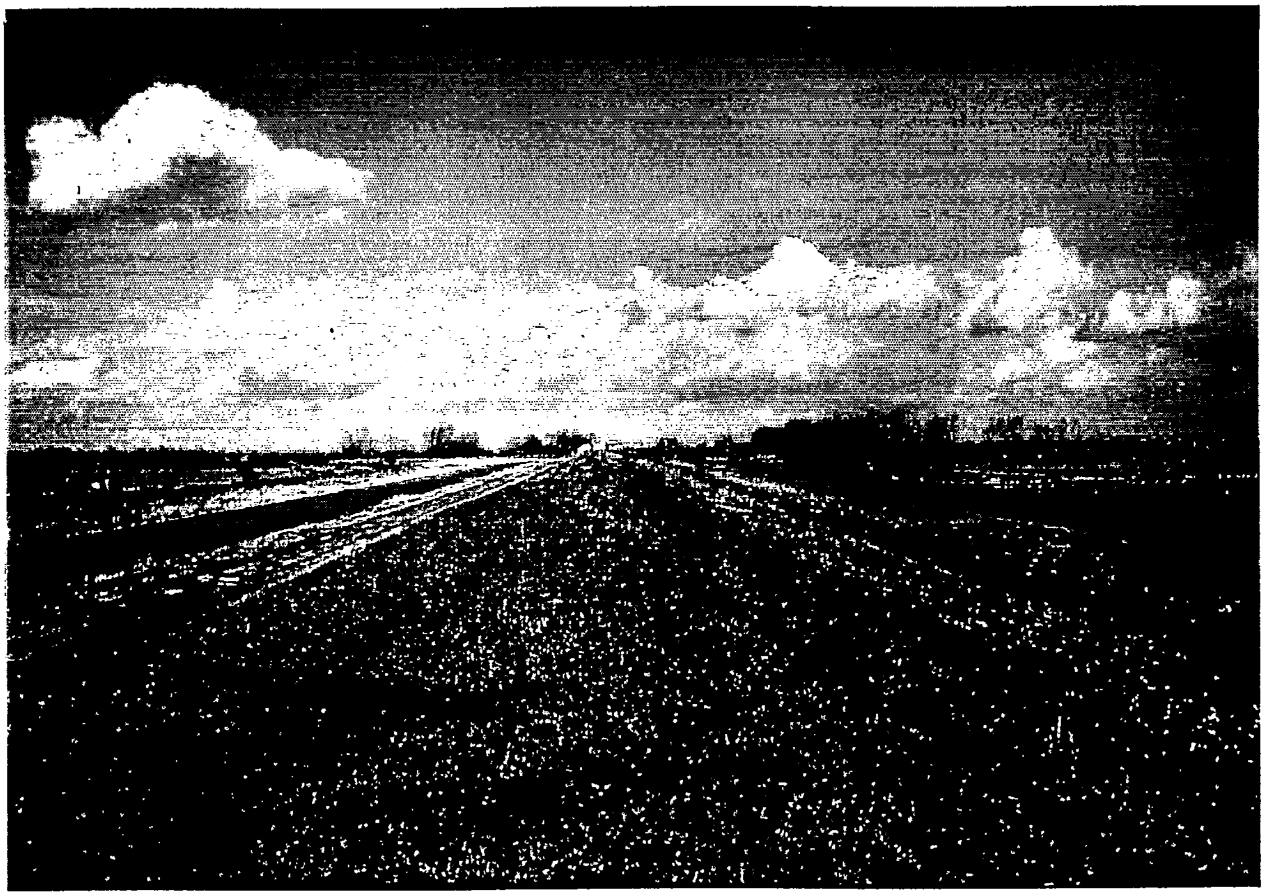


Figure 5. View (looking north-east) along the Middle Level barrier bank near Welches dam on the Ouse washes. The outer river is on the left of the picture and the inner river and the partly flooded washes are on the right.

Figure 6. Using a hand trawl in the inner river at the Ouse washes

At the second level of comparison, the retention of material within a trawl also allowed certain gross habitat variables to be quantified, using simple rank scores (from 0-5). The variables included:

- Macrophyte cover and species richness.
- Cover of filamentous algae.
- Volume and type of mud.
- Biomass and species richness of other fish species.

A mean of each variable was determined for each of the six sites sampled in each river. The relationship between mean density (n m^{-2}) of spined loach recorded at the site and the mean of each variable was then explored using linear regression.

Results

Habitat implications of associations between spined loach and other fish species

Within the hierarchical cluster analysis (Fig. 7), spined loach was associated (at a cluster distance of 4) with fluvial species such as brown trout (*Salmo trutta*), stone loach and minnow (*Phoxinus phoxinus*). However, the closest association was with three-spined stickleback (*Gasterosteus aculeatus*) and carp (*Cyprinus carpio*), the latter of which is more typically associated with lakes and large rivers. The link with stickleback and carp bears a remarkable resemblance to the situation within *Chara* beds in Lake Veluwe (Perrow & Jowitt 1996). A similar result was obtained from analysis of 233 sites in 13 drainage basins in Lincolnshire and South Humberside by Penczak *et al.* (1991). Here, spined loach was broadly associated with a group of fluvial species including rainbow trout (*Oncorhynchus mykiss*), minnow, stone loach, brown trout and bullhead (*Cottus gobio*).

The implication that spined loach is associated with streams and rivers, needs to be treated with some caution, for two reasons. First, spined loach was only recorded from 30 of the 345 sites (i.e. 8.7%). The association with particular species may be a function of the analysis tending to group the rarer species (the 6 rarest, ranked from 17-22 are in the same cluster-Fig. 9), rather than be truly indicative of shared habitat preferences. This is reinforced by the data of Penczak *et al.* (1991), where spined loach was associated with the other species in its cluster at only 2.1% similarity. Second, the chances of spined loach being recorded may also be different within different types of waterbody, which are sampled by different techniques (see *Frequency of occurrence of spined loach within different types of watercourse* below). An increased tendency to sample spined loach in streams/rivers may cause an apparent association with fluvial species.

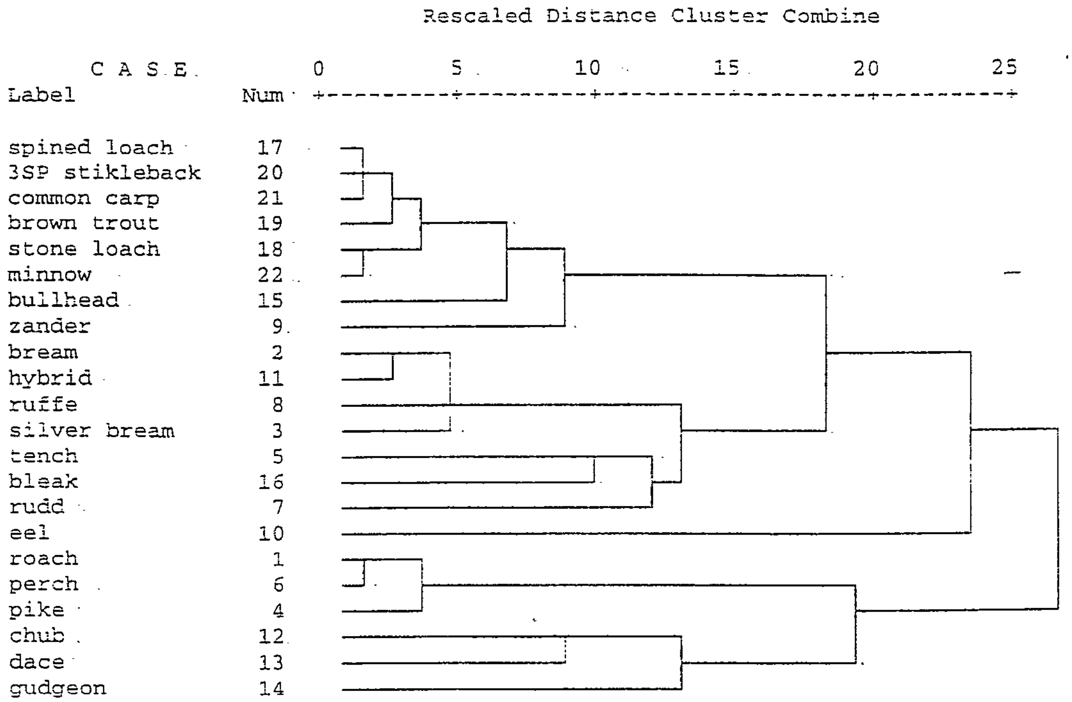


Figure 7. Dendrogram from hierarchical cluster analysis, illustrating the association (average linkage) between different fish species. Data are from surveys of 345 sites from 51 watercourses conducted by the fisheries team of the Central Area of the Anglian region of the Agency.

Table 2.
Frequency of occurrence of spined loach in watercourses from which it has been recorded, during routine fisheries surveys in Central Area of Anglian Region of the Agency. Details of the most recent survey in each watercourse are shown.

Type of watercourse	*Name of watercourse*	*Date*	*No. of sites*	*Sites with spined loach*	*%*
Small rivers/ streams	Ivel	1995	11	1	9
	Sapiston	1995	11	5	46
	Thet	1995	7	1	14
	Great Ouse-Brackley to N. Pagnell	1991	14	5	36
	Upper Little Ouse	1996	13	3	23
	Upper Wissey-u/s Whittlington	1993	8	1	13
	Nar	1996	13	2	15
	Claydon/Padbury	1994	9	1	11
	Ouzel	1987	13	1	8
	Tove	1995	10	3	30
	Watton Brook	1990	5	1	20
	Stringside Brook	1992	2	1	50
	Granta	1993	4	2	50
	Rhee	1993	8	2	25
Large rivers	Great Ouse-N. Pagnell to Bedford	1992	20	2	10
	Great Ouse-Brampton to St. Ives	1995	11	1	9
	Great Ouse-St. Ives to Earith	1989	6	1	16
	Lower Little Ouse	1993	8	1	13
	Lower Wissey-d/s Whittlington	1988	11	1	9
Drainage channels	Sixteen Foot Drain	1983	10	4	40
	Relief Channel	1979	8	1	13
	Cut-off Channel	1986	19	1	5
	Old Bedford River (counterdrain)	1993	9	1	11
	Soham Lode	1990	4	1	25
Canals	Grand Union	1990	15	1	7

Frequency of occurrence of spined loach within different types of watercourse

Within Central area of the Anglian region of the Agency, which represents something of a stronghold for the species (Fig. 2), spined loach is known from a wide variety of watercourses including, small streams, large rivers and small and large drainage channels (Table 2). There is the suggestion however, that spined loach tended to be encountered more frequently in small streams/rivers and the upper reaches of larger rivers (mean frequency 25%) than in the other habitats (mean frequency 11%). This may however result from the differences in methods employed in different types of watercourse. For example, seine netting is typically used in large channels whereas electrofishing is used in small channels. Electrofishing, with the ability of the technique to draw fish from cover (in sediments or amongst plants or debris) is likely to be more efficient, introducing a bias.

Habitat associations derived from routine fisheries and RCS surveys

From the data set, there were no significant differences between any habitat and water quality variables generated from watercourses with and without spined loach (Table 3), suggesting that spined loach is not restricted to particular habitats.

Table 3.

Mean (± 1 S.E.) values of the habitat and water quality variables in watercourses in which spined loach is known to be present or thought to be absent. Probabilities resulting from student t-tests are shown.

Variable	*spined loach present*	*spined loach absent*	*p*
width (m)	12.87 ± 2.16	12.75 ± 3.58	NS
depth (m)	0.79 ± 0.16	0.77 ± 0.14	NS
bank slope (°)	57.56 ± 2.17	66.33 ± 5.38	NS
sand (score/5)	0.78 ± 0.58	0.00 ± 0.00	NS
gravel (score/5)	3.22 ± 0.60	3.11 ± 0.74	NS
silt (score/5)	3.89 ± 0.31	3.33 ± 0.69	NS
submerged/floating macrophytes (rank DAFOR)	2.21 ± 0.24	2.74 ± 0.25	NS
littoral emergent macrophytes (rank DAFOR)	3.40 ± 0.20	3.22 ± 0.25	NS
BOD (90 percentile)	3.41 ± 0.35	3.93 ± 0.57	NS
ammonia (90 percentile)	0.35 ± 0.12	0.26 ± 0.04	NS
dissolved oxygen (90 percentile)	67.92 ± 2.51	63.70 ± 3.61	NS

However, this 'broad-brush' analysis was based on the derivation of mean values from an entire (or large section of a) watercourse and simply whether spined loach was present or absent. Comparison may have been confounded by high variability between and within sites. For example, a river may be channelized (overwidened and straightened) in one section and be almost natural (meandering with a variety of habitats) in another. In this analysis there was thus no scope to determine whether spined loach was associating with particular habitats within each system.

Habitat relationships in Lake Veluwe

Detailed sampling in Lake Veluwe, where a large population of the species was present (density reaching 0.36 m^{-2} in favoured habitats - Fig. 8), illustrated strong preferences of spined loach for particular habitats. Apart from the first sampling occasion, the density of spined loach was always significantly different between habitats during both day and night (Table 4). The pattern of selection for particular habitats also changed over the season and from day to night (Fig. 8). In early season, when spined loach numbers were at their lowest, although more were present in the *Chara*, this was not significantly different from the other habitats. At this time, there was also no evidence of selection for particular components of the habitat within the *Chara* beds (Table 5). In contrast, in July, fish were clearly selecting for areas with a greater proportion of bare sediment, within *Chara* beds (Table 5). This is reinforced on a larger scale, by the greatest numbers in the patchy *Chara* of the transition zone during the day, at this time (Fig. 8).

As *Chara* reached its peak cover in August, spined loach had become concentrated in the sparser *Chara* beds at the transition with open water, with significant differences between this and all other habitats. However, at night, spined loach were more abundant in the more open habitat of the *Potamogeton* zone, which at this point in time contained patches of filamentous algae but virtually no *Potamogeton* (*pers obs.*). This pattern of being found in patchy *Chara* during the day and more open habitats at night was reinforced in September, particularly as the extent of cover in the open water zone had increased through the abundance of *Alisma* spp. By October, the transition zone and the open water zone contained a similar density of fish during the day. At night, with the general decline of macrophytes in this period, spined loach was relatively evenly distributed throughout all habitats, apart from the littoral zone.

The pattern of distribution of 0+ fish was broadly similar to that of the entire population (Table 4). However, in July and August when 0+ fish were small (< 45 mm), no differences in density between habitats was observed, whereas when older fish were included in the analysis, strong significant differences, with the transition zone being favoured, were introduced. It is clear, however from Fig. 9, that the number of 0+ fish captured increased, rather than decreased as a result of mortality, during the season. This indicates that the 0+ were not captured efficiently at a smaller size, early in the season. The most likely reason for this is that these small fish were hidden within the sediments or the macrophytes, by day and easily missed.

Table 4.

Results of ANOVA on the density (n m^{-2}) of spined loach of all age classes and 0+ alone (in parentheses) , in the range of habitats (littoral, *Potamogeton*, *Chara*, *Chara*-open water transition and open water zones) in Lake Veluwe from June-October 1996. F values and associated probability (NS, * p<0.05, ** p<0.01, *** p<0.001), are shown.

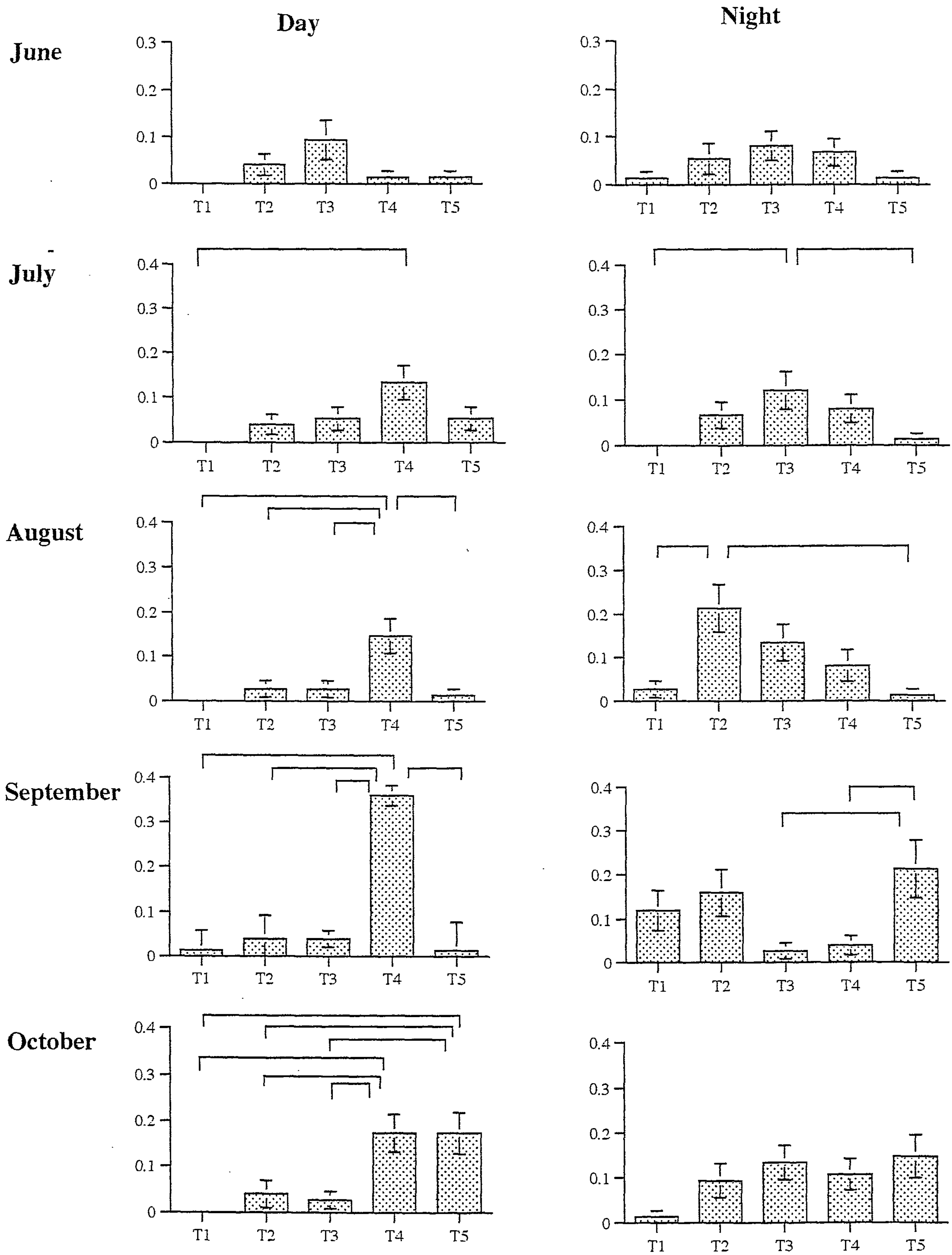
Date	*Sample*	*F value*	*p*
June	day	2.6	NS
	night	1.5	NS
July	day	3.8 (1.0)	**(NS)
	night	3.5 (5.3)	**(***)
August	day	7.1 (1.5)	***(NS)
	night	5.3 (4.4)	***(**)
September	day	15.1 (15.1)	*** (***)
	night	3.3 (11.1)	** (***)
October	day	9.3 (7.2)	*** (***)
	night	2.7 (2.2)	* (NS)

Table 5.

Comparison between characteristics of *Chara* beds (mean ± 1 S.E.) at systematically sampled locations, and at those occupied by spined loach, from transects conducted in Lake Veluwe in June and July 1996. Significant differences, as revealed by t-test, are shown (* p<0.05, ** p<0.01, *** p<0.001).

Variable	*June*			*July*		
	occupied	*systematic*	*p*	*occupied*	*systematic*	*p*
height of *Chara* (cm)	9.75 ± 0.29	10.3 ± 0.54	NS	14.8 ± 1.13	19.0 ± 1.27	*
% bare sediment	26.3 ± 3.55	24.2 ± 4.09	NS	33.8 ± 3.45	14.6 ± 3.96	***
distance to bare sediment (cm)	13.9 ± 39.7	45.4 ± 202.1	NS	9.8 ± 2.91	127.3 ± 40.7	***

Figure 8. Mean (±1 S.E.) density (n/m2) of spined loach in PAS transects during day and night from June to October in Lake Veluwe. Where T1 = *Phragmites* zone, T2 = *Potamogeton* zone, T3 = *Chara* zone, T4 = *Chara* transition zone, T5 = open water. Significant differences between habitats according to one-way ANOVA are marked.



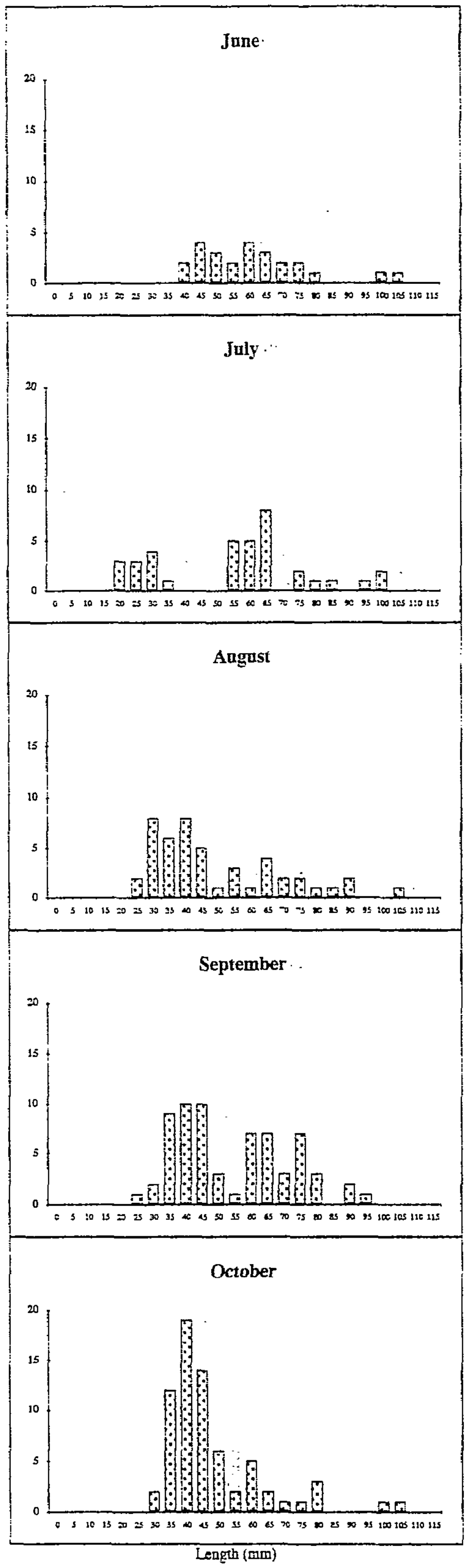


Figure 9. Length frequency histograms of all spined loach captured in Lake Veluwe from June to October 1996

Habitat preferences in the Ouse washes

There were clear differences in a number of ecological variables between the two rivers as predicted from Agency RCS data (Table 6). A greater abundance (0.92 ± 0.26 to 0.15 ± 0.08) and species richness of macrophytes (0.48 ± 0.25 to 0.12 ± 0.06) and algae (3.04 ± 0.77 to 0) was recorded in the outer river. The inner river, in contrast, had a greater quantity of mud (2.42 ± 0.88 to 0.34 ± 0.22), which was typically black and anoxic.

Table 6.
Mean (± 1 S.E.) scores (on a scale of 0-5) for a number of ecological variables in both inner and outer rivers at the 6 sites sampled.

Ecological variable	*River*	*Site 1*	*Site 2*	*Site 3*	*Site 4*	*Site 5*	*Site 6*
mud	outer	0	0.2 ± 0.1	1.2 ± 0.5	-		
	inner	0	0.3 ± 0.2	4.7 ± 0.3	3.5 ± 0.4		
macrophyte	outer	0.2 ± 0.2	0.7 ± 0.3	0.7 ± 0.3	-	1.6 ± 0.4	1.4 ± 0.3
abundance	inner	0.3 ± 0.2	0.5 ± 0.2	0.1 ± 0.1	0	0	0
number	outer	0.2 ± 0.2	0.8 ± 0.3	0	-	0.1 ± 0.1	1.3 ± 0.3
of species	inner	0.3 ± 0.2	0.3 ± 0.2	0.1 ± 0.1	0	0	0
algal	outer	5.0 ± 0.0	2.3 ± 0.7	0.7 ± 0.5	-	4.4 ± 0.5	2.8 ± 0.4
abundance	inner	0	0	0	0	0	0

The gross habitat differences are borne out by the fish community in each river. Species typically associated with macrophytes, including rudd (*Scardinius erythrophthalmus*) tench (*Tinca tinca*) and pike (*Esox lucius*) (de Nie 1987, Perrow & Jowitt 1997), were only recorded in the outer river (Table 7). In contrast, bream, typically a fish of unstructured turbid waters, was only recorded in the inner river. Ten-spined stickleback (*Pungitius pungitius*) was also only present in the inner river, although this may be a result of the direct link with the dyke system of the washes themselves, where this species dominated the community (see *Key issues of a conservation strategy for spined loach* below). Overall, the species richness was typically higher in the outer river (4.33 ± 0.56 to 3.67 ± 0.21) (Table 7), as was the overall density of fish (0.40 m^{-2} compared to 0.19 m^{-2}).

In accordance with the overall results for the fish community, MANOVA showed there was a significantly greater density of spined loach in the outer compared to the inner river (Table 8, Fig. 10). Moreover, although there was a considerable variation in density between sites within each river (Fig. 10), there were no significant differences (Table 8).

Table 7. Mean (± 1 S.E.) density (n/m2) of all fish species captured by hand trawl at each survey site in both outer and inner rivers in February 1997. Species richness, diversity (derived from Simpson's diversity index) and equitability are also shown.

	Site		Roach	Bream	Rudd	Tench	Spined loach	Perch	Pike	Ruffe	Stickleback	Total	Richness	Diversity	Equitability
Outer river	1	Mean	0.000	0.000	0.067	0.150	0.000	0.117	0.017	0.000	0.000	0.350	4	3.00	0.75
		se	*0.000*	*0.000*	*0.027*	*0.052*	*0.000*	*0.043*	*0.017*	*0.000*	*0.000*	*0.088*			
	2	Mean	0.000	0.000	0.019	0.038	0.133	0.210	0.019	0.000	0.000	0.419	5	2.75	0.55
		se	*0.000*	*0.000*	*0.019*	*0.025*	*0.064*	*0.078*	*0.019*	*0.000*	*0.000*	*0.079*			
	3	Mean	0.000	0.000	0.000	0.000	0.167	0.250	0.000	0.067	0.000	0.483	3	2.47	0.82
		se	*0.000*	*0.000*	*0.000*	*0.000*	*0.079*	*0.094*	*0.000*	*0.027*	*0.000*	*0.135*			
	4	Mean	0.017	0.000	0.017	0.017	0.233	0.233	0.017	0.017	0.000	0.550	7	2.74	0.39
		se	*0.017*	*0.000*	*0.017*	*0.017*	*0.145*	*0.067*	*0.017*	*0.017*	*0.000*	*0.183*			
	5	Mean	0.000	0.000	0.000	0.117	0.067	0.067	0.000	0.050	0.000	0.300	4	3.60	0.90
		se	*0.000*	*0.000*	*0.000*	*0.050*	*0.037*	*0.051*	*0.000*	*0.025*	*0.000*	*0.111*			
	6	Mean	0.107	0.000	0.000	0.040	0.053	0.067	0.000	0.000	0.000	0.267	4	3.51	0.88
		se	*0.056*	*0.000*	*0.000*	*0.020*	*0.029*	*0.022*	*0.000*	*0.000*	*0.000*	*0.066*			
Inner river	1	Mean	0.000	0.000	0.000	0.000	0.015	0.015	0.000	0.015	0.015	0.059	4	4.00	1.00
		se	*0.000*	*0.000*	*0.000*	*0.000*	*0.015*	*0.015*	*0.000*	*0.015*	*0.015*	*0.033*			
	2	Mean	0.000	0.000	0.000	0.000	0.015	0.104	0.000	0.044	0.000	0.163	3	2.05	0.68
		se	*0.000*	*0.000*	*0.000*	*0.000*	*0.015*	*0.039*	*0.000*	*0.023*	*0.000*	*0.047*			
	3	Mean	0.000	0.000	0.000	0.000	0.119	0.074	0.000	0.030	0.015	0.237	4	2.72	0.68
		se	*0.000*	*0.000*	*0.000*	*0.000*	*0.048*	*0.025*	*0.000*	*0.020*	*0.015*	*0.071*			
	4	Mean	0.013	0.067	0.000	0.000	0.000	0.253	0.000	0.027	0.000	0.360	4	1.86	0.47
		se	*0.013*	*0.054*	*0.000*	*0.000*	*0.000*	*0.115*	*0.000*	*0.018*	*0.000*	*0.168*			
	5	Mean	0.000	0.000	0.000	0.000	0.044	0.015	0.000	0.000	0.000	0.059	2	1.60	0.80
		se	*0.000*	*0.000*	*0.000*	*0.000*	*0.023*	*0.015*	*0.000*	*0.000*	*0.000*	*0.033*			
	6	Mean	0.044	0.000	0.000	0.000	0.000	0.193	0.000	0.015	0.000	0.252	3	1.61	0.54
		se	*0.023*	*0.000*	*0.000*	*0.000*	*0.000*	*0.088*	*0.000*	*0.015*	*0.000*	*0.088*			

Figure 10. Mean (± 1 S.E.) density (n/m2) of spined loach captured by hand trawl, at each survey site in both outer and inner rivers of the Ouse washes, in February 1997.

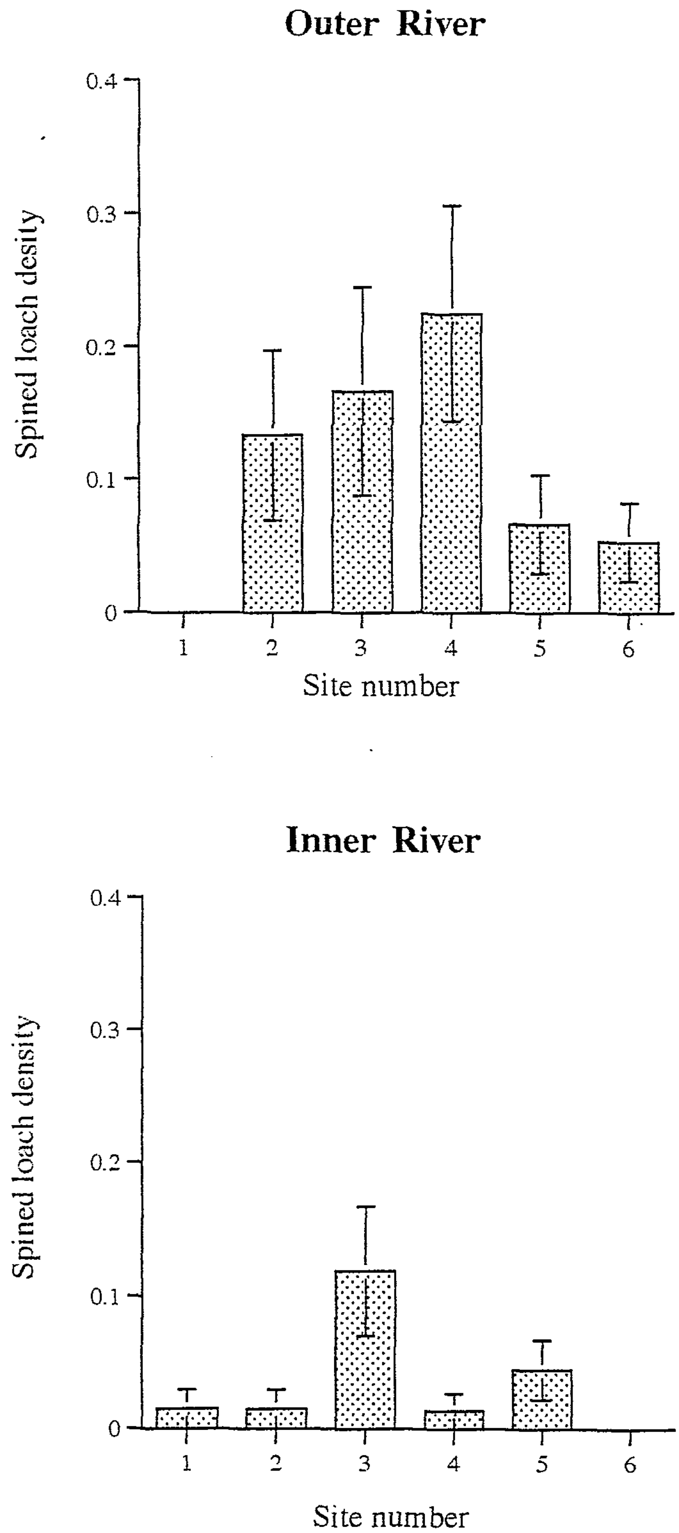
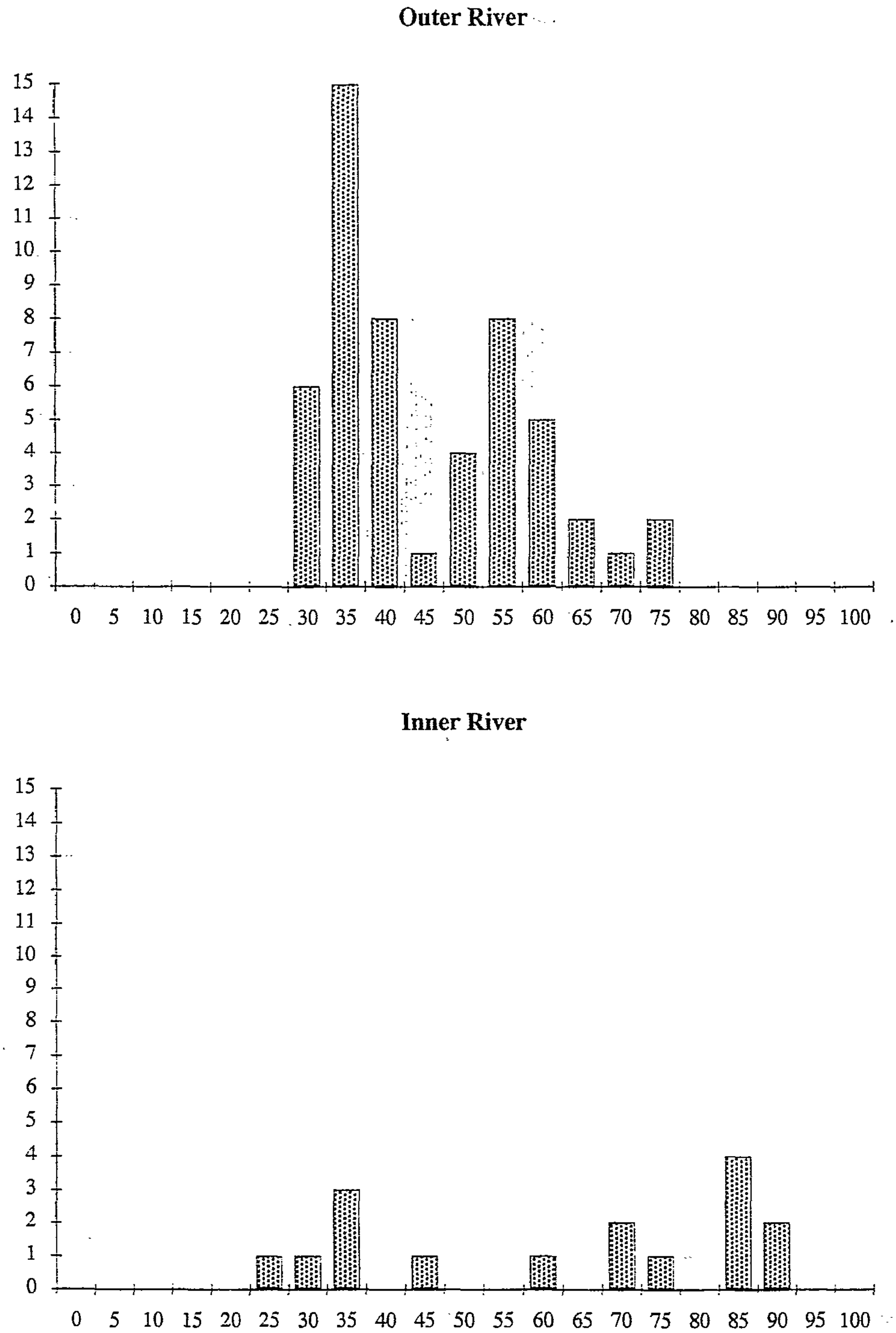


Figure 11. Length frequency histograms of all spined loach captured in the outer and inner rivers of the Ouse washes, in February 1997.



Mean length inner river = 61.3 mm
Mean length outer river = 43.7

t = 3.832, df = 66, p = 0.0003

Table 8.
Results of MANOVA on the density (n m^{-2}) of spined loach between the inner and outer rivers and between sites within a river, at the Ouse Washes.

Source of variation	*Sum of squares*	*Degrees of freedom*	*Mean squares*	*F value*	*p*
within & residual	4.00	128	0.03		
between rivers	0.18	1	0.18	5.61	0.019
sites within a river	0.56	10	0.06	1.79	0.069
model	0.86	11	0.08	2.51	0.007
total	4.86	139	0.03		

The age structure of the populations in the outer and inner rivers are quite different (Fig. 11). In the outer river, a number of size classes were represented, corresponding perhaps to three age classes; 0+ (born in 1996), 1+ (born in 1995) and 2+ (born in 1994). Underyearlings (0+) were numerically dominant. In contrast, few 0+ were present in the inner river, although a number of age classes including perhaps a 3+ age class (larger than any recorded in the outer river), were represented. Size differences in the populations were significant, with the mean size of spined loach in the outer river being smaller than that in the inner (t-test: mean outer river, 43.7 mm; mean inner river, 61.3 mm; df=66, t=3.83, $p<0.001$).

Combining all age classes there were no significant relationships between any environmental variable and spined loach density in the inner river (Fig. 12). This was probably due to the low number of spined loach present. However, in the outer river, the abundance of spined loach was significantly negatively correlated with filamentous algal cover (n=5, r^2= 0.76, $p<0.05$) (Fig. 12). There were no significant relationships between the density of 0+ spined loach in the outer river and any environmental variable, although there was a tendency for 0+ to be associated with macrophytes (r^2= 0.43) (Fig. 13).

Figure 12. Relationships between mean density of all spined loach and mean score of each environmental variable, at each site in both outer and inner rivers of the Ouse washes.

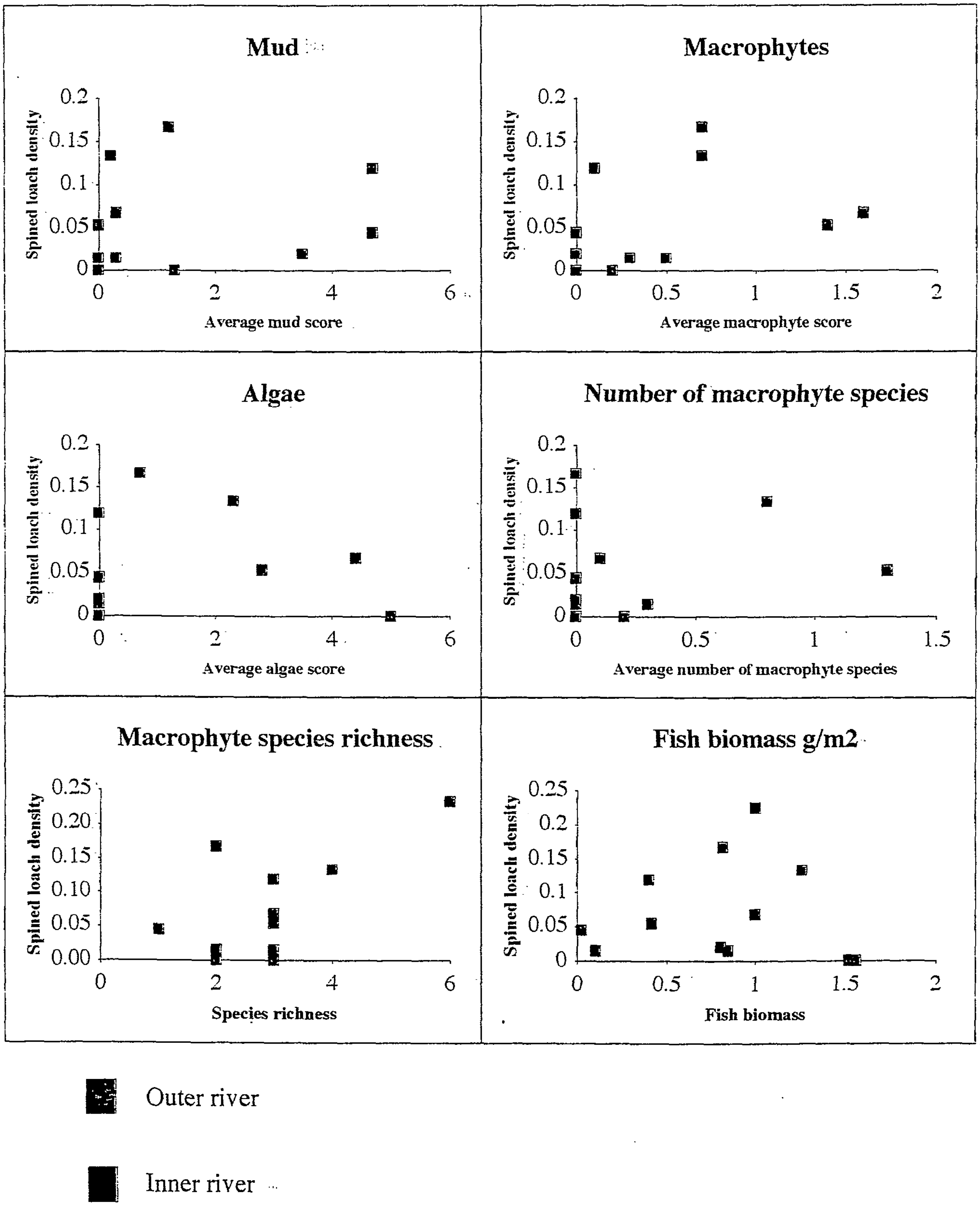


Figure 13. Relationships between mean density of all 0+ spined loach and mean score of each environmental variable, at each site in the outer river of the Ouse washes.

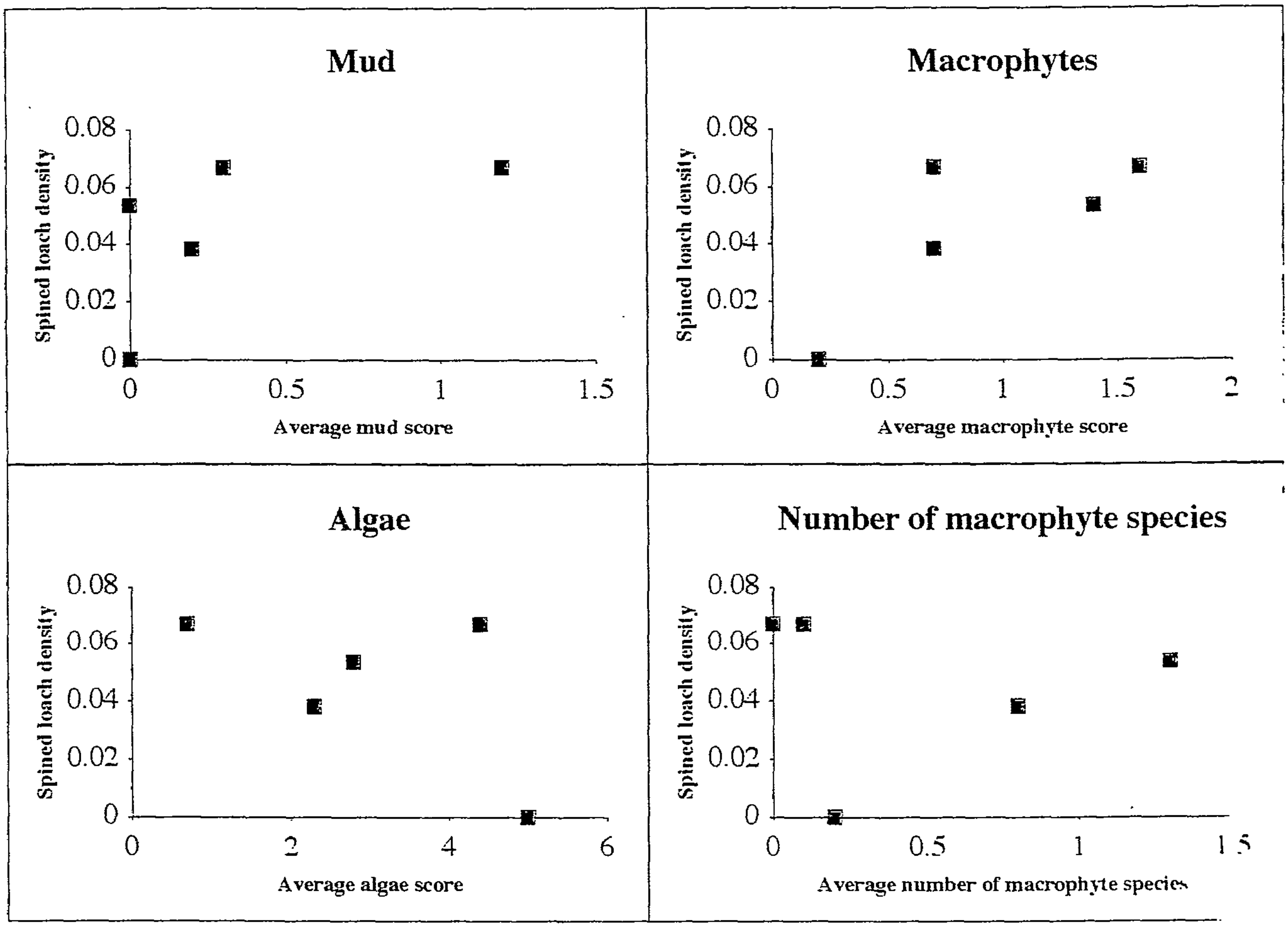


Figure 14. Point-abundance sampling (PAS) by electrofishing in the dykes at the Ouse washes

Discussion

Spined loach has two distinctive morphological/physiological features which give a clue to its habitat preferences. First, it has a relatively high gill surface area through the presence of large numbers of secondary lamellae, for the absorption of oxygen (Robotham 1978b). Like other species of loach, it probably can also take in atmospheric oxygen at the water surface for absorption through the gut. This suggests the species can tolerate relatively productive waters. By implication, this also suggests that it can tolerate enhanced levels of other potentially limiting factors such as ammonia (as opposed to non-toxic ammonium), typical of productive waters. Further, unpublished data (Habitat Geschiktheid Index model: Kleine modderkruiper (Habitat suitability index model for spined loach-Witteveen & Bos *unpubl. data*) suggests spined loach can also tolerate a wide range of pH (5-10) albeit with an optimum around 7. Overall, it is suggested that water quality criteria typically limiting fish populations (apart from salinity for which there is no information) do not appear to limit spined loach. This is supported by the observation of Agency fisheries staff that spined loach often survive conditions that lead to the mass mortality of other species (fish-kills). However, like stone loach (which is known to be able to take in atmospheric oxygen), this does not restrict it from occupying or even preferring waters of higher quality (see below).

The second feature is the specialised feeding mechanism, in which it pumps fine material through its buccal cavity and extracts food particles from it with mucous (Robotham 1982). The diet of spined loach is accordingly dominated by small items (0.2-0.75 mm), both animal; particularly chydorids, copepods (especially copepodites and nauplii) rhizopods, ostracods, rotifers; and plants principally desmids and filamentous algae (Robotham 1977). All of the important food items are associated with the surface of the substrate. The diet and feeding mechanism intuitively restricts spined loach to fine, presumably food-rich sediments, which can be directly ingested. Indeed, the field sampling and laboratory choice experiments of Robotham (1978a) (the only published reference on factors affecting the distribution of spined loach) confirmed the preference of the fish for sediments of particle size of 0.15-0.34 mm containing organic material.

However, Robotham then argued that the major factor limiting the distribution of spined loach in his study site in the Great Ouse was the presence of fine sediment. Such a sediment is typically abundant in many if not all, rivers, lakes and artificial channels within the known, effectively lowland, area of distribution of spined loach. Much heavy loading of fine sediments results from drainage and wash-out from arable land and is generally seen as undesirable and is frequently the target of river rehabilitation schemes (e.g. Perrow *et al.* 1996b). The abundance of muddy or silty sediments in many large rivers and drainage channels is also clearly at odds with its rather (apparently) patchy distribution and its rarity in such habitats (Table 2).

Experiences from the Netherlands from sampling in the Kleine beek (stream), Nordieep lake (4.5 ha), the Botshol wetland area (see Simons *et al.* 1994) and the very large lakes Wolderwijd (2700 ha) and Veluwe (3400 ha) (Witteveen & Bos *unpubl. data*), throw more light on the optimal sediment composition of spined loach. Results from all these situations suggest the species prefers a sandy substrate. Indeed, the habitat suitability index model developed for the spined loach (Habitat Geschiktheid Index model: Kleine modderkruiper-Witteveen & Bos unpubl. data) is based on this premise. Further support for this substrate preference is present in the general document on the status of the species by Lelek (1980), who also suggests that sand is preferred. It may also be no coincidence that in the data set from the Agency's Central Area of Anglian region, analysed above (although there was no significant relationship), spined loach was absent from those watercourses that did not contain any sandy substrate (Table 3).

The presence of spined loach in good numbers in the outer river of the Ouse washes and in Wicken and Burwell Lodes (Peacock 1997), does however, show that spined loach can tolerate other substrates such as silt or mud. Perhaps the key is that the sediment surface contains a good food supply, which is probably more likely if it is rich in organic material, but is still oxic. Heavy loading of organic material, with accompanying increase in BOD, ultimately produces anoxic sediments. These require specialised adaptations (e.g. many sediment-dwelling worms and fly larvae have enhanced levels of haemoglobin) and support a lower faunal and floral diversity and biomass. This is likely to disfavour spined loach and the comment of Lelek (1980) that the layer of mud should not be 'thick or coherent' seems particularly pertinent. Peacock (1997) provides some field evidence that dense accumulations of silt were avoided. However, in laboratory experiments, a thin layer of silt, was actively selected. Silt may also be unsuitable for reproduction. Spined loach appear to broadcast eggs which then sink onto whatever substrate is available (Lodi & Malacarne 1990 - see below). It is conceivable egg survival is reduced on anoxic silty sediments. This may be a further explanation of the absence of 0+ spined loach on the inner river at the Ouse washes (Fig. 13).

Workers in the Netherlands also perceive spined loach to be strongly associated with vegetation. In the waters outlined above, this included the moss (*Fontinalis antipyrecta*), the submerged macrophytes, *Chara* spp. and *Ceratophyllum demersum* and also emergent vegetation including reed (*Phragmites australis*) and reed sweet-grass (*Glyceria maxima*). The habitat suitability index model (Witteveen & Bos *unpubl. data*) also suggests that spined loach prefers, perhaps a 50-80% coverage of macrophytes with 100% cover being less suitable. This is in close agreement with the results from the study in Lake Veluwe and indicates that spined loach prefers a heterogeneous environment with macrophytes and open sediment. The creation of a such a habitat within Veluwe appeared to be linked to depth, and consequent availability of light for macrophytes. In addition, grazing by mute swans (*Cygnus olor*) appeared to create open patches within the *Chara* itself.

Spined loach may require direct access to the sediment surface to feed efficiently, and is therefore likely to avoid total macrophyte cover. Where macrophytes are patchy, it must move in open water to feed. In Lake Veluwe this occurred at night, in keeping with the general feeling that spined loach is a crepuscular feeder (Maitland & Campbell 1992). The laboratory experiments of Peacock (1997) also showed the active selection for filamentous algae or *Phragmites* stems during the day, was relaxed at night, with fish spacing themselves randomly between vegetation and open water. Robotham (1977) has however, recorded foraging activity in some populations after dawn and even up until midday. Clearly, feeding is likely to be at least as efficient during the night as it is in the day. However, spined loach is a very small species that could readily be consumed by a variety of vertebrate and even invertebrate (large beetles, dragonflies etc.) predators. These may include facultative piscivores but also omnivorous species. The fact that a small carp (< 20 cm) was observed to predate spined loach in the laboratory (*pers obs.*), illustrates that even benthivorous fish may present a considerable threat to spined loach. What may be perceived to be a general anti-predator strategy of spined loach, to bury itself in the sediment when inactive or as a direct response to disturbance (Lodi & Malacarne 1990, Maitland & Campbell 1992, Peacock 1997) is probably of little defence against such species.

Overall, it is suggested that the risk of predation is a major force in determining the pattern of distribution of spined loach. This has frequently been demonstrated for a number of other small, albeit zooplanktivorous species, whose typical response is to undertake diel migrations from cover during the day to feed in open water under the cover of darkness (e.g. Naud & Magnan, 1988, Werner & Hall 1988, Turner & Mittelbach 1990, Gliwicz & Jachner 1992). In Lake Veluwe, one would predict this to be a profitable strategy. First, the dominant piscivore in open water, the perch (*Perca fluviatilis*), is generally thought to be diurnal (Perrow & Jowitt 1996). Second, eel (*Anguilla anguilla*) although efficient at night was generally associated with the littoral vegetation and not the open water. Third, the large benthivorous fish typically avoided the *Chara* beds (Perrow & Jowitt 1996), when feeding during the day, as they allowed little or no direct access to the sediments. Although there would have been some risk from these fish in open water at night, this would, nevertheless, have been significantly lower than that experienced from a suite of potential predators during the day.

Macrophytes, with structural complexity increasing the chances of remaining hidden and increasing the possibility of escape, even if attacked (Gotceitas & Colgan 1987), may thus be particularly important as refuges against predation. Intuitively, smaller 0+ fish may be at a greater risk from a greater range of predators and this may explain the tendency for these to be associated with macrophytes both in Lake Veluwe (Table 4) and in the outer river in the Ouse washes (Fig. 15). Annual recruitment is likely to be critical to maintain populations of this short-lived species (see *Key issues of a conservation strategy for spined loach* below), and a healthy population is thus likely to be numerically dominated by 0+ (Fig. 9). The availability of suitable habitat for juvenile fish may be the critical factor for the maintenance of viable populations (Mann 1995). The presence of good populations in the outer river in the Ouse washes and the relative lack of fish in the inner river, stemming from the poor recruitment of 0+, may be directly attributable to the presence of macrophytes.

A further function of macrophytes could be that they act as a spawning substrate for spined loach (see Mann 1995). However, there is no clear evidence to support this claim. Observations of the spawning behaviour of the species in aquaria by Lodi & Malacarne (1990) suggests the eggs are laid upon whatever substrate is available.

It is also plausible that macrophytes may support an important food source for spined loach in the form of epiphytic plants, animals and organic material (aufwuchs). Whether adult or particularly juvenile spined loach are capable of browsing on this material on the living plant is unknown. However, decaying plant material on the sediment surface is likely to contribute significantly to the potential food supply, which may be exploited in the conventional way (see above).

It appears that the principal role of macrophytes, most likely to be a refuge against predation, may be fulfilled by filamentous algae under certain conditions. For example, Peacock (1997) showed that the number of spined loach captured in a slow-flowing drainage channel, Reach Lode, by using a push-net (hand trawl equipped with a handle) was positively correlated with the volume of algae recorded in the net ($r_s = 0.40$, n=92, $p<0.001$). Furthermore, Robotham (1978a) suggested that the filamentous alga, *Cladophora,* was a major 'summer habitat and probable breeding site' in the Great Ouse. However, filamentous algae was also correlated with fine sediments in the slow flowing depositional zones of the river. Which factor was the most important determinant of spined loach distribution is unclear (see below). Both these results contradict the findings in the outer river of the Ouse washes where filamentous algae was avoided (Fig. 12). Consequently, it may be that the relationship with filamentous algae depends on the availability of other habitats. Where macrophytes are available, these are preferred and where they are absent, filamentous algae may be selected. Further, whether fish associate with algae or not may be a function of its density. If it is too dense, as it was in many places on the outer river of the Ouse washes, this may deny access to the sediment and render the habitat unsuitable for spined loach.

It must also be noted that there is also a likely interaction between filamentous algae and macrophytes, with dense coverage of filamentous algae disfavouring macrophyte growth and development (Philips *et al.* 1978). Some macrophytes also produce algal-inhibiting allelopathic substances (e.g. *Chara* spp., Wium-Anderson *et al.* 1982). Macrophytes and algae may diet and mode of foraging and vulnerability to predation, being more likely to be overcome by the broad and diverse resource base in a good quality habitat. However, provided the major requirements of fine sediment, food supply and refuge from predation or disturbance are satisfied, there are few other restrictions on its distribution, such as water quality. Therefore it appears that spined loach has a potentially wide distribution but actually a rather narrow ecological niche. Therefore within community analyses, although it may appear to associate with a variety of riverine or lacustrine assemblages, it generally has a low level of similarity with any of them, as it is not responding to the same driving variables as the other species.

Conclusions

Although spined loach may tolerate silt or mud, sand seems to be preferred. This may be linked to greater food resources and better egg survival within and on, sandy as opposed to silty, substrates. This in turn may be linked to the oxygen levels within the substrate. A combination of sand with patchy, dense macrophytes, as refuges against predation, is likely to constitute the optimal habitat for spined loach. This may be found in a variety of situations from streams to large lakes, but on balance may be more abundant in natural streams and rivers. Rivers are after all, the ancestral habitat of spined loach, through which they colonised the UK (see *Distribution of spined loach* above). The potential of these habitats is illustrated by the study of Marconato & Rasoto (1989) in a small (12-15 m wide and < 30 cm deep), stream in Northern Italy. Here, the density of 0+ spined loach reached a massive 73.8 m^{-2} just after hatching. Although, the density subsequently declined rapidly to 0.6 m^{-2}, the mean density over the season (May-November) was still 2.28 ± 1.6 m^{-2}, higher than any other recorded during this study (e.g. 0.36 m^{-2} in Lake Veluwe and 0.2 m^{-2} in the Ouse washes).

More work is clearly needed on the distribution and abundance of spined loach in streams and rivers in the UK. A focus for this work may be the relative suitability of natural and modified (e.g. channelized) channels. The latter tend to have higher silt levels with little instream structure as a result of poor flow diversity (Perrow *et al.* 1996b), implying they may be generally unsuitable for spined loach. Spined loach may also be limited by flow velocity. For example, Robotham (1978a) in his study on the Great Ouse, showed spined loach selected for lower (mean of 15 cm sec^{-1}) and avoided higher (mean of 29 cm sec^{-1}) flow. However, the presence of fine sediment and filamentous algae were also negatively correlated with flow (see above), and it is unclear which was the important variable in this association. Whether or not spined loach, can tolerate higher flows, like its relative the stone loach, therefore also requires clarification.

therefore be mutually exclusive to some extent. The factors favouring the development of filamentous algae relative to macrophytes are unclear. Experiences in the Norfolk Broads, suggests that development of filamentous algae is linked to the presence of reducing nutrient-rich sediments. This is just one expression of an increase in the rate of supply of nutrients, typically termed eutrophication.

As eutrophication typically leads to the loss of macrophytes, often through increases in algal production which subsequently shade out submerged plants, eutrophication is likely to be detrimental to spined loach. Other effects may include the tendency for sediments to become black and anoxic. This will influence the food supply available to spined loach (see above) and as in the inner river and the dykes at the Ouse washes (see above and *The conservation of spined loach in the Ouse Washes cSAC* below) populations are likely to be affected.

High stocks of zooplanktivorous/ benthivorous fish are also known to reduce submerged macrophytes and promote the effects of eutrophication through various mechanisms:

- Selective predation on large-bodied Cladocera which may in turn reduce grazing pressure on phytoplankton populations causing turbid water and shading out of submerged macrophytes (Phillips *et al.* 1996).
- The indirect increase in phosphorus available to phytoplankton through enhanced release from the sediments as a result of disturbance from foraging fish (Tatrai *et al.* 1990).
- The direct increase in phosphorus available to phytoplankton through egestion (Tatrai & Istvánovics 1986).

As well as presenting a direct threat to spined loach (see above), the vigorous feeding action of benthivorous fish, digging deep into the sediment may disturb resting loach and also change the nature of the substrate and thus the benthic community (Breukelaar *et al.* 1994, Tatrai *et al.* 1994). This may adversely affect the density and biomass of the small animals and plants associated with the surface layers of the mud and vegetation. Any impact will increase in accordance with the biomass of the benthivore population. This may be artificially enhanced by stocking for angling purposes. Some supportive evidence of this hypothesis is provided by the Central area data set. Here, sites with spined loach had a significantly lower density of the numerically dominant roach, than those without (t-test, $n=315$ & 30, $t=2.01$, $p<0.05$). Moreover, within this data set, spined loach was also associated with more diverse fish communities (t-test, $n=315$ & 30, $t=2.44$, $p<0.05$). A similar result was also found in the Ouse washes. This is generally indicative of an association with higher quality water and structurally diverse habitat. This may result from the constraints imposed upon spined loach by a specialised

C. Key issues of a conservation strategy for spined loach

Background information & methods

Specific information on the distribution of spined loach within the UK (see *Distribution of spined loach in the UK* above), within the framework of a general understanding of its ecology- including habitat preferences (see *Habitat preferences of spined loach* above), population dynamics and genetics allows the key issues of any conservation strategy to be determined. Material used in the section was gathered during the general search for information (see *General information gathering* above).

Results & Discussion

Implications of the taxonomic status of spined loach in the UK

Spined loach is known to occur in a number of races or subspecies, typically referred to as the *Cobitis taenia* complex (Saitoh 1990). In Japan, there is good evidence through sarcoplasmic protein banding that one such subspecies *C. taenia taenia* originates from a hybrid of *C. taenia striata* and a related species *C. biwae* (Sezaki *et al.* 1994). There is also sound evidence that differently-sized sympatric races or forms of spined loach are reproductively isolated, with different spawning sites and general habitat preferences i.e. small irrigation creeks for the small form and the main stream and tributaries for the middle form (Saitoh 1990). Further, Saitoh & Aizawa (1987) showed seven races tended to occupy specific geographic ranges and where sympatric, hybridisation was not effective.

Within Europe, Lelek (1980) recognised eight subspecies (Table 9). There is some debate, however, as to whether such differentiation is valid. For example, Marconato & Rasotto (1989), working in a small river in northern Italy, illustrated that males within a population may exhibit great differences in colour pattern within a season with *puta*, *intermedia* and *bilineata* forms being recognised (Marconato & Rasotto 1989). *Bilineata* appears to be the livery adopted by mature males during the breeding season. Lodi & Malacarne (1990) showed that both forms may exist within the reproductive season and that some males maintain *puta* colouration even when sexually active, although *puta* males show considerably less reproductive activity and potentially less reproductive success than *bilineata*.

Table 9.
Possible subspecies of the spined loach in Europe (after Lelek 1980).

Subspecies	*Distribution*	*Authority*
C.t. bilineata	northern Italy	Canestrini 1866
C.t. dalmatina	River Cetina, Dalmatia	Karaman 1928
C.t. haasi	eastern Spain	Klausewitz 1952
C.t. meridionalis	Lake Prespa	Karaman 1924
C.t. paludicola	Tejo basin and northern Africa	F. de Beun 1930
C.t. puta	Po, Brenta & Dese basins	Cantoni 1882
C.t. strumicae	Struma basin	Karaman 1955
C.t. zanandreai	Campania, Italy	Caricchioli 1965

In the UK, populations of spined loach have been isolated from those in continental Europe for around 10 000 years, since the end of the last ice age and the severing of the land bridge. Further, although there is potential for mixing of populations between the Trent & Witham, neither catchment is connected to the Great Ouse system. Mixing of these populations is not likely to have occurred through typical agents such as stocking by anglers (see *Distribution of spined loach in the UK* above). Thus, it is plausible that the UK contains a number of endemic forms (with characteristic morphological differences analogous to the races of brown trout-see Maitland & Campbell 1992), subspecies or even full species of 'spined loach' (see Robotham 1981). Any of these may exhibit different habitat requirements (Saitoh 1990). Indeed, this may explain some of the disparities in habitat preferences shown by the 'species' in different types of waterbody (see *Habitat preferences of spined loach* above).

Without detailed research on different populations, including molecular work such as chromosome banding, their taxonomic status will remain unclear. This will demand further resources including finances and time. The pragmatic approach may thus be to establish SAC's in each of the Trent and Great Ouse catchments to safeguard potentially different spined loach populations. Even if subsequent work shows the fish in these populations to be of the same taxonomic status, the setting up of at least two SAC's in each is likely to meet the principal objective of Annex II of the EC Directive, to ensure the conservation status of the species through conservation of viable populations.

Conservation implications of life history traits

The lifespan of spined loach rarely exceeds three or four years (Robotham 1981, Marconato & Rasotto 1989). Females tend to live longer and grow faster than males, reaching around 130 mm considerably larger than males, which barely reach 70 mm. Both males and females tend to mature in their 1+ year (Robotham 1981, Marconato & Rasotto 1989). For males this may occur at only 40 mm in length. The short lifespan of spined loach, means that populations are typically dominated by young fish (see Fig. 9 & Fig. 11 for examples from Lake Veluwe and the outer river at the Ouse washes, respectively). Recruitment in any one year is thus essential to maintain the population. Factors limiting recruitment typically include:

- A limited adult stock or inappropriate sex ratio.
- Poor spawning conditions (water temperature, various aspects of water quality, lack of suitable substrate).
- Poor egg survival.
- Poor larval and juvenile survival (through predation, food limitation etc.).

The spawning behaviour of spined loach is described by Lodi & Malacarne (1990). There is some evidence that spined loach undergo a simple courtship as a prelude to mating. This may involve just one male and one female, as opposed to the group spawning observed in many other fish species. Unequal sex ratios with a female bias may thus limit recruitment to some extent. This could occur through selective predation upon the smaller male fish. During courtship, the pair participate in synchronous swimming, with the male using his sub-ocular spine as a tactile stimulant. The organ of Canestrini, a blade-like bony appendage issuing from the base of the second ray of the pectoral fin, found only on males, may also have a role in courtship, but this is unclear as yet. During the final stages of courtship, the male coils laterally around the females body and squeezes. A batch of around 50 eggs is extruded and fertilised as the females swims or wriggles along the bottom. This sequence may be repeated 4 or 5 times a day. The total number of eggs laid during the observations of Lodi & Malacarne (1990), was around 100-400. In contrast, Marconato & Rasotto (1989) estimated a 90 mm female could produce around 1000 or so eggs. As the pattern of gonad development mirrors that of other fractional spawners, it is likely that during the course of spawning season, a female may produce far more eggs than first appears. The ability to mate several times during the course of an extended mating season (May to July with a peak in June in Italy - Marconato & Rasotto 1989), probably with different partners, decreases the chances of failure due to adverse conditions. It also allows individual females to maximise their reproductive output within a short lifespan.

The reproductive strategy adopted by spined loach gives the impression that the factors affecting breeding up to the point of laying eggs are unlikely to limit the potential for recruitment. It is considered to be more likely that the bottleneck for recruitment is related to egg or larval survival (see Mann 1995). Unfortunately, there is no information available on the factors affecting either at the current time. It is clear, however, from the study of Marconato & Rasotto (1989) that losses following hatching may be massive. Predation is suggested to be a major influence (see *Habitat preferences of spined loach* above) and the abundance of refuges such as macrophytes may be critical in determining the strength of recruitment and thus the viability of the population in the long term.

Conclusions

The taxonomic status of the spined loach in the UK is unclear. The lengthy timescale of reproductive isolation both from the source stock in Continental Europe and also between stocks in different catchments within the UK, results in the possibility of endemic races, subspecies or even species. SAC selection must take this into account. However, in the absence of detailed information on genotypes, required to make a considered decision, the pragmatic option is to set up SAC's within at least the Great Ouse and Trent catchments. Moreover, as the connection between the Trent and Witham system is limited (though the artificial channel the Fossdyke) and thus mixing of populations may be limited, it may also be prudent to also establish at least one SAC within the Witham.

The conservation of viable populations both in protected areas and in all waterways it occurs, appears challenging at first sight. This is because spined loach is thought to be highly vulnerable to anthropogenic influences in any one season. This results from its dependence on annual recruitment and the constraints of a specialised feeding mechanism, specific habitat requirements and vulnerability to predation (see *Habitat preferences of spined loach* above). Factors such as habitat changes resulting from management (see *Preliminary management guidelines* below) and perhaps stocking of other fish (potential competitors or predators), particularly where they impact upon larval/juvenile survival (see above), may reduce the viability of the population, ultimately leading to local extinction. Spined loach may thus be something of an indicator species of habitat change (like other 'minor' fish species), being among the first to decline as the quality of the habitat changes.

Whether or not spined loach is capable of quickly colonising areas where any formerly limiting factor has been removed, is open to question. However, the fact that spined loach has successfully colonised several gravel pits associated with rivers and also crossed catchments via a water transfer scheme (see *Distribution of spined loach* above) suggests it may be.

With more detail on the specific habitat requirements of spined loach, especially juvenile/larval fish, it is possible that aquatic systems may be managed to favour spined loach (see *Preliminary management guidelines* below). Moreover, ecological improvement through more general restoration/rehabilitation schemes, especially in streams and rivers, may also have considerable direct benefit. Where spined loach are able to colonise and conditions are favourable, the r-type reproductive strategy of spined loach may lead to rapid population expansion. This should be exploited wherever possible, within the current range of spined loach. Where there are restrictions to natural colonisation, (as a result of physical barriers such as weirs or ecological barriers such as a lack of suitable habitat between the source and area to be colonised) introduction of individuals of the specific genotype may be considered.

D. The conservation of spined loach in the Ouse Washes cSAC

Background information

The Ouse washes comprise a 1914 ha area of lowland wet grassland (the largest example in the UK). These are sandwiched between the Hundred Foot river to the east, and the Old Bedford River/River Delph and the Counterdrain/Old Bedford River, separated from each other by the Middle Level Barrier Bank, to the west. As stated earlier (see *Habitat preferences of spined loach* above), for ease of reference and following the nomenclature used by the RSPB, the Old Bedford/Delph will be referred to the inner river and the Counterdrain/Old Bedford River, the outer river, throughout this document. The washes are of huge conservation importance, as recognised under SSSI, Ramsar site and SPA status. The site is noted for wintering wildfowl and breeding waders, although several nationally rare/uncommon plants are also represented. The area is drained by 140 km of ditches which form an important habitat for aquatic plants and animals. Floral and invertebrate diversity is high in places, partly dependent on substrate type and more importantly, nutrient loading (Cadbury *et al.* 1993-see below). The dykes also act as wet fences to control the movement of livestock. The latter maintain the grass dominance of the site, which would otherwise quickly become dominated by *Glyceria maxima* and willows (N. Lambert, RSPB, *pers comm.*).

The current Ouse washes cSAC incorporates an approximately 19 km length of the outer and inner rivers (Fig.'s 4 & 5). The likely effectiveness of the SAC was however, compromised by the lack of knowledge of the species in this area and of the effects of the intensive management regime in this largely artificial system. Records of spined loach were limited to a report of a large (but undetermined) number of spined loach encountered in the outer river during a fish rescue operation (R. Handford, Agency, *pers comm.*), a single site record (density of <0.001 n m^{-2} -Agency *unpubl. data*) from the same (Old Bedford River at that point) and a single individual accidentally captured by site wardens during collection of material for a demonstration of animal and plant life in the washes. There is a further unconfirmed sighting of what may have been a spined loach by a RSPB researcher (G. Tyler, RSPB, *pers comm.*) from the inner river near Sutton Gault (the Old Bedford River). There are no known records from the main, Hundred Foot (New Bedford) River or the system of ditches, both of which are currently outside the SAC. As the latter particularly are an integral component of the freshwater resource on the washes, it was also desirable to ascertain whether the ditch habitat is important and if there was a case to incorporate the ditches into the SAC (see Mann 1995). The ditches are however subject to dredging ('slubbing') work on a regular basis in order to increase the efficiency of water management across the washes. Information on whether this limited their value for spined loach, or not, was also desirable.

The principal question to be answered is whether the Ouse washes justified its proposed designation as a SAC for spined loach. Further, key issues affecting the conservation of viable populations of spined loach at the site needed to be identified. This also needed to be set in the more general context of conserving and promoting populations of spined loach in the UK.

Methods

Distribution of spined loach within the Ouse washes

Prior to sampling the efficacy of a number of sampling methods was assessed (see *Further monitoring and research requirements* below). Following this, PAS by electrofishing (see *Habitat relationships in Lake Veluwe* above) was selected to sample the dykes and the hand trawl (see *Habitat preferences in the Ouse Washes* above) was selected to sample the inner and outer rivers. Sampling was conducted from 17th - 25th February 1997.

To cover as large an area as possible, whilst providing sufficient replication within a site to have confidence in the resulting estimate, ten trawl samples were taken at each 6 sites in both outer and inner rivers. Sites were spaced at approximately 3 km intervals along the length of the washes, controlled by the RSPB from Earith in the south-west to Welney in the north-east (Fig. 4) (TL405773, TL433807, TL447828, TL465853, TL49887 and TL525933 respectively). Trawls were taken in the outer river, the equipment moved over the Middle Level barrier bank (Fig. 3) and then used in the inner river. The use of the hand trawl is outlined above (see *Habitat preferences in the Ouse Washes*).

The presence of abundant vegetation and the narrow (2-3 m), shallow (around 1m) nature of the dykes prevented the use of the trawl and PAS by electrofishing was used instead (Fig. 14). The strategy was to sample sections of a number of dykes, over approximately a 1 km area. Of the 10 dykes selected: 3 had been dredged the previous year (1996), 4 dredged 2/3 years ago (2 each in 1994 and 1995) and 3 dredged more than 10 years ago (1 in 1985 and 2 in 1983). This also allowed the impact of the frequency of dredging to be investigated. Twenty points were sampled at 5 m intervals within a 100 m section by either sampling from the bank with a 100 m cable attached to bank/boat mounted gear (Fig. 5), or, where the channel was too wide or deep, fishing directly from the boat (3m dinghy) (for full details of methodology see *Habitat relationships in Lake Veluwe*). The boat was also used to move equipment and personnel between dykes.

Factors affecting the conservation value of the Ouse Washes cSAC

To provide general information, a site visit to the Ouse Washes RSPB reserve, which form a large proportion (c. 800 ha) of the washes area associated with the cSAC, was undertaken on 21st January 1997. This involved in depth discussions with Neil Lambert (warden) and Cliff Carson (senior warden) on the management of the system and the factors affecting its conservation value. Additional background information was provided by the in-depth report by Cadbury *et al.* (1993) on the dyke flora.

Results

Distribution of spined loach within the Ouse washes

Spined loach was recorded at all but one site in each river (TL405773 in the outer river and TL525933 in the inner river) (Fig. 4) along the length of the Washes from Earith in the south-west to Welney in the north-east, indicating it is has a wide distribution. However, it occurred at significantly higher density in the outer compared to the inner river (Table 8), principally as a result of the abundance of young (0+ and perhaps 1+) in one and not the other (Fig. 11). Although MANOVA indicated no significant difference between the densities between sites in either river (Table 8), it does appear that in the more suitable, outer river (apart from at site 1), a higher density (i.e. the 'best' populations) of spined loach was present above Welches Dam (sites 1-4) than below it.

In contrast to the two major drainage channels, no spined loach were captured in the dykes. Consequently, any impact of the frequency of dredging upon spined loach populations within the dyke system could not be determined as no spined loach were captured. The fish community was dominated by ten-spined stickleback which had a rather patchy distribution, with no obvious relationship to the frequency of management (Table 10). A total of only 5 species were captured, and no more than 2 fish species were captured in any one section of dyke.

Table 10.
Mean (± 1 S.E.) density (n m^{-2}) of individual fish species in dykes subject to different frequencies of dredging.

Category	*Year dredged*	*Roach*	*Dace*	*Pike*	*Ten-spined stickleback*	*Eel*
Annual	1996	0.03 ± 0.03	0.03 ± 0.03			
	1996			0.03 ± 0.03		
	1996				0.07 ± 0.05	
2/3 years	1994				0.47 ± 0.15	
	1994					
	1995					
	1995				0.03 ± 0.03	
>10 years	1983				0.27 ± 0.11	
	1983				0.13 ± 0.08	0.03 ± 0.03
	1985					

Discussion

Although spined loach was widely distributed within the two rivers comprising the cSAC, it was more abundant in the outer river compared to the inner. In the outer river, there is evidence to suggest that the population density is broadly comparable with that recorded in the few other known studies. To illustrate, the maximum density recorded in the outer river in February, after winter mortality and thus at a potential low point, was > 0.2 m^{-2}. This is higher than that recorded in June in Lake Veluwe, and similar to the maximum value of 0.36 m^{-2} recorded in one habitat in September (Fig. 8). Even in the study of Marconato & Rasotto (1989) in a small river in northern Italy, after the spring recruitment of 0+ with a massive density of 73.8 m^{-2}, the population was only 0.6 m^{-2} at the end of the growing season.

In contrast, the density in the inner river only exceeded 0.1 m^{-2} at one site. Moreover, only in the outer river, does the relatively high abundance of 0+, suggest that the population is self-sustaining (see *Key issues of a conservation strategy for spined loach*) Overall, it is suggested that the Ouse Washes cSAC would be likely to meet the objective of conserving a viable population of spined loach within one of its population centres (see *Distribution of spined loach in the UK* above). However, the low density in the inner river as a whole and at some sites in the outer river are causes for concern. The apparent absence of spined loach in the dykes, a major part of the freshwater resource at the site, which considerably limits the scope for their inclusion in the cSAC, is also disturbing. Clearly steps must be taken to ensure that the cSAC continues to meet its objective through the maintenance and if possible, improvement, of the current situation. To begin to identify the critical issues affecting the suitability of the system for spined loach, it is necessary to understand the water control of this relatively complex entirely regulated system.

In simple terms (see Cadbury *et al.* 1993), the Hundred Foot river takes the flow of the system from the Bedford Ouse, past the washes, to Denver Sluice and ultimately to the Wash. When it reaches a particular level, water is diverted via the sluice at Earith. As this overtops, the washes begin to fill. As the levels vary considerably within the washes, this movement of water is relatively complex, but in general terms the washes in the Welney area (site of the RSPB and Wildfowl and Wetlands Trust (WWT) flood last and drain first, and all washes fill from the bottom third first. Moreover, the outer river (counterdrain) receives water from adjacent arable land. When the levels within this are high, water is pumped into the inner river by the pumping station at Welches Dam. A sluice gate on the inner river downstream at Welney is closed prior to pumping and is reopened as the levels rise. Water is then allowed downstream to Denver Sluice. This sequence of events usually occurs in winter. However, the incidence of flooding in spring and summer has increased since 1974 and in the last few years has increased to such an extent as to create problems for nesting waders (C. Carson, RSPB, *pers comm.*). The reasons for this increase are largely unknown but may be linked to changes in operational procedure and channel capacity (through silting) of the river below Denver sluice. All of this water level control is undertaken by the Environment Agency flood defence engineers. There is some current concern that with changes in water level control, the levels of salinity will increase (R. Hall, EN, *pers comm.*), although in the absence of any available information (see *Habitat preferences of spined loach* above) it is not possible to predict if any detrimental impact is likely should this occur.

The outer river is thus virtually isolated from the inner river and its water supply which in turn is related to the Hundred Foot river and the dykes within the washes. Water largely originates from run-off from arable land, during the winter months. Therefore, in the summer the outer river is effectively a 'linear lake' (C. Carson, RSPB, *pers comm.*). In contrast, inner river is ultimately connected, although sporadically, via the dykes to the Hundred Foot river. The movements of any fish, particularly small species such as spined loach are therefore unrestricted. This is indicated by the presence of dace (*Leuciscus leuciscus*), a riverine species, within the dyke system thought to have most likely originated (as may have the roach, *Rutilus rutilus*, captured in the same dyke) from the Hundred Foot river. Moreover, as the systems are connected, it is plausible that the same factors are responsible for the apparent absence of spined loach in the dykes and the low density in the inner river.

Samples taken on site (N. Lambert, RSPB, *pers comm.*) indicate that the nutrient levels within the Hundred Foot river place it into the hypertrophic category. Evidence that the nutrient loading, to the system has increased in recent years is provided by the detailed surveys of the dyke flora conducted in 1978 and 1992 by Cadbury *et al.* (1993). During that period, the botanical richness of the site declined dramatically with a notable increase in nutrient tolerant species such as *Ceratophyllum demersum* and *Lemna* spp. These aggressive species may be responsible for the poor species richness in many dykes. Six species have declined (including *Chara vulgaris*) and four (including the pondweeds *Potamogeton berchtoldii* & *P. compressus* and *Zannichellia palustris*) are thought to have become extinct (Cadbury *et al.* 1993). A heavy loading of fine sediments is also likely to have accompanied the increase in nutrient levels. The presence of peat or even marl based sediments in many dykes in the past has now been replaced by a thick layer of black, anoxic silt, which covers the bed of both the dykes and the inner river. In the shallower dykes, poor water quality with low oxygen and high ammonia, is likely to be the principal cause of the low diversity and biomass of the fish community. Circumstantial evidence that water quality may drop below the levels required to support fish was illustrated by the presence of a dead stickleback and a dead pike in two of the dykes sampled.

The loss of macrophytes and changes to the nature of the sediment compromising its ability to support a suitable food resource, through eutrophication, is argued to be ultimately responsible for the dearth of spined loach in the waters of the Ouse washes, excepting the outer river. The isolation of the outer river from the general sources of nutrients to the washes, through the Hundred Foot river and the inner river once water is diverted to it via the Earith sluice (see above) appears to have allowed the maintenance of a peaty sediment and macrophytes and thus a good population of spined loach. Run-off from agricultural land (see above) is however, by its very nature, nutrient-rich. Although this does not appear to have reduced the macrophyte population to any significant degree through eutrophication as yet, this process is insidious and once nutrient levels reach a critical threshold the system may 'switch' and become dominated by planktonic algae. Further, for a given level of nutrient loading shallow water bodies like the outer river may exist as alternative stable states, either dominated by submerged macrophytes or planktonic algae (Irvine *et al.* 1989, Scheffer *et al.* 1993). The switch from one state to the other may be instigated by changes in fish community structure (Bronmark & Weisner 1992).

Winter or summer kill of zooplanktivorous or benthivorous species may cause or perpetuate a clear water state dominated by macrophytes through the mechanisms outlined earlier (see *Habitat preferences of spined loach* above). There is evidence of a least one major fish kill in the outer river in the recent past as a result of a pollution incident (R. Handford, Agency, *pers comm.*). Regular events of this type may thus help maintain clear water even in the face of continued nutrient loading in the outer river and ultimately help conserve spined loach populations.

Conclusions

Spined loach is widely distributed in the cSAC (outer and inner rivers). Although more work is clearly needed to establish what constitutes a 'good and viable' or 'representative' population (see *Further monitoring and research requirements* below), through sampling other populations in a range of waterbodies in the UK, it appears that the Ouse Washes cSAC would meet its objective of conserving a viable population of spined loach within one of its population centres (see *Distribution of spined loach* above). There are however considerable differences in the current ability of outer and inner rivers to support spined loach, with the outer river supporting a more age-structured and dense population. This is related to the presence of macrophytes and a suitable sediment. There is concern that continued nutrient loading and the resultant loss of macrophytes and the loading of fine anoxic sediments will further compromise the ability of the site to support spined loach and ultimately jeopardise its conservation value. Future work to safeguard and if possible, improve the status of the cSAC and the site as a whole should include:

- Monitoring of water quality; particularly in the outer river, but also in the inner river, dykes and Hundred Foot river.
- If the nutrient levels are either increasing or are currently at a high enough level to mean there is risk of reversion to a turbid, algal dominated state in the outer river, the source should be identified and appropriate action taken. This may involve reduction of run-off of nutrient rich water, perhaps through changes in catchment land use with reversion to grassland rather than arable crops.
- If nutrient levels are currently unacceptably high in the wider system, including the inner river, ditches and Hundred Foot river, long term action to reduce nutrient loading (e.g. installation of phosphate strippers at source in sewage works upstream) should be instigated.

Management of the outer river during routine maintenance operation is another major issue. There is some evidence from the dykes in the washes that dredging tends to favour the development of more speciose macrophyte communities after 2/3 years (Cadbury *et al.* 1993). Whether or not this applies to larger, less silty channels such as the outer river is unknown. If it does, dredging may favour spined loach in the medium term.

In the short term, however, dredging may be detrimental through:

- Potential removal of spined loach buried in the sediments
- Changes to the nature of the sediment and its associated microfauna and flora (Pearson & Jones 1975)
- Promotion of dense filamentous algal mats denying spined loach access to the sediment;

As the presence of high numbers of benthivorous/zooplanktivorous fish may directly and indirectly impact the ability of shallow systems to support macrophytes and thus spined loach, any stocking of fish into the outer river, even after fish-kill, should be carefully considered. Given the statutory duties of the Agency to both angling and conservation interests, perhaps a pragmatic solution is to only undertake the introduction of coarse fish, where absolutely necessary, below Welches Dam. This would protect the greater population of spined loach in the river upstream of this point (Fig. 4).

E. Preliminary management guidelines

Background information

The dependence of spined loach populations upon annual recruitment combined with specific habitat requirements makes them vulnerable to habitat change (see *Key issues of a conservation strategy for spined loach* above). The multi-functional aspect of many waterbodies, within the range of spined loach (see *Distribution of spined loach in the UK* above) such as flood control, water supply etc., necessitates a programme of routine maintenance such as dredging and control of both submerged and emergent plants, which in turn, may impact upon spined loach populations.

There is some circumstantial evidence to support this contention. For example, of the 24 generally intensively managed waterways, in which spined loach was recorded from Central Area of Anglian region, only 3 (Upper Great Ouse, River Nar and the River Wissey) contained spined loach in more than one (and never more than 2) surveys (between 2-7 were conducted on each waterway between 1979 and 1996). This suggests spined loach populations may wax and wane, colonising new areas as they become suitable, and then disappearing as they change for the worse, perhaps following intensive management.

Unfortunately, an attempt to gather more specific information on one form of management, dredging, was confounded by the absence of spined loach in the samples taken from the dyke system in the Ouse washes (see *Distribution of spined loach within the Ouse washes* above). In the outer river however, there was some evidence that dredging may have a indirect impact on spined loach. Many sections which had been recently dredged (with vegetation and substrate piled on the bank) had become dominated by filamentous algae, with a consequent impact on the density of spined loach (see *Habitat preferences in the Ouse washes* above).

Consequently, at this stage, any management guidelines can only be preliminary. These are based on rather general information on the ecology and life history traits of spined loach. Moreover, a precautionary, inclusive, approach has been adopted to reduce the possibility of potential areas of relevance being excluded. Both general and more specific guidelines are provided below.

Results & Discussion

General management guidelines

The following guidelines stem from the optimal habitat for spined loach being a sandy substrate with patchy, although dense, macrophytes. Silt or muddy substrates are tolerated although these should not be thick or coherent. Favourable habitat may be found in a variety of waterbodies, although it may be commonplace in natural streams and rivers. Spined loach are therefore representative of diverse habitats, where they are part of a diverse fish fauna. Spined loach are thus not typically associated with fish assemblages dominated by a few species, generally omnivorous coarse fish.

All of the following apply to any system containing important populations of spined loach, as well as SAC's:

- Eutrophication leading to the loss of submerged macrophytes in any water body in which spined loach is present is likely to adversely affect the population. Action should therefore be taken to significantly reduce nutrient loading.

- Excessive loading of fine sediments is likely to be detrimental to populations of submerged macrophytes and benthic flora and fauna and ultimately spined loach Action should therefore be taken to significantly reduce any sediment loading.

- Management causing a significant reduction in habitat diversity e.g. channelization (widening, straightening, deepening, removal of woody debris and other channel features), of river and stream channels is likely to impact upon spined loach. Action should therefore be taken to limit or even cease such intensive management either in capital schemes or during routine maintenance programmes.

- A high biomass of omnivorous fish may change the nature of the sediment and deplete its invertebrate resources, disfavour populations of submerged macrophytes (through a variety of mechanisms- see *Habitat preferences of spined loach* above) and may even present a direct predation risk to spined loach. Action should therefore be taken to a) regulate excess stocking of species such as roach and bream (*Abramis brama*) b) prevent any introductions of further species not native to the catchment (e.g. carp) and limit any unregulated manipulations (e.g. removal of pike, which may help suppress the development of high biomasses of coarse fish and indirectly promote the domination of macrophytes-see above).

Any of the actions recommended above may also be used to promote the suitability of a waterbody for spined loach. Furthermore, tackling any of the broad issues cited may form the focus of more general enhancement/rehabilitation/restoration schemes currently adopted by a variety of organisations. Of direct relevance to the Agency, the rehabilitation of streams and rivers, currently gathering pace in the UK (see Perrow & Wightman 1993, Driver 1997) may have the spin-off benefit of promoting spined loach populations even where these do not form the target of the scheme in question.

Specific management guidelines

Specific information on the effects of various management practices used by the Environment Agency and other organisations, such as dredging, weed-cutting and channel profiling, on populations of spined loach will be required before concise operational guidelines can be developed. This will be critical for those organisations involved in routine maintenance work. For example, the flood defence function of the Agency. Such information is likely to be an essential component of the strategy to conserve and promote spined loach populations (see *Further research and monitoring requirements* below).

The following constitutes a preliminary attempt to construct specific operational guidelines:

- Adopt sensitive weed-cutting. For example, cutting down just the centre, or perhaps one side, of the channel, to create a heterogeneous habitat suitable for spined loach.

- Consider longer term management of macrophytes, through tree planting where appropriate, to create shade along one bank.

- Although some dredging may also promote a heterogeneous habitat, this should not be undertaken across the whole width of the channel as the short term consequences are likely to be considerable. Dredging in the centre of the channel, leaving undisturbed refuge areas, may be acceptable.

- The frequency of dredging should not be more than once every 4 years to enable populations of spined loach to recover and achieve maximum lifespan. The frequency of dredging may however be increased to every 2/3 years where a rotational regime is adopted, again always leaving suitable refuge areas.

F. Further monitoring and research requirements

Background information

The distribution of spined loach is centred on the Great Ouse and Trent catchments, the latter of which includes the Witham and connected waterways (see *Distribution of spined loach in the UK* above). However, records within each system are generally rather patchy. But is the result of inefficient sampling methods or that spined loach have specific habitat requirements? To clarify the distribution and status of spined loach, in order to ensure populations are conserved and promoted, there is a clear need to assess the efficiency of standard and more specific sampling methods. The most appropriate methods may then be used to facilitate the selection of further SAC's within each of these catchments, which forms the basis of the conservation strategy for spined loach (see *Key issues of the conservation strategy for spined loach* above).

Caveats in the knowledge of spined loach include the habitat requirements of the species, but especially juveniles and also a greater understanding of population dynamics. Combined with information on the impact of habitat management upon populations, management prescriptions for spined loach may be developed. This will be a critical aspect of the conservation and management of spined loach populations.

Methods

Assessment of sampling methods

A preliminary assessment of the efficiency of different sampling methods was conducted in the outer river on 17th-18th February 1997, prior to the survey of the distribution of the species within the system (see *The conservation of spined loach in the Ouse Washes cSAC* above).

The methods used were:

- Standard seine netting as typically used by the Agency fisheries teams. Two nets were used: a) a 50 m long x 5 m deep net with 25 mm mesh in the wings and 5 mm mesh in the bag b) a 50 m long x 2.5 m deep with 5 mm mesh throughout.

- PAS by electrofishing which had previously been used to great effect in sampling spined loach in Lake Veluwe (see *Habitat preferences of spined loach* above).

- A modified push net (designed for catching shrimps) used in the manner of a hand trawl. (see *Habitat preferences in the Ouse Washes* , above).

- Bottle traps, which had successfully caught spined loach during sampling for bitterling (*Rhodeus sericeus*) used at Wicken Fen by Dr John Reynolds *et al.* at UEA.

A total of 8 seine net hauls (5 with the shallower fine mesh net and 3 with the deep net), 100 point samples and 20 trawls were taken. Twenty bottle traps (standard 1.5 litre plastic bottles cut in half with the neck inverted and pushed inside the lower half, creating a funnel) were set at intervals of about 20 m at various distances from the bank. These were marked with floats and left for 24 hours before being collected. Density estimates of all fish species, as well as spined loach were calculated in the standard way for each quantitative method (see *Habitat relationships in Lake Veluwe* above for PAS & *Habitat preferences in the Ouse washes* for the hand trawl). For seine nets this was derived by sampling a known area with a net of known length set in a circular fashion. Catches for the qualitative bottle traps were expressed as CPUE.

Results & Discussion

Assessment of sampling methods

No fish were captured by the bottle traps, probably as a result of the low water temperature inhibiting fish movement and the possibility of fish encountering and entering traps. The different quantitative sampling methods generated very different estimates of virtually all fish species.

Seine netting was clearly adept at sampling the species important to the fishery such as roach, bream , perch, rudd and pike. By far the highest estimate of density was obtained by this method (Table 11). A large size range of fish from roach of 30 mm to pike of >500 mm was also captured. However, even though a proportionally large area was sampled by this method (nearly 1600 m^{-2}), no spined loach were captured. It is thought that even a 5 mm mesh may be too large to sample spined loach effectively and their capture by nets relies on them becoming entangled in macrophytes, algae or the substrate retained by the net. Few macrophytes were actually retained by the net during the current sampling, although they were present. Macrophytes appeared to become flattened against the rather hard peaty substrate with the net riding over the top. It is thought spined loach are only likely to be sampled in softer substrates where the lead line sinks in to some extent, disturbing buried spined loach and at least providing a chance of them being captured.

Table 11.

Mean (± 1 S.E.) density (n m-2) of all fish species captured by the different quantitative methods used in the outer river of the Ouse washes, in February 1997.

Species	*Seine net*	*Hand trawl*	*PAS electrofishing*
Pike	0.005 ± 0.001	0.008 ± 0.008	0.023 ± 0.013
Eel	-	-	0.015 ± 0.011
Roach	1.003 ± 0.342	0.033 ± 0.020	-
Rudd	0.021 ± 0.012	0.008 ± 0.008	0.015 ± 0.011
Bream	0.030 ± 0.008	-	-
Tench	-	0.016 ± 0.035	-
Spined loach	-	0.220 ± 0.082	0.015 ± 0.011
Perch	0.050 ± 0.024	0.179 ± 0.044	0.062 ± 0.024
Ruffe	0.006 ± 0.004	0.016 ± 0.012	-
Total	1.266 ± 0.351	0.481 ± 0.014	0.131 ± 0.031

Overall it is suggested that the somewhat low efficiency of seine netting will also be variable according to the nature of the substrate and the presence of macrophytes. This means that routine Agency surveys using these methods may only provide records of spined loach. Spined loach may be present where it is suggested to be absent and the density is always likely to be a considerable underestimate.

The disappointing performance of point-sample electrofishing during the current assessment was related to the excessive maximum depth (>2 m) in the centre of the channel. Captures of fish, including spined loach, were thus limited to the shallower water close to, and within, the littoral margin. In general, point abundance sampling (PAS) by electrofishing (Copp & Penáz 1988, Perrow *et al.* 1996a) has several advantages over the standard techniques employed by the Agency (depletion fishing between stop-nets), as it involves taking a large number of samples leading to a low variance to mean ratio (Perrow *et al.* 1996a). Electrofishing may draw the fish from cover (including the sediment) and point sampling provides a means of generating quantitative estimates of fish density. Quantification of environmental variables at each point, is also a powerful way of assessing the factors determining the distribution and abundance of the fish.

Experience has shown that even where water clarity precludes seeing small fish near the bottom, netting through the area sampled by the anode results in the capture of any stunned fish. Point sampling may thus be undertaken successfully in relatively turbid water. However, point sampling by virtue of sampling only a small area at each point and even with considerable numbers of points, the area sampled may not be large (200 points would only be 300 m^{-2}), may mean rare species are ineffectively sampled. This is particularly relevant in the case of spined loach which appears to show an aggregated distribution (*pers obs*).

Therefore, in sites which have few spined loach, a more qualitative technique, sampling a larger area may prove to be more effective. Conventional electrofishing, exploring the habitat, may be used. The choice of gear will however be critical. For example, pulsed DC and DC forms may draw fish from cover, whereas AC does not. Routine electrofishing using AC may therefore be less likely to sample spined loach effectively. Moreover, high frequency gear will minimise possible injury to fish (see Perrow *et al.* 1996a). Even with appropriate gear, the efficiency of electrofishing will be different in relation to depth, width and the relative size of the anodes (Zalewski & Cowx 1990). Further modifications such as the use of oversize anodes (> 45 cm diameter), a slow sampling speed with careful exploration of any macrophytes etc. and fine-meshed (c. 2 mm) lightweight nets may be required. Even then, catch-per-unit-effort (CPUE) measures may be more appropriate and 'free' electrofishing over a known time period or perhaps known length of littoral margin undertaken.

During routine surveys, where species of importance to the fishery are the target, minor species such as spined loach are likely to be missed. Modifications to the standard techniques such as those recommended above, may also detract from sampling the major species of interest. Therefore, any modifications may be inappropriate. Consequently, without modification and even in small streams where conventional electrofishing is likely to be at its most efficient, the density of spined loach will not be effectively sampled by routine surveys. Further presence/absence is only likely to be reliably recorded in small streams.

Of the quantitative techniques used, the hand trawl was the most effective at capturing spined loach. It also has several distinct advantages over the other more standard techniques :

- Readily quantifiable through sampling of a known area.
- A reasonably large area may be sampled leading to sampling of rare or aggregated species such as spined loach (see discussion below).
- Relatively inexpensive of time and effort.
- Little operator bias.

The actual efficiency of the hand trawl in sampling spined loach is unknown at the present time. It is likely that the efficiency will also change according to the nature of the substrate and the abundance of any macrophytes and especially filamentous algae. Without trials on known populations under different circumstances, this cannot be addressed. At this stage, the hand trawl is likely to be effective in still or slowly flowing water of almost any depth. It cannot be effectively used where there is emergent vegetation or macrophytes or algae dominate the water column. The hand trawl may typically be used in range of large rivers and drainage channels.

Establishing further SAC's

Detailed molecular work (e.g. chromosome banding) is required to establish the taxonomic relationships between the different populations in the UK and also the ancestral stock in Continental Europe. This will also shed further light on the origin of spined loach in the UK. (see *Distribution of spined loach in the UK* above). In the absence of this information, the strategy of establishing SAC's within the Great Ouse and Trent/Witham catchments is a pragmatic one, based on the possibility that the spined loach present in each, are genetically different from each other (see *Key issues of a conservation strategy for spined loach* above).

The SAC designation generally overlays previous designation, at least SSSI status, at a particular site. For many SAC species, included within the SSSI framework, designation of SAC's may be relatively straightforward. However, spined loach has only recently been recognised as being worthy of conservation interest and had therefore not been included in the established legislative framework. Consequently, many good sites for spined loach (once these are determined - see below) are not likely to be SSSI's. However, as spined loach may often be associated with high quality, diverse habitats (see *Habitat preferences of spined loach* above), at least some riverine or lacustrine SSSI's are likely to contain good populations of spined loach. It may thus be pragmatic to exploit the latter, whilst alternative mechanisms of designating SAC's are sought.

Establishing further SAC's within the Great Ouse and Trent/Witham catchments relies on determining the status of populations and identifying key areas.

The following 'rules of thumb' may be used to target areas of potential value:

- Determine the distribution of any riverine SSSI's.
- Determine the distribution of other sites of lesser status, such as County Wildlife sites.
- Determine the distribution of non-designated areas of generally good habitat quality and a low level of anthropogenic disturbance. This may use the knowledge of staff of relevant organisations including Agency, EN and Trusts as well as specialist individuals. Agency RCS data may also be exploited.
- Using any available records from the catchment, check for any clustering or repeat records of spined loach, that may indicate good areas.
- Begin preliminary surveys in the small tributaries off the main channel as these will often have relatively high quality habitats, lower fish biomasses and a preponderance of smaller species with which spined loach tends to be associated.

The Great Ouse and associated waterways, already contains a candidate SAC, the Ouse washes (see *Key issues of a conservation strategy for spined loach* above). Preliminary surveys revealed good numbers of spined loach in the outer river at least, indicating that the site is worthy of its status. However, there are a number of issues associated with the system that are of concern (e.g. nutrient enrichment). At this stage, without further information the long-term value of the site cannot be assured (see *Conservation of spined loach in the Ouse washes cSAC* above). Therefore, it is desirable to establish at least one further SAC within the Great Ouse catchment.

Wicken Fen appears to be a most suitable candidate, with its current status as an National Nature Reserve (NNR), SSSI and cSAC for fen meadow communities (R. Hall, EN, *pers comm.*). The wide distribution of spined loach in the channels (lodes) of the fen has been confirmed during sampling undertaken as part of the research on bitterling, led by Dr. John Reynolds and his team at UEA. Bottle traps, electrofishing (some of which has been undertaken by ECON) and the 'push-net'(see above) have all successfully captured the species. Good numbers are also known to be present, with Peacock (1997) capturing >100 individuals using the push-net.

A further site of interest is the ARC Wildfowl refuge at Great Linford. Spined loach has colonised from the Great Ouse and is reputed to be very common, frequently being encountered in invertebrate samples (N. Giles, consultant, *pers comm.*). There is thus merit in establishing the size of the population on the site and if it is freely distributed between the different lake types, varying from macrophyte- to phytoplankton dominated (Giles 1992).

It is thought that there are few sites of conservation value within the Trent and Witham catchments. Attenborough gravel pits SSSI alongside the Trent is the only obvious site. This means that designation of SAC's within the Trent & Witham will have to rely on the use of alternative mechanisms to establish SAC's (see above).

During any sampling for spined loach, habitat and water quality variables should be quantified to provide additional data on the habitat preferences of spined loach, particularly juvenile fish, in different situations (see below). Of the water quality variables, determining any impact of salinity is of high priority due to the lack of knowledge of its influence and it's particular relevance to the Ouse Washes cSAC (see *Habitat preferences of spined loach* above).

Clarifying the habitat use of different age classes of spined loach

The habitat use of spined loach, especially that of juveniles, requires further clarification. In particular, the details of the potential refuge effect of macrophytes needs to quantified. For example, what plant species and coverage is important? From a population perspective, the ultimate question that needs answering is - What is the role of refuges in determining recruitment strength? Some useful information may be provided by habitat association determined during sampling of cSAC's (see *Establishing further SAC's* above) or streams (see *Determining the effects of routine management practices* below). However, a more targeted programme of research is clearly needed, along the lines of that adopted in Lake Veluwe (see *Habitat relationships in Lake Veluwe* above).

It would be beneficial to sample two distinct habitat types such as a stream/river and a larger drainage channel, with for example, a sandy and a more silty substrate respectively. Sampling should be conducted in all available habitats using transects or perhaps random sampling. Electrofishing (PAS and/or free sampling-see above) within the stream and the hand trawl in the drainage channel are the most appropriate techniques (see *Assessment of sampling methods* above) The sampling period should be at least one year. Additional information on sex ratios, fecundity, spawning periods, mortality rates and perhaps even diet should also be taken. An attempt to sample the diet of potential predators of spined loach including eel, perch, chub (in the stream) should also be made in an attempt to account for changes in population density. In the fluvial study site, an attempt should also be made to determine the effect of flow on different size (age) classes of spined loach.

Determining water quality criteria

The effect of different water quality criteria on spined loach is as yet unknown, although there is a suggestion that spined loach is adapted to low oxygen conditions and thus may tolerate other factors likely to be encountered in such circumstances (e.g. ammonia) (see *Habitat preferences of spined loach* above). High nutrient levels through changes to habitat structure are predicted to impact spined loach populations (see *Conservation of spined loach in the Ouse washes cSAC* above). Other variables such as heavy metals, salinity etc. may also have a direct effect. The best approach in determining any impact upon spined loach may be to look for relationships between the occurrence of spined loach in any particular waterbody and any particular variable. Routine Agency water quality monitoring may be utilised. An obvious problem is that the standard Agency fisheries surveys are relatively ineffective at sampling spined loach, particularly on a site basis. However, in a watercourse in which a large sampling effort has been undertaken, at least the presence of spined loach is likely to have been recorded (see *Habitat associations derived from routine fisheries and RCS surveys*). This may, however, be of insufficient detail to be useful. Consequently, laboratory eco-toxicological tests of the effects of particular variables on spined loach in the laboratory, may be the most effective approach. Such tests should only use the range likely to be encountered in natural habitats, of any particular variable.

Determining the effects of routine management practices

Several types of routine management practice undertaken particularly by the flood defence function of the Agency, may directly impact populations of spined loach (see *Preliminary management guidelines* above). In perceived order of importance these are:

- Channelisation (widening, deepening, straightening) of small streams.
- Dredging.
- Weed cutting.
- Channel profiling and littoral margin management .

During sampling to determine distribution of spined loach within the Trent and Witham catchments (see above), a comparison of spined loach populations between channelized and more natural streams is recommended. This could be achieved by sampling a minimum of 5 streams of each type. PAS by electrofishing is thought to be the most suitable sampling method (see below). At each point, the density of spined loach and the abundance of particular habitat variables may be determined with the aim of adding to the information on habitat relationships. The impact of littoral margin management may be investigated in the same way, perhaps within the same date set.

In the case of dredging and weed-cutting, monitoring of replicate (n>5) stretches at an experimental site, where controlled dredging and weed-cutting could be applied is deemed to be the most scientifically rigorous approach. Monitoring should be conducted pre- and post-management for at least one year to investigate short and longer term effects on habitat use, population structure and recruitment patterns. If effects prove to be significant, monitoring may be extended over a longer time period. Waterbodies subject to routine dredging such as the drainage channels of the lower Great Ouse and Witham system, are the most applicable to this type of approach. Weed-cutting may be investigated in these channels and also perhaps in streams in the Trent catchment which are also subject to an annual weed-cut in late summer/autumn to increase drainage efficiency in periods of increased flow.

Conclusions

The current conservation strategy for spined loach is to a) implement the EC directive through the establishment of SAC's and b) to conserve, and if possible, promote spined loach in all waters in which it occurs.

The strategy of establishing SAC's within each of the catchments in which spined loach occurs is a pragmatic solution to the possibility that different populations are genetically distinct from each other. Detailed knowledge of the taxonomic relationships between the different populations in the UK and the ancestral stock in Continental Europe, through detailed molecular work, should be sought at the earliest opportunity. This is likely to require a high level of expertise (such as that found in a number of University's in the UK) and considerable financial and time resources. Such a project is thought most likely to funded through the EC, with a number of partners in different member countries.

The conservation (and promotion) of spined loach in all waters in which it occurs requires further detailed knowledge of its habitat preferences, population dynamics and response to routine management practice. Knowledge on these three aspects will allow management prescriptions to be generated for different types of waterbody.

The principal components of a future programme of research and monitoring should therefore include:

- Determining the distribution and status of spined loach in the Trent & Witham and Great Ouse catchments with the view to establishing further SAC's. Useful information to add to the base of knowledge on the habitat preferences of spined loach may also be gathered.

- Specific medium term (at least one-year) research on the habitat requirements, especially of juveniles, and population dynamics of spined loach. This to be conducted in two study sites; one in a stream/river and the other in a large drainage channels. These to have different substrates, preferably sand and silt, respectively. Such a detailed programme of research may be most appropriately undertaken during a PhD.

- Monitoring the impact of routine management practices such as channelization, dredging and weed-cutting. Study sites in both streams and large drainage channels are required. A scientifically rigorous experimental design using replicates and a range of treatments incorporating controls, is recommended. This is because a high level of confidence in the results is required, as these have the potential to shape future management policy, with considerable financial implications.

From an assessment of sampling methods, it is clear that specific methods including the use of the hand trawl and point-abundance sampling by electrofishing, are required to sample spined loach effectively. These should be used in all aspects of future research on, and monitoring of, the species (see above).

Conversely, there is evidence to suggest that standard fish sampling methods such as seine netting and electrofishing between stop-nets are inefficient at sampling spined loach. The recording of spined loach in routine fisheries surveys conducted by the Agency, although adding to the base of knowledge on spined loach, is therefore of limited value in determining the distribution and status of spined loach. Although populations in small rivers and streams may be monitored after some modification to the standard electrofishing techniques, more specific methods are generally required. The incorporation of hand trawl sampling and point-abundance sampling by electrofishing, where appropriate, into routine Agency sampling of waters within the distribution of spined loach, is recommended.

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Appendix 1. Terms of Reference.

Spined Loach (*Cobitis taenia*): A review of habitat and management requirements

BACKGROUND

The Spined Loach is a small bottom dwelling fish which is confined to the rivers and drainage channels in the Midlands and eastern England. It is generally considered to be widely distributed within these areas, but since it is often overlooked in fish surveys, detailed information is lacking. Apart from selected studies its ecology appears to have been little studied in England.

The spined loach is considered to be threatened within Europe and is therefore listed on Appendix 3 of the Bern Convention and Annex II of the EC Directive on the conservation of natural habitats and wild flora and fauna. The latter places a duty on member states to ensure the long term conservation of this species, and specifically requires that special areas of conservation (SACs) should be designated for it and that appropriate actions should be defined and undertaken which will enable them to ensure its long term favourable conservation status (fcs) to be ensured. Following a review of available information, one site in the UK, the Ouse Washes, has been proposed for designation as a SAC. It is likely that it will be confirmed. However, it is clear from the review that the lack of detailed information on either the distribution of the spined loach or its habitat requirements coupled with the lack of general awareness about the species had not only restricted the ability to identify key sites but could potentially also hinder the development of best management practice to protect this and other sites where it occurs.

In view of this, there is now an urgent need to more fully review the existing knowledge and information on the distribution and habitat requirements of the Spined Loach and to define where possible preferred habitat and best practice for those operations and functions for which bodies such as the Environment Agency and the Internal Drainage Boards are responsible. In addition it will be equally important to identify those aspects of ecology and distribution which will need further research if the requirements of the Directive are to be fully met.

Overall Objective

The overall objective of the project is to ensure that the requirements of the EC Directive on the conservation of natural habitats and wild flora and fauna can be met.

It should be noted that the overriding requirement of the project is to inform management decisions which need to be taken now. As such the emphasis is to draw together the best available advice, testing this where appropriate, rather than seeking to set up and undertake a detailed research programme.

Project Aims

There are five broad aims.

1. To review and consolidate all existing information on the distribution of the Spined Loach in England, so as to provide a clearer picture than currently exists of its distribution.

2. to identify habitat requirements;

3. To identify and where possible quantify the key factors/issues which will need to be addressed if favourable conservation of the Spined loach is to be achieved across the range of habitats in which it is found;

4. to produce management guidelines which will raise awareness of the issues relevant to conserving the spined loach and also enable operational staff to ensure that sympathetic management of those sites where Spined loach occurs can be undertaken with particular reference to weed and silt control; and

5. to identify those aspects of ecology and distribution where further research or review is needed.

Methodology

The main aims of the project will be met through the following approaches.

1. A review of the published literature and any information held by regional EA staff and other interested bodies ie IDBS, NT, RSPB to identify all known records of Spined loach in its area of distribution.

2. A review of habitat requirements in both the published and grey literature to produce clear guidelines of physical and chemical and biological characteristics of its preferred habitats.

3. Analysis of the information held on the Ouse Washes to confirm the habitat characteristics of those sites where Spined Loach occurs, and to identify other possible sites where they may occur.

4. Limited survey, using appropriate techniques such as 'point electric fishing', to confirm the presence and if possible the population characteristics of Spined Loach from a selection of sites known to support the species and a selection of sites, which from an analysis of their attributes should support Spined Loach.

5. The synthesis of the results from 1 to 4 to produce draft management guidelines covering those operational functions, particularly weed and silt control, undertaken by the EA, IDBs and others. As part of these guidelines it will be important for the contractor to identify existing management practices and to indicate clearly whether or not these need to be modified. Where there are clear gaps in knowledge, advice should reflect the precautionary principle. Raising awareness of the likelyhood of finding and recording the presence of spined loach is an important part of this and a section of the guidelines should be devoted to this.

6. Recommendations for future research.

7. Recommendations for monitoring whether favourable conservation status is being maintained, including details of any actual survey techniques.

Results

The results of this project will be presented in the form of a written report, produced to the satisfaction of the project board. If appropriate a distinction should be drawn between different channel types ie river, ditch or dyke. Management guidelines should be produced in the format adopted by the EA and illustrated to the example included in Appendix 1.

Project Management

The project will be overseen by a project board comprising officers from EN and the EA.

Timescale

A draft report will be produced by December 1996.

A final report by April 1997.

Appendix 2.

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Appendix 3.

List of Consultees

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Thames Region:

West Area Office: Isis House, Howbery Park, Wallingford, Oxon, OX10 8BD

Waltham Cross: The Grange, 97 Crossbrook St, Waltham Cross, Hartfordshire, EN8 8HE

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Guildford Office: Ladymead, Bypass Road, Guildford, Surrey, GU1 1BZ

Midlands Region

Upper Trent Area Office: Sentinel House, 9 Wellington Crescent, Fradley Park, Lichfield, Staffs, SW13 8RR

Lower Trent Area Office: Trentside Offices, Scarrington Road, West Bridgford, Nottingham

Upper Severn Area Office: Hafren House, Welshpool Road, Shrewsbury, SY3 8BB

Lower Severn Area Office: Riversmeet House, Northway Lane, Tewkesbury, GL20 8JG

Anglian Region:

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North West Region:

Regional Office, Richard Fairclough House, Knutsford Road, Warrington, WA4 1HG

Appendix 4. List of all confirmed spined loach records

Grid references in brackets were worked out by AJ from discriptions

River	Site Name	NGR	Year	Source
Ouse	Whitings stretch	(SP805714)	1990	Mann 1995 (Copp 1990b)
Ouzel	Stoke Hammond	(SP885364)	1990	Mann 1995 (Copp 1990b)
Ouzel	Caldecote: channels	(SP885424)	1990	Mann 1995 (Copp 1990b)
Ouse	Kempstone: side channel	(TL021476)	1990	Mann 1995 (Copp 1990b)
Elstowe Brook		(TL051474)	1990	Mann 1995 (Copp 1990b)
Kym	Hail Weston	(TL170623)	1990	Mann 1995 (Copp 1990b)
Ouse	Hall Green Brook	(TL303680)	1990	Mann 1995 (Copp 1990b)
16 Foot Drain	Sparrow Hall	(TL465943)	1983	Mann 1995 (NRA Anglian))
Swaffham Bulbeck Lode		(TL550640)	1990	Mann 1995 (Copp 1990b)
Delph	DS Earith - fish resuce	(TL576856)	1993	Brampton EA
16 Foot Drain	Poplar Farm Bridge	?	1983	Mann 1995 (NRA Anglian))
16 Foot Drain	Crown Drove Road	?	1983	Mann 1995 (NRA Anglian))
Rippingdale Running Dyke	Dunsby Fen	?	1984	Mann 1995 (NRA Anglian))
Sincil Dyke	d/s 5 Mile House	?	1982	Mann 1995 (NRA Anglian))
Witham	Cherry Willingham	?	1978	Mann 1995 (NRA Anglian))
Ancholme	Brigg Sports Centre	SE993069	1979	Mann 1995 (NRA Anglian))
Sow	Eccleshall	SJ831296	1992	Lichfield (EA)
Sow	Yoxhall Bridge	SJ831296	1993	Lichfield (EA)
Sow	Eccleshall	SJ831296	1993	Mann 1995 (NRA Seven Trent)
Trent	U/S Scotch Brook	SJ901334	1995	Lichfield (EA)
Penk	Atherstone Rattcliffe Bridge	SJ915137	1993	Lichfield (EA)
Penk	Penkridge-Cuttlestone Bridge	SJ915137	1993	Mann 1995 (NRA Seven Trent)
Sow	Eccleshall	SJ918233	1993	Lichfield (EA)
Sow	Broad Eye Bridge	SJ918233	1993	Mann 1995 (NRA Seven Trent)
Penk	Stafford Radford Bridge	SJ938216	1995	Lichfield (EA)
Penk	Stafford-Radford Bridge	SJ938216	1995	Mann 1995 (NRA Seven Trent)
Sow	St. Thomas Bridge	SJ946228	1992	Lichfield (EA)
Sow	Penkridge-Cuttlestone Bridge	SJ946228	1995	Lichfield (EA)
Sow	St Thomas Bridge	SJ946228	1995	Mann 1995 (NRA Seven Trent)
Penk		SJ949221	1993	Lichfield (EA)
Penk		SJ949221	1994	Lichfield (EA)
Penk		SJ949221	1996	Lichfield (EA)
Trent	Hilton	SK131177	1992	Lichfield (EA)
Trent	Yoxall Bridge	SK131177	1992	Mann 1995 (NRA Seven Trent)
Mease		SK235113	1994	Lichfield (EA)
Anker	R.Sence to R.Tame	SK237048	1996	Lichfield (EA)
Hilton Brook	Hilton	SK242306	1992	Mann 1995 (NRA Seven Trent)
Derwent	Wilne	SK242314	1994	Mann 1995 (NRA Seven Trent)
Sibson Brook		SK334004	1996	Lichfield (EA)
Grantham Cannal		SK350290	since 1990	Nottingham (EA)
Trent & Mersey Cannal	Twyford	SK350290	since 1990	Nottingham (EA)
Trent	Swarkestone	SK375283	since 93	Lichfield (EA)
Trent	Swarkestone	SK375283	1993	Mann 1995 (NRA Seven Trent)
Trent	Kings Mills	SK417274	1994	Mann 1995 (NRA Seven Trent)
Trent	Shardlow	SK447299	1994	Mann 1995 (NRA Seven Trent)
Trent	Thrumpton	SK510315	since 93	Lichfield (EA)
Trent	Thrumpton	SK513317	1994	Mann 1995 (NRA Seven Trent)
Soar	Aylestone	SK570001	1995	Mann 1995 (NRA Seven Trent)
Trent	Ladybay Bridge	SK585387	1993	Mann 1995 (NRA Seven Trent)
Trent	Stoke Bardolph	SK650405	1995	Mann 1995 (NRA Seven Trent)
Trent	Stoke Bardolph	SK651407	since 93	Lichfield (EA)
Devon	Cotham	SK780470	since 1990	Nottingham (EA)
Trent	South Muskham	SK803565	since 93	Lichfield (EA)
Trent	South Muskham	SK803565	1994	Mann 1995 (NRA Seven Trent)
Trent	Winthorpe Bridge	SK805567	1995	Mann 1995 (NRA Seven Trent)
Till	Broxholme	SK903768	1978	Mann 1995 (NRA Anglian))
Till	Squires Bridge	SK903824	1994	Mann 1995 (NRA Anglian))
Till	Till Bridge	SK907797	1994	Mann 1995 (NRA Anglian))
River Brant	Navenby Road Bridge	SK940580	1994	Mann 1995 (NRA Anglian))
Skellingthorpe Main Drain	Kews Holt	SK945740	1994	Mann 1995 (NRA Anglian))
Fossdyke	Pyewipe Inn	SK949723	1978	Mann 1995 (NRA Anglian))
Burton Catchwater Drain	Bishops Bridge	SK950733	1982	Mann 1995 (NRA Anglian))
Witham	Lincoln Power Station	SK993714	1981	Mann 1995 (NRA Anglian))
Anker	Broad Eye Bridge	SP317985	1993	Lichfield (EA)
Anker	Atherstone Ratcliffe Bridge	SP317985	1993	Mann 1995 (NRA Seven Trent)
Anker		SP318986	1996	Lichfield (EA)

Sence		SP320996	1996	Lichfield (EA)
Soar	Narborough	SP541973	1994	Mann 1995 (NRA Seven Trent)
Soar	Whetstone	SP552985	1993	Mann 1995 (NRA Seven Trent)
Padbury or Claydon Brook	Hillfarm	SP728285	1994	Brampton (EA)
Padbury	Thornborough	SP729332	1990	Mann 1995 (Copp 1990b)
Great Ouse	Mounthill farm	SP763376	1991	Brampton (EA)
Tove	Bozenham	SP776483	1990	Mann 1995 (Copp 1990b)
Great Ouse	Passenham	SP782393	1989	Mann 1995 (Copp 1990a)
Great Ouse	Passenham	SP782393	1990	Mann 1995 (Copp 1990b)
Great Ouse	d/s Passenham Weir	SP785401	1991	Brampton (EA)
Great Ouse	Manor Farm	SP808425	1991	Brampton (EA)
Great Ouse	ARC Wildfowl reserve	SP840430	1990 on	Giles pers com
Great Ouse	Backwater	SP853448	1997	Brampton (EA)
Great Ouse	Ravenstone: mill stream	SP854486	1989	Mann 1995 (Copp 1990a)
Great Ouse	Ravenstone: side channel	SP855485	1989	Mann 1995 (Copp 1990a)
Grand Union	Woolstone	SP872390	1990	Brampton (EA)
Great Ouse	Newport Pagnell	SP877440	1974	Robotham 1977
Great Ouse	Newport Pagnell	SP882441	1992	Brampton (EA)
Great Ouse	Sherington: side channel	SP883455	1989	Mann 1995 (Copp 1990a)
Great Ouse	Sherrington: side channel	SP883455	1990	Mann 1995 (Copp 1990b)
Great Ouse	Sherington Bridge	SP884454	1989	Mann 1995 (Copp 1990a)
Great Ouse	Sharnbrook	SP990579	1984	Mann 1995 (Unpublished IFE data)
Ancholme	North Kelsey Carrs	TA006006	1979	Mann 1995 (NRA Anglian))
Witham	Greetwell Hall	TF015711	1978	Mann 1995 (NRA Anglian))
Ancholme	TF015970	TF015970	1979	Mann 1995 (NRA Anglian))
Ancholme	Snitterby Carrs	TF018948	1989	EA Anglian (Northern)
Ancholme	Pease Holme	TF023936	1993	Mann 1995 (NRA Anglian))
Ancholme	Pilford Bridge	TF036886	1989	EA Anglian (Northern)
Witham	5 Mile House.	TF059715	1978	Mann 1995 (NRA Anglian))
Barling's Eau	Newballwood	TF082758	1982	Mann 1995 (NRA Anglian))
Sincil Dyke	Bardney Locks	TF105702	1982	Mann 1995 (NRA Anglian))
Witham	u/s Bardney Bridge	TF110614	1994	Mann 1995 (NRA Anglian))
Witham	Bardney	TF112691	1981	Mann 1995 (NRA Anglian))
Farroway Drain	Praie Grounds	TF136523	1994	Mann 1995 (NRA Anglian))
Witham	Southrey	TF139663	1981	Mann 1995 (NRA Anglian))
Witham	Stixwold station	TF155655	1981	Mann 1995 (NRA Anglian))
South 40 Foot Drain	Dowsby Road	TF167324	1990	Mann 1995 (NRA Anglian))
Witham	Kirkstead Bridge	TF175621	1981	Mann 1995 (NRA Anglian))
South 40 Foot Drain	Bicker Fen	TF185395	1995	Mann 1995 (NRA Anglian))
Head Dyke	Pump Station	TF186467	1995	Mann 1995 (NRA Anglian))
Witham	Thorpe Tilney	TF189589	1981	Mann 1995 (NRA Anglian))
Witham	Tattershall Bridge	TF196563	1981	Mann 1995 (NRA Anglian))
Witham	Dogdyke	TF208554	1981	Mann 1995 (NRA Anglian))
West French Drain	Dovecote	TF281528	1990	Mann 1995 (NRA Anglian))
West French Drain	Newham drain	TF292500	1993	Mann 1995 (NRA Anglian))
Witham	Anton's Gowt	TF301474	1981	Mann 1995 (NRA Anglian))
West French Drain	Medlam drain	TF322539	1993	Mann 1995 (NRA Anglian))
French Drove		TF331089	1995	Mann 1995 (NRA Anglian))
Sibsey Trader System		TF339597	1990	Mann 1995 (NRA Anglian))
Cowbridge Drain	d/s Kelsey Bridge	TF346465	1995	Mann 1995 (NRA Anglian))
Hobhole Drain	Kelsey Bridge	TF346465	1993	Mann 1995 (NRA Anglian))
East Fen Catchwater	Holmes Road, Stickney	TF350566	1993	Mann 1995 (NRA Anglian))
Hobhole Drain	Hemholme Bridge	TF403586	1993	Mann 1995 (NRA Anglian))
Bellwater Drain	Bellwater Farm	TF423592	1993	Mann 1995 (NRA Anglian))
Lym	Mill Bridge	TF430641	1993	Mann 1995 (NRA Anglian))
Steeping	Firsby	TF457621	1993	Mann 1995 (NRA Anglian))
Steeping	Relief channel	TF488602	1993	Mann 1995 (NRA Anglian))
Steeping	Tasco's Bridge	TF508599	1993	Mann 1995 (NRA Anglian))
Nar	d/s Setchey	TF635135	1996	Brampton (EA)
Nar	Wormegay High Bridge	TF671135	1996	Brampton (EA)
Stringside stream	Barton Bendish	TF703039	1993	Brampton (EA)
Watton Brook	d/s Carbrooke	TF938020	1990	Brampton (EA)
Great Ouse	Radwell Bridge	TL005573	1989	Mann 1995 (Copp 1990a)
Great Ouse	Radwell Bridge	TL005573	1990	Mann 1995 (Copp 1990b)
Great Ouse	Bromham Hall	TL012510	1989	Mann 1995 (Copp 1990a)
Great Ouse	Hillgrounds Park: side channel	TL021476	1989	Mann 1995 (Copp 1990a)
Great Ouse	Kempston	TL023476	1992	Brampton (EA)
Great Ouse	Bedford: Barns Drain	TL072486	1989	Mann 1995 (Copp 1990a)
Great Ouse	Mill Farm: side channel	TL080480	1989	Mann 1995 (Copp 1990a)
Great Ouse	Great Barford mill stream	TL134517	1989	Mann 1995 (Copp 1990a)

Ivel		362	TL154526	1995	Brampton (EA)
Great Ouse	Little Paxton gravel pit		TL197628	1985	Richard Hall - English Nature
Great Ouse	Godmanchester (u/s Cookes backwater)		TL243710	1989	Mann 1995 (Copp 1990a)
Great Ouse	Dolphin Meadow		TL309714	1995	Brampton (EA)
Rhee	Wimpole		TL333485	1993	Brampton (EA)
Rhee	Malton Farm		TL374483	1993	Brampton (EA)
Old West		225	TL396744	1996	Brampton (EA)
Inner River/Ouse Washes			TL405773	1997	ECON survey
Old West		227	TL418728	1996	Brampton (EA)
Inner River/Ouse Washes			TL433807	1997	ECON survey
Outer River/Ouse Washes			TL433807	1997	ECON survey
Old West		228	TL435724	1996	Brampton (EA)
16 Foot Drain	Boots Bridge		TL446912	1983	Mann 1995 (NRA Anglian))
Inner River/Ouse Washes			TL447828	1997	ECON survey
Outer River/Ouse Washes			TL447828	1997	ECON survey
16 Foot Drain		724	TL447914	1994	Brampton (EA)
16 Foot Drain		726	TL464943	1994	Brampton (EA)
Inner River/Ouse Washes			TL465853	1997	ECON survey
Outer River/Ouse Washes			TL465853	1997	ECON survey
16 Foot Drain		727	TL474959	1994	Brampton (EA)
16 Foot Drain		728	TL485977	1994	Brampton (EA)
Inner River/Ouse Washes			TL493887	1997	ECON survey
Outer River/Ouse Washes			TL493887	1997	ECON survey
Granta	Babraham		TL496514	1993	Brampton (EA)
Granta	Babraham (I.A.P.)		TL507508	1993	Brampton (EA)
Counter Drain	Vandervells		TL512917	1993	Brampton (EA)
Bottisham Lode			TL517652	1997	Brampton (EA)
Outer River/Ouse Washes			TL525933	1997	ECON survey
Reach Lode			TL545697	1996	Reynolds, UEA pers com
Wicken Lode			TL565705	1996	Reynolds, UEA pers com
Soham Lode	Soham Cotes		TL576745	1990	Brampton (EA)
IDB drain near Little Port	Paddinal Fen - Fish resuce		TL576856	recent?	Brampton EA
Cut off Channel	u/s Hockwold Bridge		TL727875	1986	Brampton (EA)
Little Ouse	Hockwold Common		TL736873	1993	Brampton (EA)
Wissey	Bodney Meadows		TL831983	1993	Brampton (EA)
Stour			TL866413	94	Essex EA
Little Ouse	Nunnery Golf Course		TL873815	1996	Brampton (EA)
Little Ouse	Barnham Village		TL878800	1996	Brampton (EA)
Sapiston	Euston		TL889798	1995	Brampton (EA)
Sapiston	u/s Second Riffle		TL914753	1995	Brampton (EA)
Sapiston	d/s Third Riffle		TL914758	1995	Brampton (EA)
Sapiston	d/s Bardwell Mill		TL933742	1995	Brampton (EA)
Sapiston	Micklemere		TL937699	1995	Brampton (EA)
Little Ouse	Knettishall Heath		TL951809	1996	Brampton (EA)
Thet	Snetterton		TL994918	1995	Brampton (EA)
Stour			TM045334	1995	Essex EA

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Survey of selected sites and habitats for spined loach (*Cobitis taenia*)

Contract No. P127/02/177

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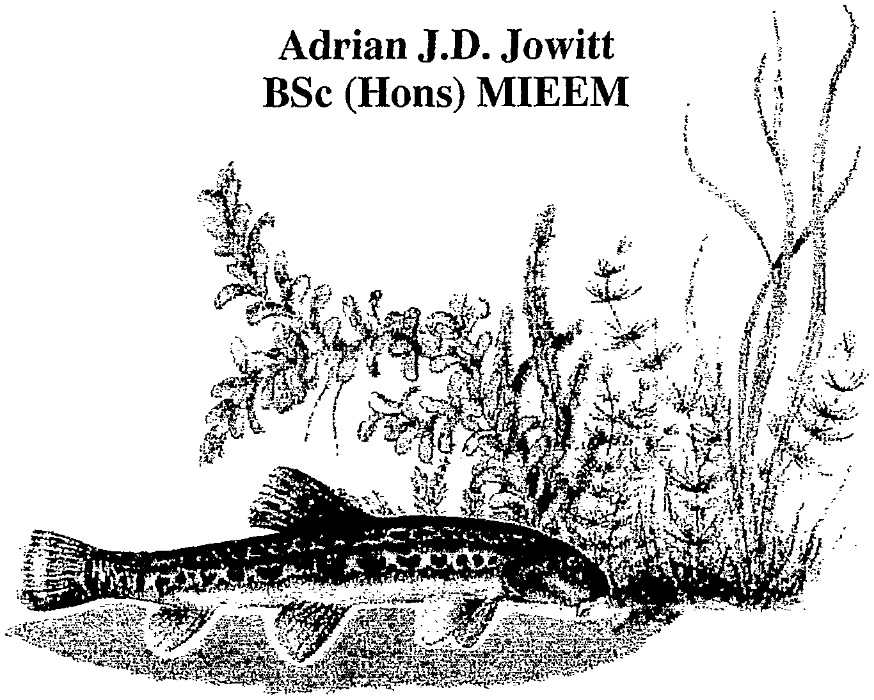


March 1998

4. RESULTS

The data sets from both sites are massive, with over 2,600 individuals marked in Pembrokeshire and 2,900 in the New Forest, and this report should therefore be considered as a preliminary analysis of these data sets. The data was entered on the spreadsheet software Microsoft Excel 4.0, with the statistical analyses reported here performed on Minitab release 8.2. The data is currently held with Dr D.J. Thompson at the University of Liverpool.

4.1 BRYNBERIAN, MYNYDD PRESELI, PEMBROKESHIRE (SN118344)

4.1.1 The locality

The Pembrokeshire study was undertaken on Mynydd Preseli, the locality with the second largest population of *C. mercuriale* in Britain. The New Forest is believed to support the largest British population. Mynydd Preseli is an extensive area of unenclosed common that is heavily grazed by sheep. The detailed distribution of *C. mercuriale* in the area is reported by Skidmore (1996). The site is divided into a northern and southern half by the ridge of the Mynydd which is above 300 m in altitude.

Skidmore (1996) reported that there were a number of localities for the species, arranged in a west-east orientation on the north face of the common, up to an altitude of about 170 metres a.s.l. He identified three catchments on this slope, with the central one, the Glan-yr-Afon catchment, containing the largest area of suitable habitat. This region (Fig. 1) therefore comprised the core of the study area where most effort in marking and recapturing was employed. This area would be the source of most dispersers, which could move either east or west. Concentrating re-capture effort in this area would allow the detection of any dispersers moving from sites to the east or west.

The main study stream and the marked valley mire formed the areas where the quantitative mark-recapture study was undertaken. The three large subsidiary sites were the main areas where additional marking and recapture was undertaken. The *Juncus* beds were dry river courses, where small numbers of *C. mercuriale* could be found away from the main study stream. As Fig. 2 shows, however, marking was also undertaken wherever individuals were found, including a number outside the core study area.

Establishing further SAC's

A good population appears to be indicated by a autumn/winter figure of 0.1 - 0.2 m^{-2}. The viability of the population seems characterised by:

- A high proportion (preferably at least 50 %) of 0+ fish.
- Representation of a further two/three age classes.
- A maximum length of the fish in excess of 85 mm and preferably larger.

On the basis of this, the South Delph Drain, part of a County Wildlife site owned by Anglian Water, may be suitable as a candidate SAC (cSAC) within the Witham catchment. However, this will obviously depend on the site fulfilling a number of environmental and legal criteria to be answered by English Nature. The impact of the presence of a sewage treatment works (STW) discharging treated effluent and routine maintenance of the site will need to be understood if the site is to maintain its value.

There is also a sound basis for proposing Wicken Fen as a second cSAC (the Ouse Washes being the other) in the Great Ouse catchment. This would benefit, however, from incorporating at least part of Reach Lode. The effects of routine maintenance of the system, including dredging and cutting of emergent vegetation, upon spined loach, need to be understood if their populations are to be effectively conserved and promoted.

No candidate SAC for spined loach can be proposed for the Trent catchment at the current time, although it is clear that reasonable densities of the species may occur at least in some of the tributaries (e.g. the Mease, Sence and Smite).

Habitat relationships in drains

Populations of spined loach may be of a reasonable density and display good age structure in a number of slow-flowing drainage channels, with differing habitat types. The latter may include a range of substrate types including silt. Macrophytes and filamentous algae may be selected in some situations and not others. Several factors may be responsible for these inconsistencies in habitat selection. These include a) the possibility of the occurrence of distinct types of spined loach, each with different habitat requirements b) differences in predation risk, particularly from larger fish, in different habitats in different sites and c) a lack of understanding of the influence of factors such as the abundance of food resources. If populations of spined loach are to be conserved or promoted in drains, which represent an important habitat, these aspects should form the focus of further research.

Habitat relationships in streams and rivers

The current study in tributaries of the River Trent confirmed the perception that spined loach is associated with diverse habitat structure and thus diverse fish and invertebrate communities in semi-natural compared to modified streams. Within semi-natural streams, spined loach tended to select for fine sediments, particularly sand, and structurally diverse habitats (in this case emergent macrophytes, leaf litter and overhanging vegetation in the absence of submerged macrophytes). Overall, habitat selection may be linked to a) slower flow in at least some sections of natural streams b) or the provision of refuges against predation in more structurally diverse habitats c) competition with stone loach, which may dominate in unmodified streams, or d) any combination of these factors. The relative importance of such factors in relation to population dynamics, the impact of habitat management and seasonal changes in habitat selection as fish grow, macrophytes develop and decay and flow regimes change, needs to be understood. This is best achieved through a longer term more intensive study, on one or perhaps two sites (see Perrow & Jowitt 1997 for full details).

Management guidelines

It is clear that modification of streams typically for land drainage and flood defence purposes, causing a reduction in physical habitat diversity, has a detrimental impact on spined loach (see *Habitat relationships in streams and rivers* above). The loss of preferred substrate, increase in flow above a tolerable threshold, loss of refuges against predation and an increase in potential competitors are all possible reasons behind this impact. As identified above (see *Habitat relationships in streams and rivers* above), further research is needed to determine the relative importance of these factors. Determining the impact of routine maintenance such as weed-cutting and dredging should also be a priority of further experimental work (see Perrow & Jowitt 1997 for full details).

Contents

Background information

Spined loach is listed under Annex II of the EC Directive on the conservation of natural habitats and flora and fauna. Member countries have the duty to ensure the favourable conservation status of the species through conservation of viable populations within special areas of conservation (SAC's). Developing sufficient understanding to enable this process to be achieved formed the principal target for English Nature (EN) one of the partner organisations of the preceding project (Perrow & Jowitt 1997). In areas outside SAC's, populations of spined loach may be effectively conserved or even promoted through production of a set of operational guidelines for implementation by those organisations undertaking management of waterways primarily for flood defence and drainage. This was the principal concern of the other project partner, the Environment Agency (hereafter known as the Agency). To achieve these aims, the project sought to provide information on the distribution and habitat preferences of spined loach, with emphasis on potential constraints on populations, particularly the role of habitat management.

From the 180 records of spined loach gathered during the previous project, it was clear that the spined loach is naturally restricted to the Trent (and connected Witham) and Great Ouse catchments. This restricted distribution results from a combination of the patterns of colonisation from ancestral riverine connections prior to the severance of the land bridge at the end of the last ice age some 10 000 year ago, and the lack of subsequent dispersal through human means. Metapopulations in the Great Ouse and Trent have thus been isolated from those in Europe, and probably each other, for around 10 000 years. Given the tendency of 'spined loach' to occur as morphologically and/or genetically distinct forms within the *Cobitis taenia* complex, it is plausible that the UK contains one or more endemic races, subspecies or even species of spined loach. This must be incorporated into the UK conservation strategy for spined loach.

In the absence of detailed information on genotypes, setting up SAC's within the Great Ouse and Trent catchments was suggested to be the pragmatic option. Two within each catchment was thought likely to ensure the favourable conservation status of the species. Moreover, as the connection between the Trent and Witham system is restricted to the Fossdyke, and thus mixing of populations may be limited, establishing at least one SAC within the Witham was also thought to be prudent.

Spined loach may occur in a wide variety of waterbodies including large rivers, small streams, artificial drainage channels and lakes, which suggests it has a broad ecological niche. However, evidence from literature sources, original fieldwork and analysis of

Agency data in the report by Perrow & Jowitt (1997), suggests spined loach exhibits distinct habitat preferences, preferring a sandy substrate with a dense, yet patchy coverage of rooted, submerged macrophytes. Fine sediments are required by the specialised feeding mechanism of spined loach, in which it pumps material through its buccal cavity, and extracts food particles with mucous. Although it may tolerate silt or mud, sand may offer a greater range of food resources or be a better substrate for spawning or egg survival.

Macrophytes seem to offer refuges from potential predators. These may include a wide range of fish (including large omnivorous species such as carp or bream), birds and even invertebrates. Refuges, in the form of macrophytes, may be especially critical for larval spined loach.

Any factor leading to the loss of macrophytes or change in the nature of the sediment, and its associated benthic flora and fauna, is likely to be detrimental to spined loach. This includes eutrophication (an increase in the rate of nutrient supply), excessive loading of fine sediments, excessive stocking of benthivorous fish and any management (e.g. channelisation) that causes a significant reduction in habitat diversity of river and stream channels. Routine maintenance of river and stream channels such as dredging, weed-cutting, and channel profiling to improve channel capacity and drainage capability, is also likely to impact upon spined loach populations. Although sufficiently detailed specific information is not yet available, a number of preliminary precautionary guidelines were provided by Perrow & Jowitt (1997). These stemmed from the short-lived nature of the species with reliance on annual recruitment to maintain populations.

Aims

The current project sought to build on the findings of the previous project and had four broad aims:

- To provide the basis for the establishment of further SAC's. Defining what is a good and viable population in a range of watercourses (e.g. main river, streams, drains and dykes) was a critical starting point.

- To verify the relationships between spined loach and particular habitats and fish communities in streams and rivers. This used the tributaries of the Trent as a case study.

- To verify the relationships between spined loach and particular habitats and fish communities in drains. This used sites being investigated as possible SAC's including Wicken Fen.

- To provide further management guidelines.

These were adapted from the terms of reference for the project after discussion (see Appendix 1).

Project management

The direct manager of the project was Mary Gibson (freshwater ecologist) for EN. Andrew Heaton (Regional Conservation Officer for Severn-Trent) managed the Agency's involvement through R & D project 640, 'Species management in aquatic habitats' which supplied funds to the project.

Dr. Martin Perrow assumed overall responsibility for the project from ECON's perspective. Adrian Jowitt managed the fieldwork component and was the contact point for EN and Agency involved in site selection and the provision of data. Notable Agency staff included Tim Franklin and Jim Lyons of Upper and Lower Trent Area respectively, of Midlands Region of the Agency. Wendy Brooks of the Grantham Office was the principal contact for EN. Technical support was provided by Mark Tomlinson, Neil Punchard and Dr. Jeremy Rhodes of ECON.

Report structure

For ease of reference this report is divided into 4 sections, in accordance with the aims of the project:

- A. Establishing further SAC's.
- B. Habitat relationships in drainage channels.
- C. Habitat relationships in streams and rivers.
- E. Management guidelines.

A. Establishing further SAC's

Introduction

As outlined earlier (see *Background information* above), the strategy of establishing SAC's within the Great Ouse, Trent and Witham catchments had been suggested as a pragmatic course of action, with the possibility that different catchments may contain taxonomically distinct populations.

The current legislative framework means that SAC's are most appropriately established at sites with previous Site of Special Scientific Interest (SSSI) status. In the absence of any sites of such status within a catchment, sites of lesser designation may be considered as candidate SAC's (cSAC). This would, however, require an alternative legislative framework to be established.

Methods

Site selection

The following procedure was used to target areas to be surveyed:

- The locations of any SSSI's directly or indirectly associated with the relevant waterbody were determined.

- In the absence of SSSI's, the locations of County Wildlife Sites, directly or indirectly associated with the relevant waterbody, were determined.

Where more than one site was available in either category, the site(s) with the greatest, purely aquatic interest were selected.

In the case of the Trent and Witham, the above was achieved through contact with Wendy Brooks of EN. This then facilitated contact with other relevant individuals including landowners. The latter were contacted directly for permission for access to the site in question. Sites selected in the Trent catchment were the River Idle washlands (SK 662936-SK720963) and Mother Drain (and associated River Idle) (SK 767955-SK786947). Attenborough gravel pits (SK 522341) were also selected, although as a result of the sensitivity of the relationship between the landowners RMC Butterley Aggregates Ltd and

English Nature, it proved impossible to gain access to the site. A further SSSI, which due to time constraints, could not be sampled, was Pasturefields salt marsh (SJ 992248).

On the Witham, in the absence of any SSSI's, the South Delph Drain and River Witham (SK 991711) County Wildlife site was selected. Other sites of potential interest, which could be sampled in the future, include Delph drains (SK 965682-967691), River Witham at Bracebridge (SK 956652-970700), Catchwater Drain (SK 953702-970695), Mill Drain (TF 195572-200564) and Nocton Delph (TF 100650-127664).

In the catchment of the Great Ouse, Wicken Fen NNR had previously been identified as a site worthy of interest (Perrow & Jowitt 1997), with significant numbers of spined loach being captured in the study by Peacock (1997). Other sites outside the scope of the current study, that may be sampled in the future, include Little Paxton (TL 200637) and Great Linford gravel pits. Spined loach has been recorded at both these latter sites (Perrow & Jowitt 1997).

Further details of several of these sites are provided in Appendix 2.

Sampling strategy

All sampling was conducted between 21-29th October 1997 (Table 1). The bulk of sampling was conducted with the hand trawl, which was identified by Perrow & Jowitt (1997) as a particularly suitable method for sampling spined loach. This gear was originally designed to catch shrimps in shallow coastal waters by Dr. Bob James at the University of East Anglia. It consists of a tubular aluminium D' frame of 75 cm x 25 cm mounted on aluminium runners (0.7 m in length) which allow the trawl to be pulled or pushed (when a long metal handle is attached) across the sediment surface. A 'tickler' chain attached across the front of the runners is designed to disturb the fish (or shrimps) buried in the sediment, leading to their capture in the 1.2 m long x 2.5 mm mesh tapering net attached to the frame.

A standard procedure was adopted at all sites surveyed, with some variation in the number of hauls and length of each haul, dependent on the time available and the width of the respective channels (Table 1). During each haul, the trawl was dropped into to the water from a small (3 m) dinghy rowed to the opposite bank. Trawls were thus undertaken across the full width of the channel, which was generally between 5-12 m. The only exception to this was the River Witham. Here, the length of the trawl was restricted to 20 m by the length of rope attached to the trawl. The distance between trawls was generally around 25 m to ensure that a reasonable length (typically > 250 m) of the site was sampled.

Upon completion of the haul, any spined loach captured were measured to the nearest mm before being returned unharmed. Retention of material (substrate, macrophytes, invertebrates etc.) also allowed a number of environmental variables to be recorded during each haul. The relationships between these and the density of spined loach at the various sites were explored below (see *Habitat relationships in drains* below).

At least 10 trawl hauls were conducted at each sample site to provide sufficient replication to allow confidence in the resulting estimate of spined loach density at the site. The only exceptions to this were the Mother Drain and Monk's Lode in the Wicken system (Table 1). In Mother Drain, the very shallow (< 10 cm) water and the presence of extensive emergent vegetation restricted sampling to just 2 hauls. No spined loach were captured and sampling effort was concentrated in the adjacent River Idle. Limited sampling was undertaken in Monk's Lode as this was classed as only one site in a connected system.

Table 1.
Sampling date and the number and length (minimum-maximum) of hand trawls at the respective sampling locations.

Catchment	*Site*	*Sampling date*	*Number of hauls*	*Haul length (m)*
Trent	River Idle Washlands	29/10/97	10	10
	Mother Drain	29/10/97	2	6
	River Idle	29/10/97	15	15-18
Witham	South Delph Drain	23/10/97	20	10
	River Witham	23/10/97	20	20
Great Ouse	Wicken Lode	21 & 25/10	30	5-10
	Monks Lode	21/10	5	5
	Reach Lode	21/10	15	10-12

More extensive sampling was undertaken at Wicken Fen to examine variability in the numbers of spined loach throughout this network of connected waterways. Considerable variation in density of spined loach according to environmental variables had been previously recorded in the Ouse washes cSAC (Perrow & Jowitt 1997). A large number of trawls also allowed the relationships between spined loach density and environmental variables to be investigated (see *Habitat relationships in drains* below).

Sampling was also conducted in 3 (Malcarse Drain, Drainer's Dyke and Gardiner's Drove) small (generally around 2 m wide) dykes within the fen itself (Fig. 1). The small size and occurrence of emergent vegetation within these dykes precluded the use of the hand trawl and point-abundance sampling (PAS) by electrofishing was used instead (see Copp & Penaz 1988, Copp & Garner 1995, Perrow *et al.* 1996, Perrow & Jowitt 1997). High frequency (600 Hz) pulsed DC (rectangular wave at 300V with a variable duty cycle of 0-50%) electrofishing equipment, (Electracatch WFC11-12 volt powered by a 1.9 KVa generator) was used from a 3 m fibreglass dinghy in the case of Malcarse Drain and Drainer's Dyke. This was 'push' rowed by one operator, with a second operator electrofishing from the stern. In Gardiner's Drove, sampling was conducted from the bank through the use of a 100 m extension cable attached to the anode (see *Habitat relationships in streams and rivers* below). Samples were taken at 10 m intervals along each dyke and 16, 40 and 32 samples were taken in Malcarse Drain, Drainer's Dyke and Gardiner's Drove respectively. At each point, the anode was rapidly immersed, and any stunned fish seen were captured by a lightweight fibreglass hand net. Even where no fish were seen, as the net was routinely swept through the stunned area fish were captured regardless. The effective sampling radius of 1.3 m^2 was calculated by determining the distance from the anode at which the voltage gradient was reduced to 0.12V, the level at which inhibited swimming occurs (Copp & Penáz 1988). With a known sampling area, the density (n m^{-2}) of spined loach could be readily calculated. Spined loach were processed in the same manner as described for trawl samples.

With both trawl samples and PAS in all locations, the length frequency of all spined loach captured were determined. Both this and the density of spined loach captured at each site was then compared with other sites presented in; the literature, further riverine sites sampled in the current study (see *Habitat relationships in streams and rivers* below) and sites sampled by Perrow & Jowitt (1997), in order to define the nature of a good and viable population.

Results

The density of spined loach varied considerably between the study sites (Fig. 2). None were captured in Mother Drain and the River Idle in the catchment of the Trent. Only one individual was captured in the River Witham, conferring a negligible density, whereas a density of > 0.2 m^{-2} was recorded in the South Delph Drain. At Wicken, in the catchment of the Great Ouse, densities > 0.1 m^{-2} were recorded in both Wicken and Reach Lodes.

Populations of spined loach in the latter three sites all show a good distribution of sizes, and hence, ages, of fish (Fig. 3).

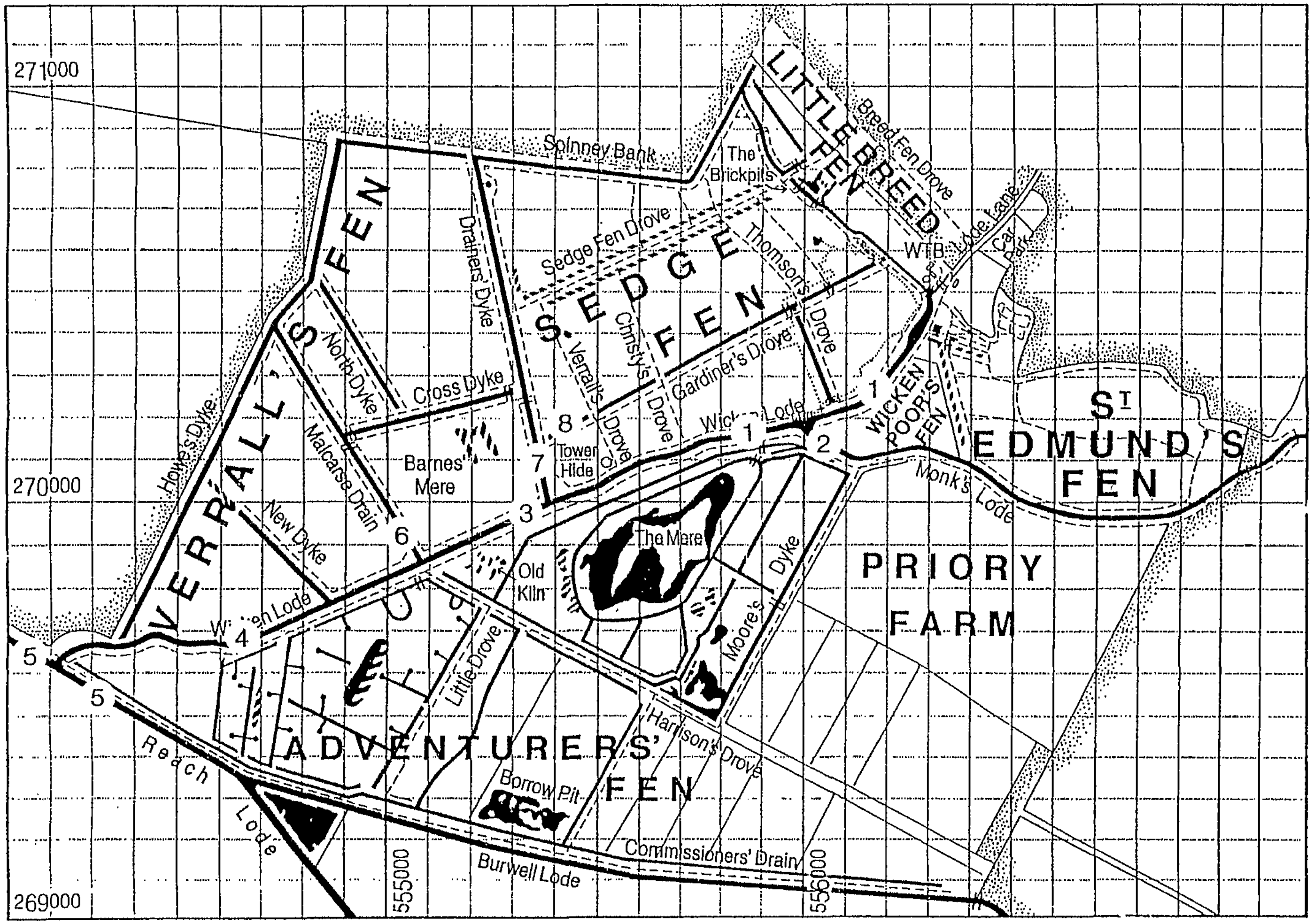


Figure 1. Map of Wicken Fen showing the sample zones in the main lodes and the three sections of dykes sampled

1: Wicken Lode 2. Monks Lode 3. Below Tower Hide 4. Reach up Wicken Lode
5a & 5b: Reach Lode 6: Malcarse Drain 7: Drainers Dyke 8: Gardiner's Ditch

Figure 2. Mean (± 1 SE) Spined loach density (n/m2) recorded in a range of habitats both in the current study and by Perrow & Jowitt (1997)

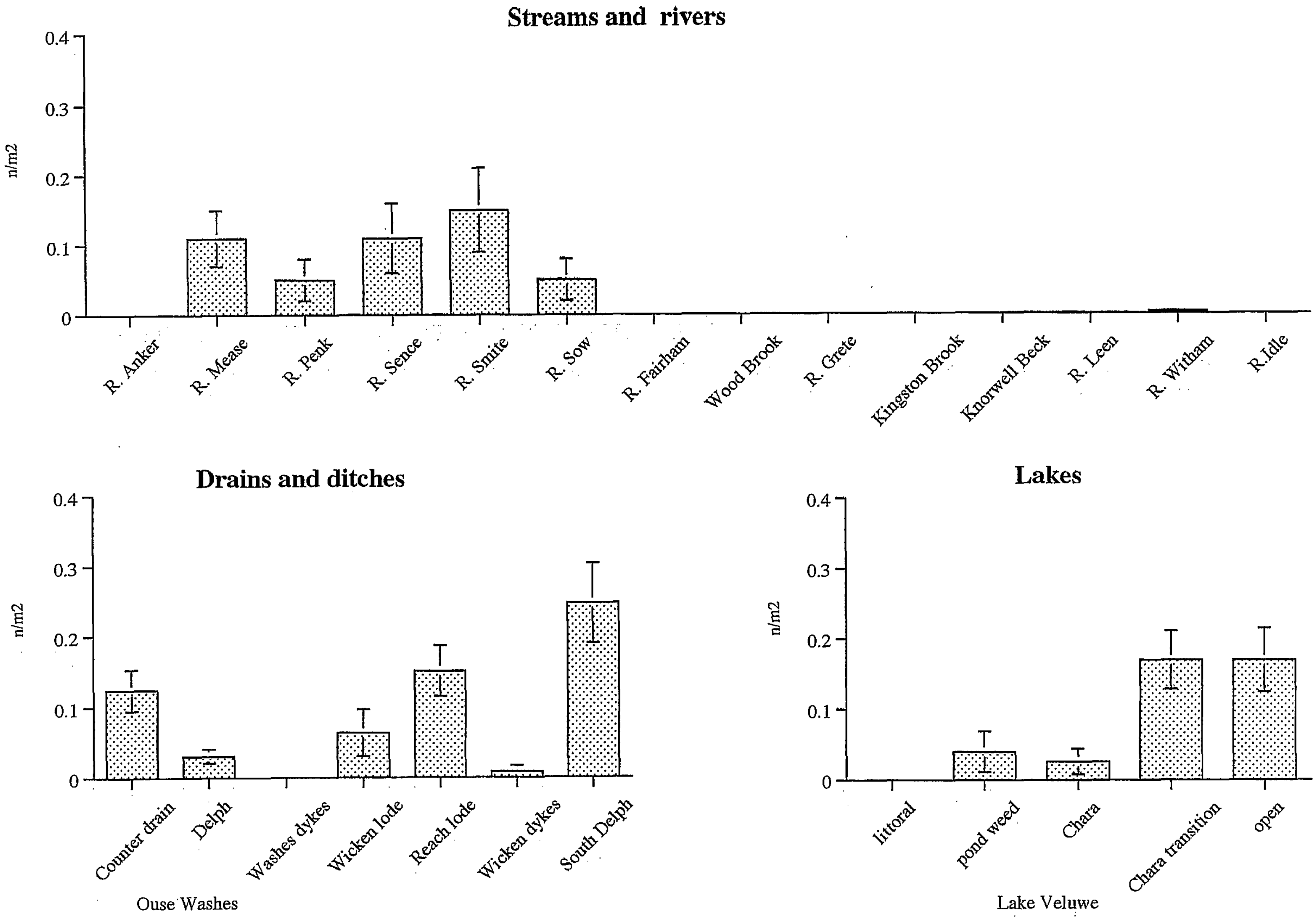
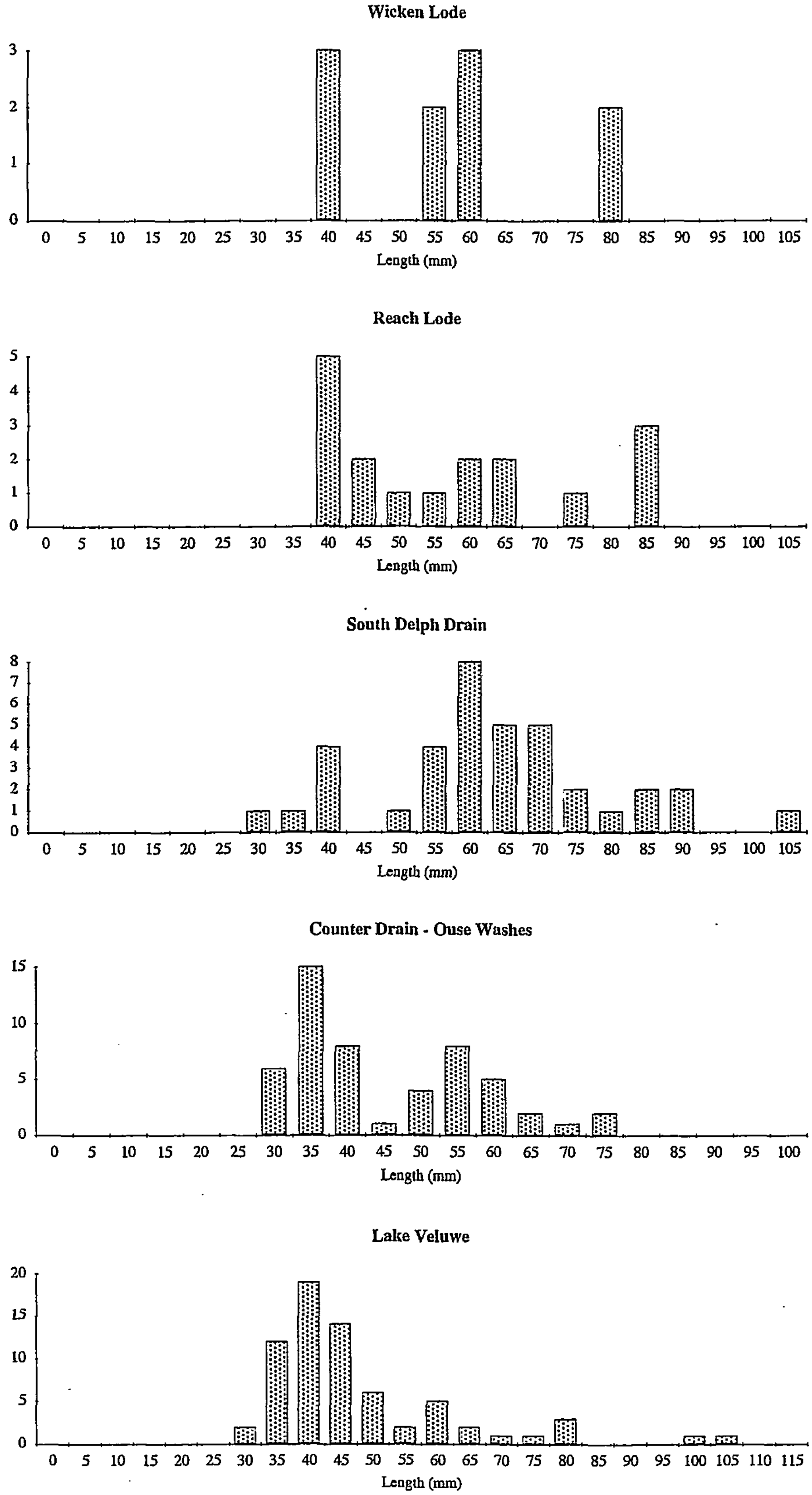


Figure 3. Comparison of the length frequency of Spined loach populations in a variety of sites sampled in the current study and in Perrow & Jowitt (1997)



Discussion

The definition of what is a good and viable population in a range of watercourses underpins any proposal to designate a site as a potential SAC.

Marconato & Rasoto (1989) sampling in a small (12-15 m wide and < 30 cm deep), stream in Northern Italy recorded a massive density of 73.8 m^{-2} of 0+ spined loach just after hatching. The density subsequently declined rapidly to 0.6 m^{-2} by November. If this pattern of extensive juvenile mortality holds, sampling in the autumn and winter represents something of a low point in the annual cycle and densities should be considerably higher during the summer months.

Sampling in the autumn/winter, was undertaken both during the current study and in that of Perrow & Jowitt (1997). These studies, which represent the only attempts to quantify the size of spined loach populations in the UK, recorded densities between 0.1 - 0.2 m^{-2} (Fig. 2) in a number of locations including the Ouse Washes cSAC, Reach Lode, South Delph Drain and several tributaries of the Trent including the rivers Mease, Sence and Smite. Comparing a variety of habitats, it appears that comparable densities may be achieved in a number of habitats from streams and rivers to slow-flowing drainage channels and lakes (Fig. 2).

A figure of at least 0.1 m^{-2} recorded in autumn/winter, although lower than that recorded by Marconato & Rasoto (1989), is suggested to be an indicator of a good population. The viability of the population, on the other hand, may be illustrated by the representation of a number of age classes, with a preponderance of 0+ fish. This is because the short life-span (probably a maximum of 3-4 years) (Robotham 1981, Marconato & Rasoto 1989), leads to a dependence on more or less annual recruitment, if the population is to be sustained. Population structure in Wicken & particularly Reach Lodes, the South Delph Drain were comparable to that in the outer river (Counterdrain/Old Bedford River) of the Ouse washes cSAC and Lake Veluwe, which were assumed to be viable (Perrow & Jowitt 1997). A viable population thus seems to be characterised by:

- A high proportion (preferably > 50 %) of 0+ fish.
- Two/three further peaks in a length-frequency distribution corresponding to the median value of older year classes.
- A maximum length of fish in excess of 85 mm and preferably larger.

Conclusions

No candidate SAC for spined loach can be proposed for the Trent catchment at the current time, although it is clear that reasonable densities of the species may occur at least in some of the tributaries.

The South Delph drain, part of a County Wildlife site owned by Anglian Water, supports a seemingly good and viable population of spined loach. On this basis it may be suitable as a cSAC within the Witham catchment. However, this will obviously depend on the site fulfilling a number of environmental and legal criteria to be answered by English Nature. Moreover there are a number of management issues surrounding the site, not least that treated effluent is discharged from the sewage works on the site. Although the site is clearly suitable for spined loach at the current time, will this be the case in the longer term in the face of further nutrient loading? The impact of any routine maintenance such as dredging also needs to be determined.

There is a sound basis for proposing Wicken Fen as a further cSAC in the Great Ouse catchment. This however, would benefit from incorporating at least part of Reach Lode which appears to support higher densities of spined loach than Wicken Lode. Reach Lode is also a much larger system and thus more likely to contain a sustainable population in the long term. There are a number of issues relating to routine maintenance of the system including dredging and cutting of emergent vegetation that will be need to be addressed.

B. Habitat relationships in drainage channels

Introduction

It has been suggested that spined loach prefers a sandy substrate with a dense, yet patchy coverage of rooted, submerged macrophytes (Perrow & Jowitt 1997). Sandy sediments are unlikely to be encountered in the slow-flowing lowland drains which are typically characterised by silty or muddy sediments (depending on the nature of the geology and the amount of material received from run-off from surrounding arable land). The occurrence of spined loach in these systems illustrates that they may tolerate silty or muddy sediments, although as stated by Lelek (1980), the layer of mud should not be thick or coherent. Thus the nature of the sediment may be critical as may the occurrence of macrophytes. In the Ouse washes cSAC, good populations of spined loach were only found in the outer river associated with macrophytes and a peaty sediment. In the absence of macrophytes and the presence of fine black anoxic sediment in the inner river, few spined loach were present. The nature of the sediment and the presence of macrophytes is dependent on the presence of algal crops, with dense algae shading out macrophytes and producing a rain of dead algal cells, which changes the nature of the sediment surface. This in turn may be dependent on nutrient loading and how this is expressed, which is typically a function of the density and biomass of coarse fish such as roach and bream. Large stocks of such zooplanktivorous/benthivorous fish may favour algal dominance by a number of mechanisms (see Perrow *et al.* 1997, Perrow & Jowitt 1997).

There was a clear need to clarify the relationships between spined loach and variables such as the occurrence of macrophytes and the nature of the sediment in drains, which may represent an important habitat in much of the range of spined loach, incorporating the lowlands of central and eastern England.

Methods

Sampling was conducted on the South Level Drain in the Witham catchment and the Wicken Fen system including Wicken, Monk's and Reach Lodes (see above) in the catchment of the Great Ouse.

In the Wicken Fen system, a series (5-10) of trawls were taken at 5 sites (Fig. 1), including 3 within Wicken Lode itself (30 in total), Reach Lode (15) and Monk's Lode (5) (Table 1). Forty-five trawls were thus taken in all.

In South Delph Drain, 10 trawls were taken both above and below the discharge of the sewage treatment works (STW) on the site, giving a total of 20 hauls.

In all hauls of all sites, the following environmental variables were recorded:

- Total number of fish species.
- Fish abundance and biomass.
- Number of macrophyte species.
- Cover of macrophytes.
- Cover of filamentous algae.
- Invertebrate abundance.
- Volume and type of sediment.

With the exception of the number of macrophyte species and sediment type, all variables were recorded as a rank score of 0-5. This approximated to the commonly used DAFOR scale used for macrophytes. In the case of invertebrates; 0 = zero individuals, 1 = 0-10, 2 = 10-50, 3 = 50-100, 4 = 100-1000, 5 = >1000. For sediment, if the net was empty this scored 0 and if it was entirely full, this scored 5. Other quantities of sediment were classified accordingly.

The relationship between the density of spined loach in each haul and any environmental variable was explored using Spearman's rank correlation coefficient (r_s).

Results

Density of spined loach

The mean density of spined loach was somewhat different in all drains sampled, being 0.25 ± 0.06 n m^{-2} in South Delph Drain, 0.15 ± 0.04 in Reach Lode and just 0.06 ± 0.03 in Wicken Lode (Table 2, Fig. 2).

In South Delph Drain there more significantly more spined loach above the discharge from the STW compared to below (Mann-Whitney Wilcoxon test, $Z=-2.0$, $p<0.05$). At Wicken, spined loach were significantly more abundant in Reach rather than Wicken Lodes (Mann-

Whitney Wilcoxon test, Z=-3.5, p<0.01). Within the Wicken system, spined loach were consequently patchily distributed (Kruskal-Wallis test, H=12.9, p=0.01) (Fig. 4)

Environmental variables

South Delph Drain contained just a few species of macrophytes (Canadian pondweed *Elodea canadensis*, hornwort *Ceratophyllum demersum*, unbranched bur-reed *Sparganium emersum* and yellow water lily *Nuphar lutea*). Coverage of these with filamentous algae, was much higher above, rather than below, the STW. A greater number of invertebrates was associated with this higher structural diversity. The lack of macrophytes below the STW was linked to considerable changes in the nature of the sediment, which became thick, and apparently anoxic, silt. As a consequence there tended to be a greater abundance and biomass of fish (excluding spined loach), particularly roach and perch upstream of the works (Fig. 5).

Even though Wicken Lode is directly connected to Reach Lode the conditions are very different in each (Table 2). A large number of macrophyte species (yellow water lily, unbranched bur-reed, water forget-me-not *Myosotis scorpioides*, water violet *Hottonia palustris*, Canadian pondweed, water crowfoot *Ranunculus* spp., starwort *Callitriche* spp., fennel pondweed *Potamogeton pectinatus* , an unidentified pondweed species and stonewort *Chara* spp.) were encountered in Wicken Lode whereas only yellow water lily, unbranched bur-reed and hornwort were found in Reach Lode. Indeed, macrophytes were largely replaced by a dense cover of filamentous algae. This was in keeping with the nature of the sediment of the two sites, with silty, flocculent sediment in Reach and peat-based sediment in Wicken Lode. The higher diversity of macrophytes in Wicken Lode led to a higher number of invertebrates, although the number of fish species represented, fish abundance and biomass were all reduced (Table 2). The fish community was however comprised of mainly tench and pike in Wicken Lode, which is characteristic of macrophyte-dominated waters (Perrow & Jowitt *in press*) (Fig. 5). In Reach, cyprinids such as roach and bitterling were numerically abundant.

Figure 4. Mean (± 1 SE) density of Spined loach in the 5 sites sampled in the lodes of the Wicken Fen system

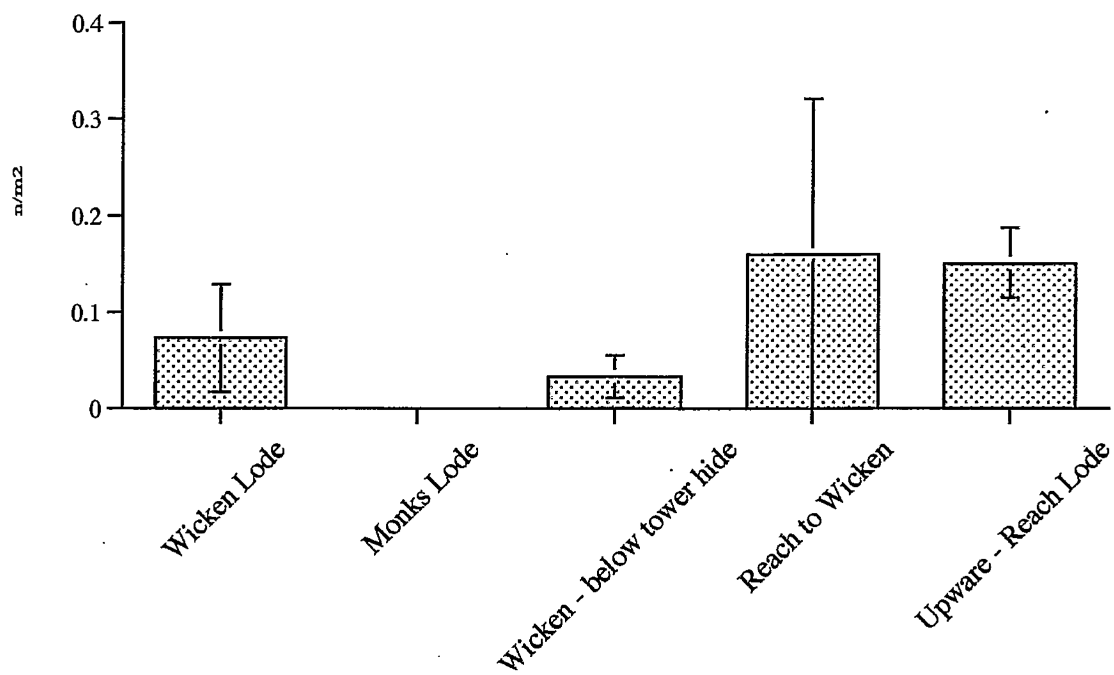


Figure 5. Species composition (% by abundance-n/m2) of the fish communities in various drainage channels sampled in the current study and by Perrow & Jowitt (1997)

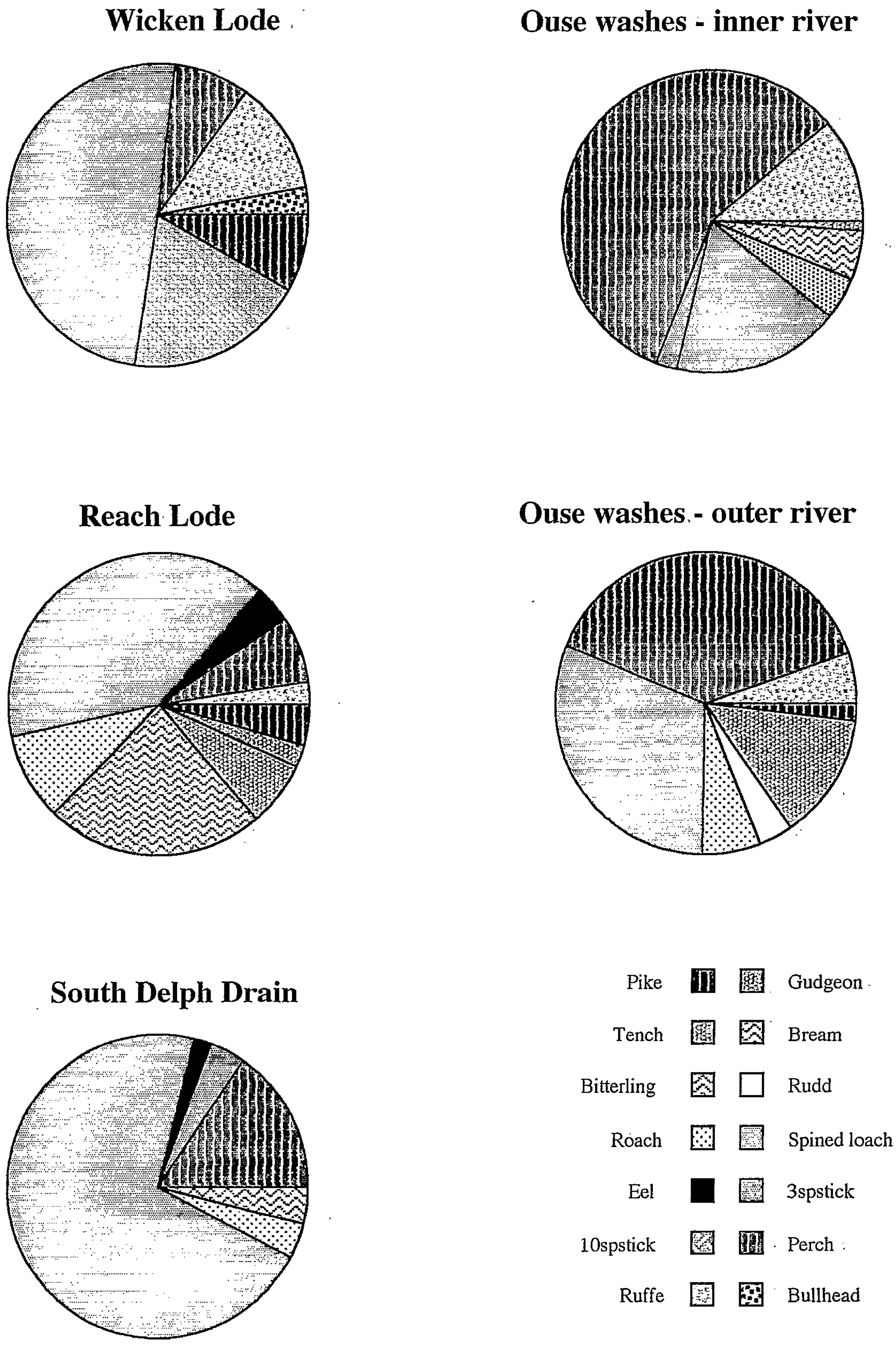


Table 2.
The mean (± 1 SE) values (different units) of a number of environmental variables recorded by trawl samples in South Delph Drain and the Wicken system.

	South Delph Drain		*Wicken Fen*	
	Above STW	*Below STW*	*Wicken Lode*	*Reach Lode*
Density of spined loach	0.15 ± 0.08	0.35 ± 0.07	0.06 ± 0.03	0.15 ± 0.04
Number of fish species	3	4	5	8
Fish abundance (n m^{-2})	0.12 ± 0.05	0.08 ± 0.03	0.07 ± 0.02	0.23 ± 0.07
Fish biomass (g m^{-2})	0.75 ± 0.37	0.34 ± 0.16	0.58 ± 0.24	4.43 ± 1.78
No. macrophyte species	1.50 ± 0.17	1.30 ± 0.33	3.28 ± 0.30	1.47 ± 0.13
Macrophyte cover	2.60 ± 0.22	1.1 ± 0.28	1.28 ± 0.11	1.87 ± 0.24
Filamentous algal cover	0.60 ± 0.22	0.0 ± 0.0	0.03 ± 0.03	4.67 ± 0.27
Invertebrate abundance	1.90 ± 0.23	0.60 ± 0.22	1.80 ± 0.14	1.07 ± 0.12
Sediment volume	0.50 ± 0.17	4.7 ± 0.21	0.89 ± 0.20	2.07 ± 0.43
Sediment type	mud	black silt	peat	brown silt

Relationships between spined loach and environmental variables

In the South Delph Drain, spined loach density was significantly positively correlated with the volume of sediment (Table 3). As a considerably higher density of spined loach was found downstream of the STW (Table 2) in the presence of the large sediment volumes, spined loach was also characteristically associated with black anoxic silt at this site.

In the Wicken system, spined loach was significantly negatively correlated with the number of macrophyte species, but positively related to the cover of filamentous algae and sediment volume (Table 3). As a considerably higher density of spined loach was found in Reach Lode (Table 2) in the presence of the large sediment volumes, spined loach was also characteristically associated with silty sediments in Wicken.

Figure 6. The River Mease, a semi-natural tributary of the River Trent

Figure 7. The River Smite, a semi-natural tributary of the River Trent

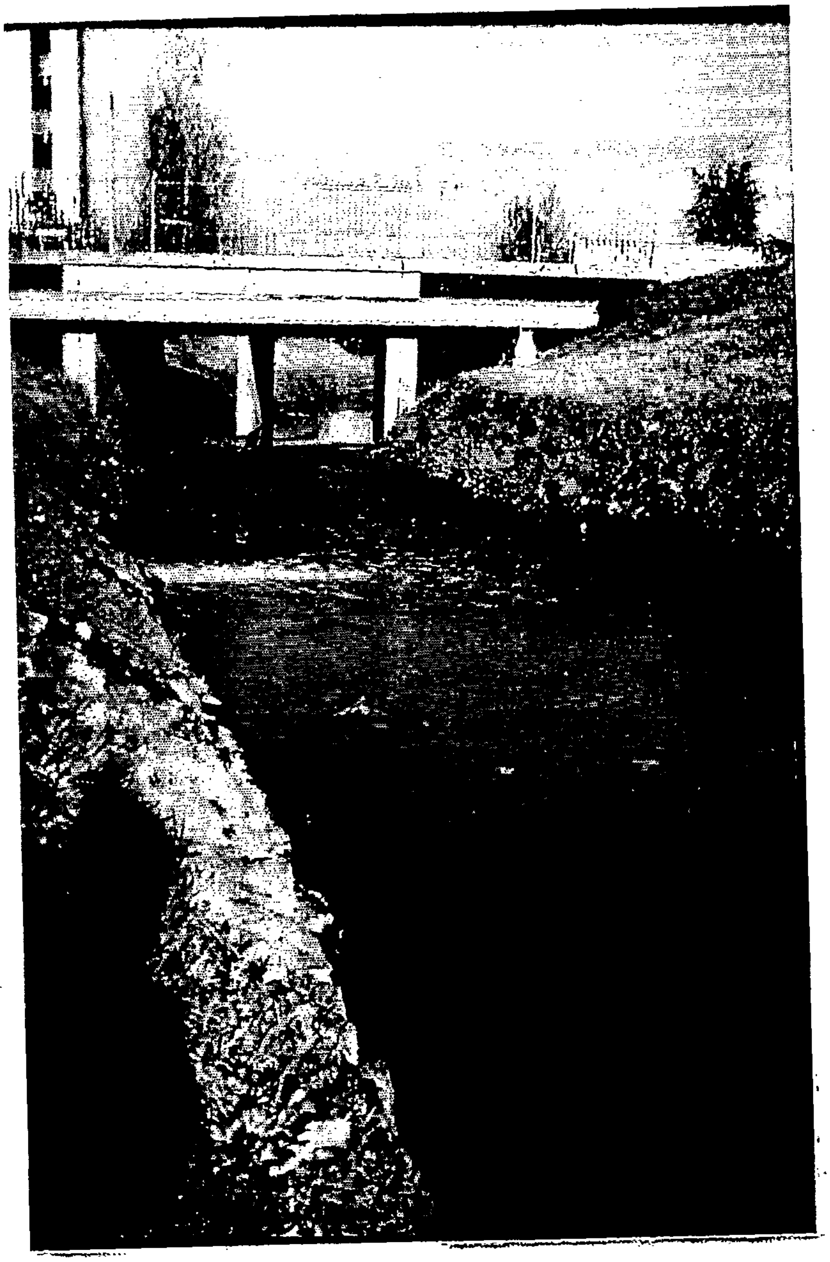


Figure 8. The River Leen, a modified tributary of the River Trent

Figure 9. The Knorwell Beck, a modified tributary of the River Trent

Table 4.
Site details of the semi-natural and modified study rivers.

Status	*Name*	*Site*	*Grid reference*	*Date sampled*	*Agency contact*
Semi-natural	River Smite	Cotham RGS	SK 786477	13/11/97	JL
	River Mease	Edingale	SK 314116	25/11/97	TJ
	River Anker	Leathermill	SK 343956	24/11/97	TJ
	River Sence	Ratcliffe Culey RGS	SP 322995	25/11/97	TJ
	River Sow	Cresswell Farm	SJ 892261	19/11/97	TJ
	River Penk	Stafford	SJ 949221	19/11/97	TJ
Modified	Kingston Brook	Sutton Bonington	SK 512269	14/11/97	JL
	River Leen	QMC	SK 550388	12/11/97	JL
	River Greet	Rolleston Mill	SK 741527	13/11/97	JL
	Wood Brook	Loughborough WRW	SK 532216	12/11/97	JL
	Fairham Brook	Bunny	SK 589292	14/11/97	JL
	Knorwell Brook	Carlton-on-Trent	SK 804641	20/11/97	JL

Sampling strategy

All sampling was conducted between 12-25th November 1997 (Table 4). Point-abundance sampling (PAS) by electrofishing, was used. Details of the gear used are provided in *Establishing further SAC's* (see above). Fifty points were sampled at 4 m intervals within the 200 m sampling section within each stream. Placing the gear on the bank in the middle of the sample section and using a 100 m cable attached to the anode, allowed the entire section to be covered by wading, without the need to transport gear during sampling.

At each point (within a radius of 1.3 m^{-2}), the following habitat variables were recorded:

- Abundance (%) of each substrate type (sand, silt, clay, gravel < 3 cm and stones >3 cm)
- % cover of woody debris and leaf litter.
- % cover of submerged, emergent and floating macrophytes
- % cover of overhanging (within 30 cm of the water surface) vegetation;
- Depth (cm).
- Flow velocity (cm sec^{-1}), determined from the time taken for a squash ball to travel 1 m.

Any fish captured at each point was identified and measured to the nearest mm. The biomass of all fish was calculated from a series of known length-weight regressions.

Data analysis

The density (determined by dividing the total number captured in each stream by the area sampled) of spined loach was compared between the two groups of streams by Mann-Whitney Wilcoxon U-tests. This was also undertaken for the mean values of the various environmental variables (see above), invertebrate community diversity (BMWP score) and a number of water quality parameters (* to be determined*) .

For selected streams in which a reasonable number of spined loach were captured, Mann-Whitney Wilcoxon U-tests were used to compare the value of the habitat variables cited above, at points with and without spined loach. This aimed to determine the habitat associations of spined loach in every stream sampled and ascertain if there were general trends in the types of habitats selected and if a potential hierarchy of habitat selection existed. Length-frequency histograms of spined loach were also prepared for streams which contained a reasonable number of spined loach, in order to determine the general age class structure and relative strength of recruitment.

Results

The density of spined loach was significantly greater in semi-natural rather than modified streams. In fact, none were captured in the modified streams whereas 5 of the 6 semi-natural streams contained spined loach (Fig. 10a). The density of these populations was not high, but in three of the streams (Mease, Sence and Smite) was between 0.1 - 0.2 m^{-2} (Fig. 2), which seems to be typical for many, apparently sustainable populations, at this time of year (see *Establishing further SAC's* above). Interpretation of the age structure and thus likely viability of the population was hampered by the small number of fish captured in all sites (Fig. 11).

The presence of spined loach was generally mirrored by the fish community structure. Semi-natural streams had a greater species richness (excluding spined loach). The community structure in the semi-natural streams tends to be more diverse with a number of small species dominating numerically, including bullhead, minnow (*Phoxinus phoxinus*), spined loach and gudgeon (*Gobio gobio*). Modified streams on the other hand tended to be dominated by stone loach (*Barbatula barbatulus*) and three-spined stickleback (*Gasterosteus* *aculeatus*) (Fig. 12). Fish biomass also tended to be dominated by larger species such as chub (*Leuciscus cephalus*), dace (*Leuciscus leuciscus*) and pike (*Esox lucius*) in semi-natural rivers, and eel (*Anguilla anguilla*) and stone loach in modified streams (Fig. 13). Overall, fish communities only responded to channel modification by structural changes as no significant differences in abundance or biomass were recorded.

In general, semi-natural streams tended to be wider and on average, deeper, with a slower mean flow. They typically had a greater abundance of emergent vegetation and the bed substrate often contained clay (Fig. 10a). ***Water quality information will be included here***Fig. 10b

In streams where spined loach was present at 5 points or more (i.e. 10%) (the Mease, Sence and Smite), spined loach selected for a different variable in each. For substrate variables, these included sand in the Smite, leaf litter in the Sence and a negative selection for gravel in the Mease. Overhanging vegetation was also selected in the Sence (Table 5).

Table 5.

Comparison of the habitat variables at sample points with and without spined loach in study rivers at which spined loach was present at 10% or more of points. The Mann-Whitney Wilcoxon test statistic Z and associated probabilities (p), where *< 0.05, ** < 0.01, * <0.001 are shown.**

	Mease		*Sence*		*Smite*	
Variable	Z	p	Z	p	Z	p
Depth	-1.49	NS	-0.07	NS	-0.24	NS
Flow velocity	-0.60	NS	-0.38	NS	-0.79	NS
% silt	-0.45	NS	-1.75	NS	-0.31	NS
% sand	-0.77	NS	-0.51	NS	-2.92	**
% clay	-1.88	NS	-0.33	NS	-4.44	NS
% gravel	-2.78	**	-0.70	NS	-1.04	NS
% stones	-0.64	NS	-1.71	NS	-0.45	NS
% leaf litter	-0.65	NS	-1.95	*	-4.44	NS
% woody debris	-0.86	NS	0.00	NS	-0.62	NS
% submerged macrophytes	-0.26	NS	-1.19	NS	-1.58	NS
% emergent macrophytes	-1.63	NS	-0.90	NS	-7.77	NS
% floating macrophytes	-0.36	NS	-0.85	NS	0.00	NS
% overhanging vegetation	-1.20	NS	-3.00	**	-0.39	NS
% filamentous algae	-0.37	NS	0.00	NS	-1.22	NS

Figure 10a. Comparison of spined loach density (n/m2) and fish and invertebrate communities, between selected semi-natural (n=6) and modified (n=6) tributaries of the river Trent.
The Mann-Whitney Wilcoxon Z statistic and associated probability (p) where * = <0.05, ** p<0.01, *** p<0.001, are shown

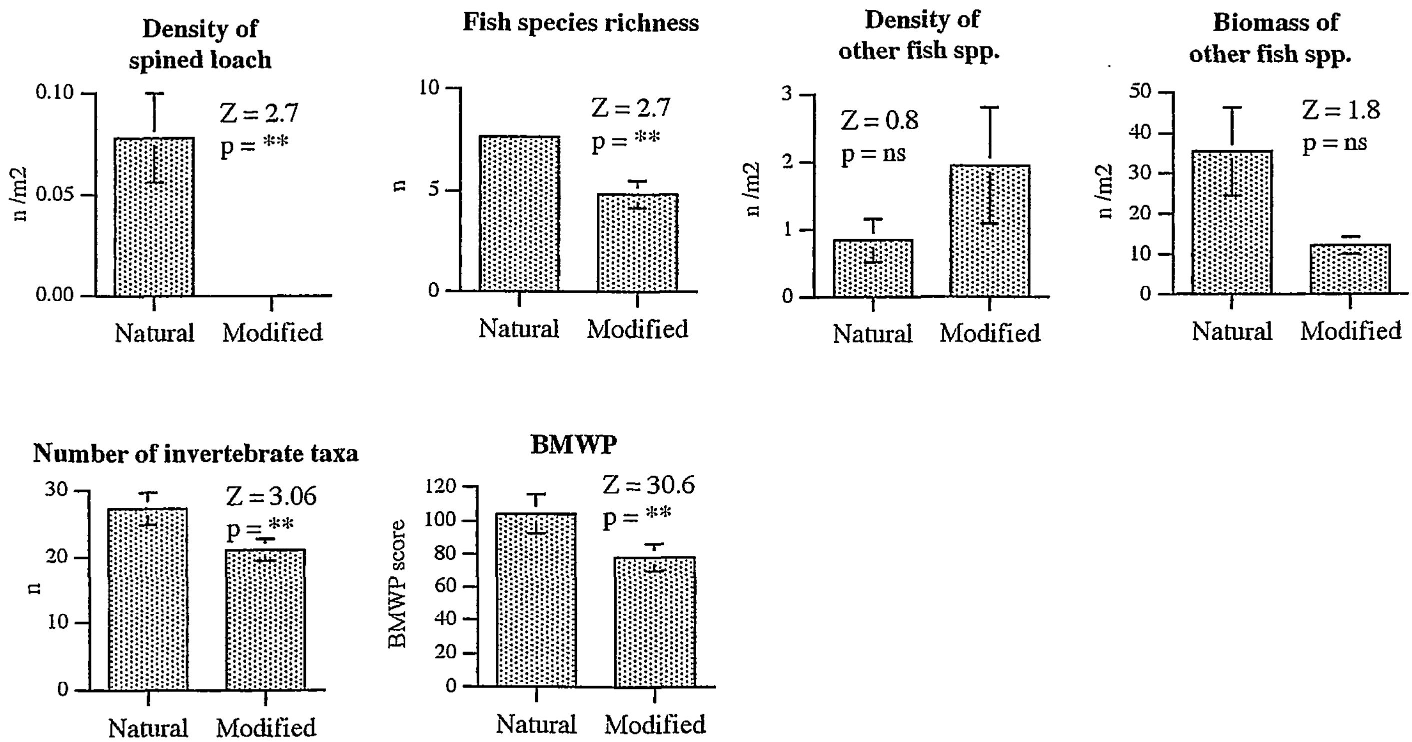


Figure 10b. Comparison of habitat variables, between selected semi-natural (n=6) and modified (n=6) tributaries of the river Trent.
The Mann-Whitney Wilcoxon Z statistic and associated probability (p) where * = <0.05, ** p<0.01, *** p<0.001, are shown

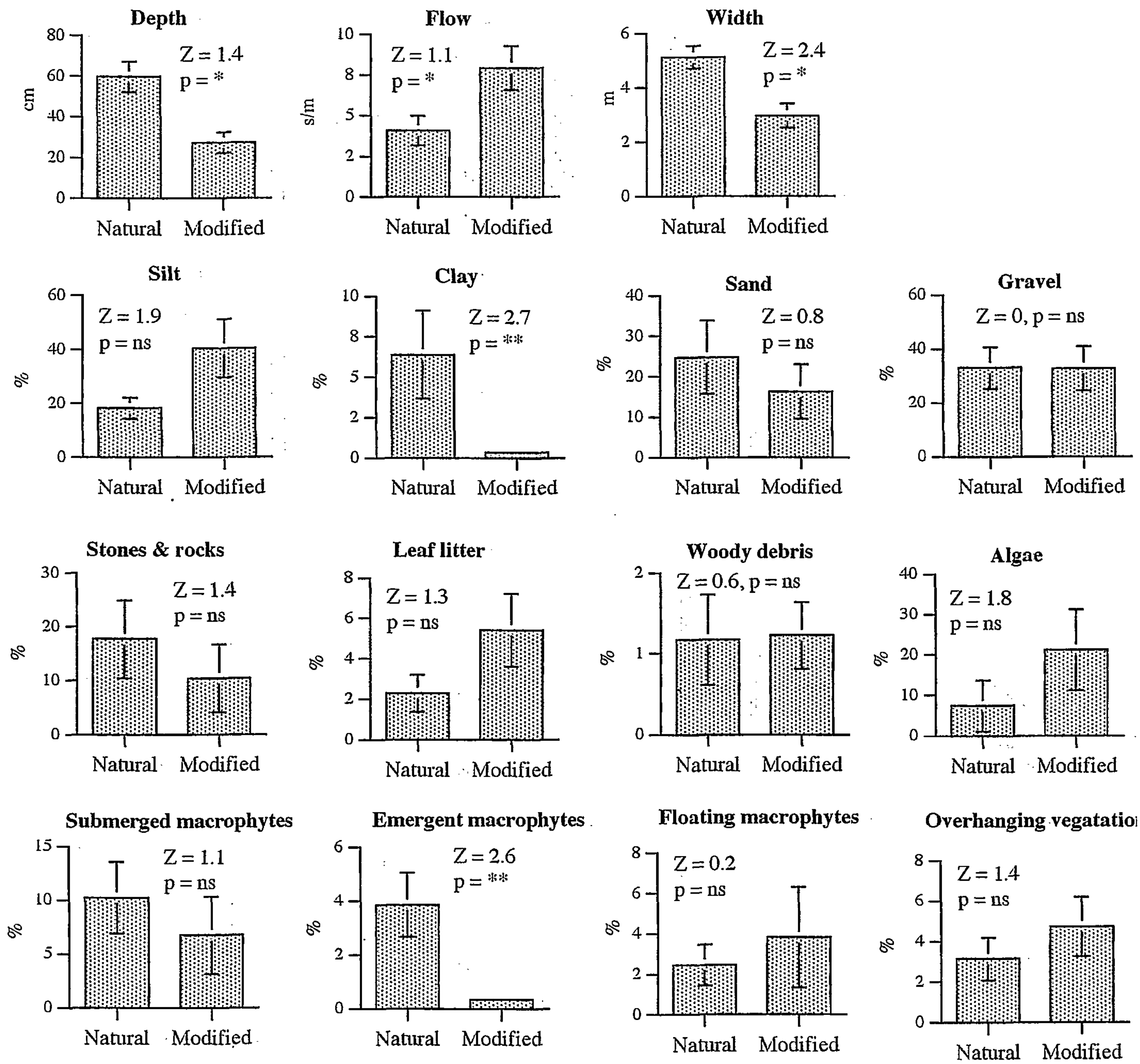


Figure 11. Length frequency distribution of Spined loach captured in the semi-natural rivers Mease (n = 7), Sence (n = 7) and Smite (n = 10)

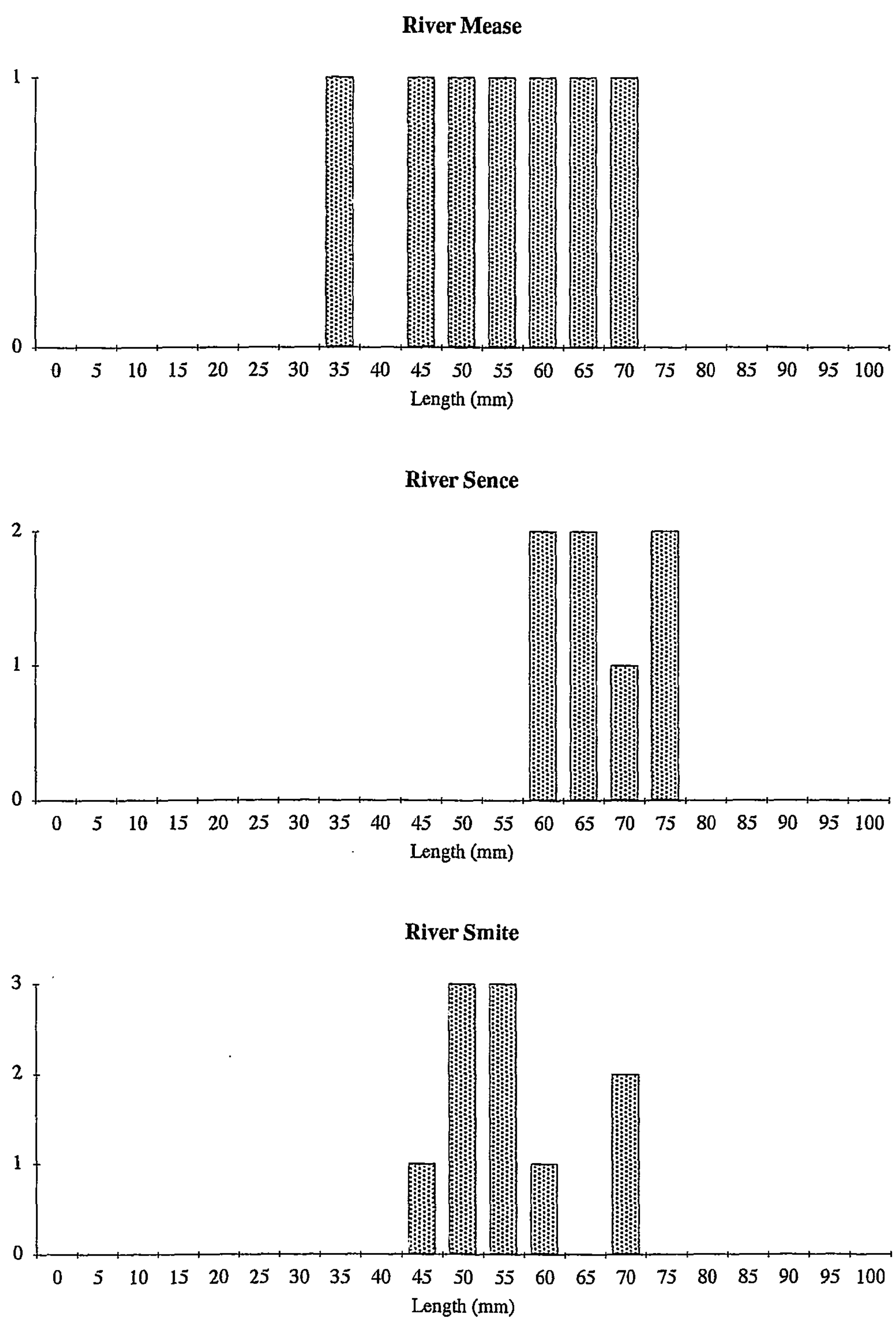


Figure 12. Comparison of fish community composition (% by number -n/m2) in selected semi-natural and modified tributaries of the River Trent

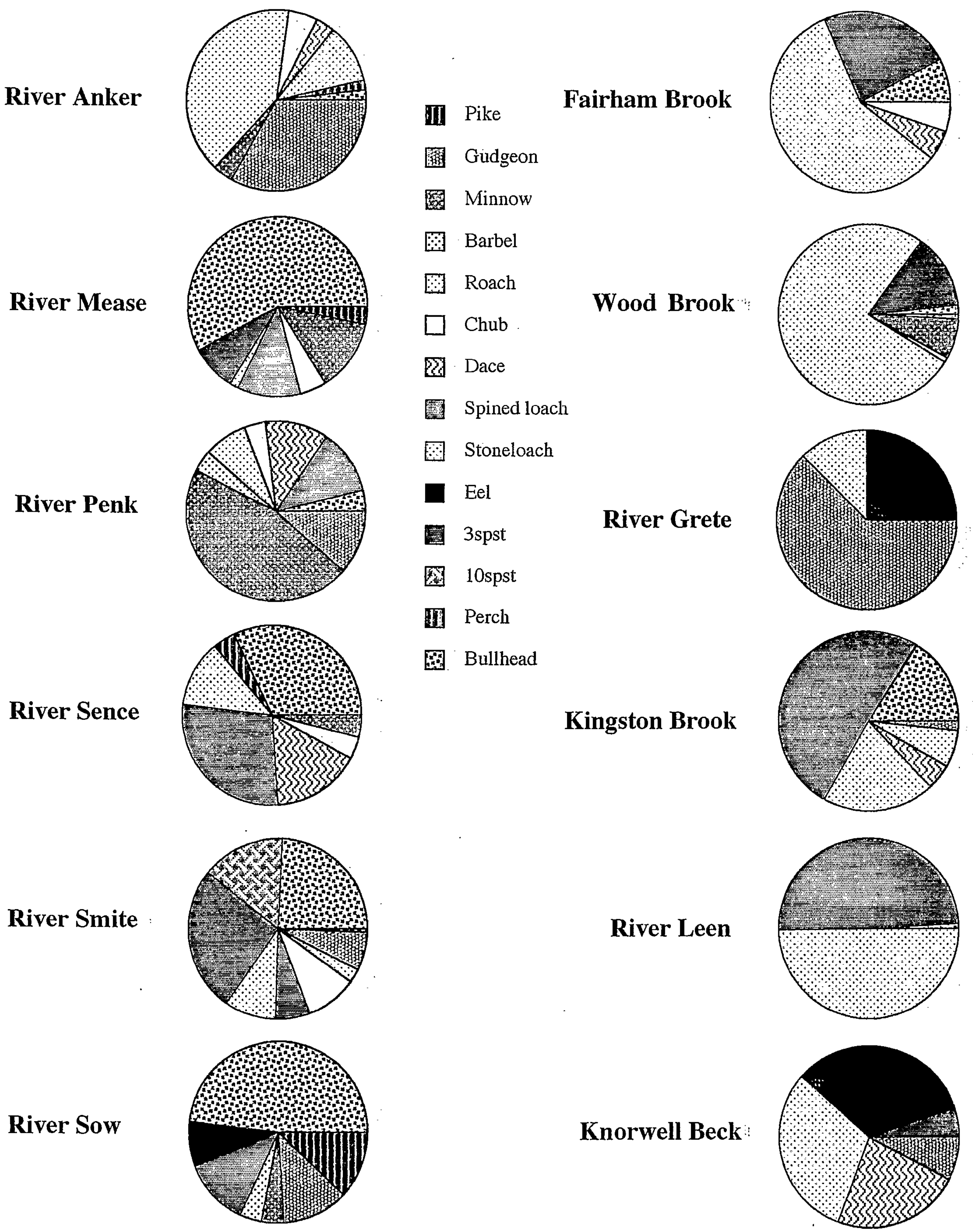
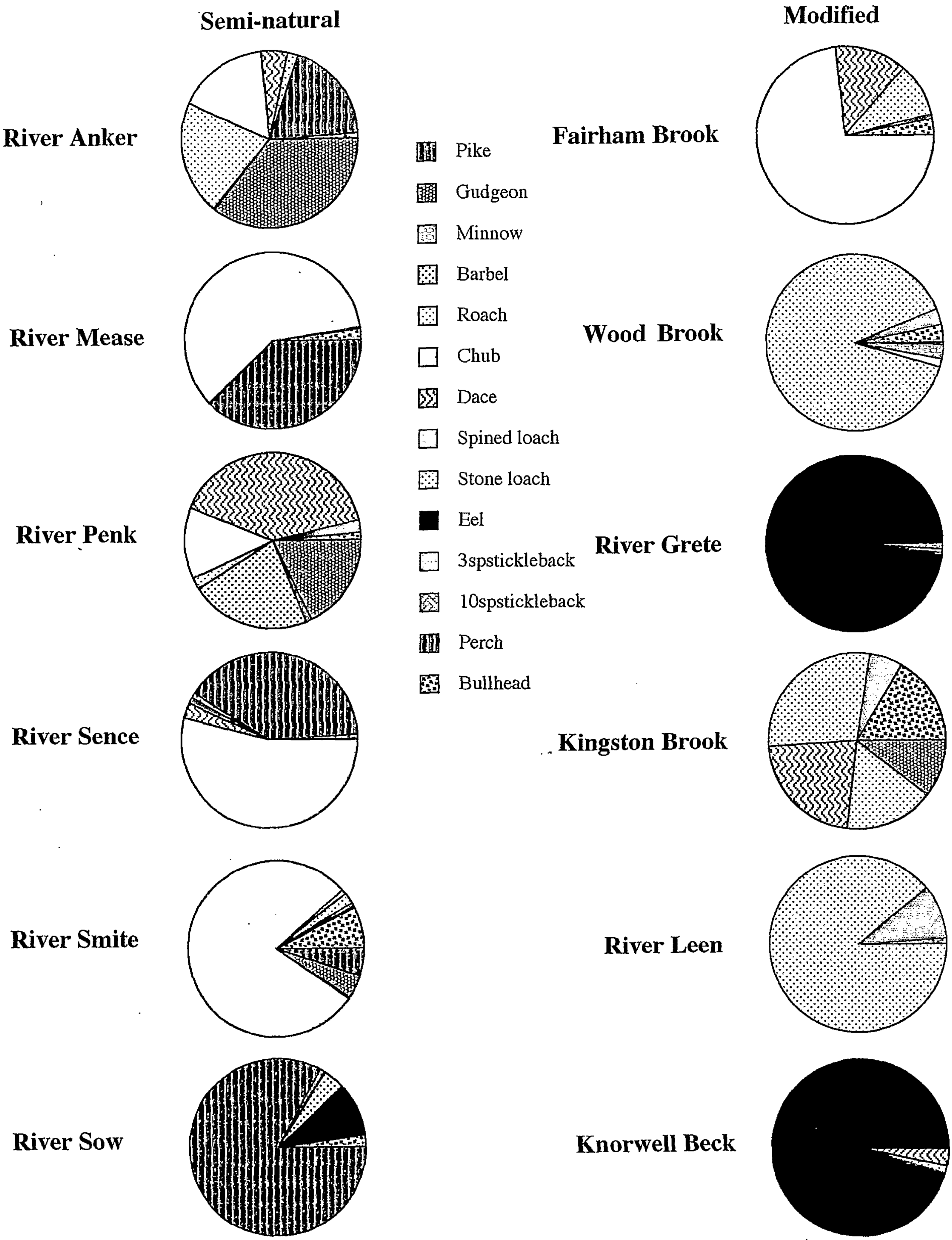


Figure 13. Comparison of fish community composition (% by biomass -g/m2 in selected semi-natural and modified tributaries of the River Trent



Discussion

The general conclusion of Perrow & Jowitt (1997) that more natural, undisturbed streams are more likely to support spined loach is borne out by the current study. The presence of spined loach in more natural streams, leads to an association between the species and diverse fish and invertebrate communities. Both of the latter are characteristic of more diverse physical habitat structure (invertebrates - Everett & Ruiz (1993), O'Connor (1991), fish - Gorman & Karr (1978), Kirchhofer (1995), Perrow *et al.* (1997)). Spined loach may therefore be an indicator of general habitat quality.

Water quality information will be included here

The timing of sampling, in late autumn, precluded a full description of the habitat characteristics of semi-natural and modified streams. Moreover, it was also clear that even semi-natural streams were subject to routine maintenance by the Agency. This included extensive weed-cutting on at least the Sow and the Penk. In the Sow at least, this lead to the loss of many small fish (possibly loach) as they were removed with the weed which was deposited on the bank. At least one member of the public complained (Agency staff *pers comm.*). Natural and anthropogenic changes in habitat quality at the end of the growing season may have been responsible for the generally low level of differentiation in habitat variables (apart from the abundance of emergent vegetation) between the two groups of streams. It is consequently difficult to determine what limits spined loach in the modified streams.

The obvious candidate, however, is flow, being significantly higher in modified channels. In his study on the Great Ouse, Robotham (1978) showed spined loach selected for lower (mean of 15 cm sec^{-1}) rather than higher (mean of 29 cm sec^{-1}) flow. In the current study, flows were far lower than in Robotham's study, being on average 7.9 cm sec^{-1} in modified, and only 4 cm sec^{-1} in more natural, streams. The general morphology and small size of spined loach suggests it is incapable of surviving in fast-flowing water. Lateral compression of the body may be an adaptation to burying or squeezing into confined spaces, for example amongst macrophytes or algae. This contrasts with the dorsally flattened profile (creating a triangular cross-section) of stone loach, which is often associated with relatively fast-flowing streams. Spined loach may therefore only be able to persist in relatively natural streams with unmodified flow regimes, as these offer areas of slack water. Fine sediments would also tend to deposit in such areas, providing a suitable habitat and food supply (Robotham 1978).

It is also possible that more natural streams provide suitable refuges from potential predation from larger omnivorous fish species such as chub, eels, perch etc. These tended to more abundant in the more natural study streams, which illustrates that spined loach may co-exist with such species, but presumably only in the presence of refuges. The lack of diversity in modified streams may leave spined loach, especially 0+, vulnerable to predation and ultimately prevent the maintenance of a population.

The presence of larger populations of stone loach in the modified streams compared to natural streams (0.21 ± 0.11 n m^{-2} and 0.06 ± 0.04 n m^{-2} respectively, Mann-Whitney Wilcoxon test $Z = -2.2$, $p<0.05$) also introduces the possibility that competition between the two loach species is important in determining the numbers of spined loach. Stone loach feeds amongst fine sediments using olfaction to detect prey. It thus may occupy, and feed in, similar micro-habitats to spined loach. The diet of stone loach typically contains a high proportion of chironomid larvae. The size of prey taken is therefore much larger than that of spined loach (0.2-0.75 mm -Robotham 1977) suggesting direct competition for shared resources is unlikely. This is not to say that disturbance and modification of sediment structure by foraging stone loach or simply the physical presence of stone loach, may not be important. Spined loach clearly co-exists with bullhead, another small fish species, in the semi-natural streams under study. This may be possible as bullheads feed visually, taking even larger prey than stone loach (particularly *Asellus aquaticus*, *Gammarus pulex*, ephemeropteran nymphs and caddis larvae as well as chironomids - Welton *et al.* 1983), and tend to feed over exposed gravels rather than fine sediments (Welton *et al.* 1983). Incidentally, there is no evidence that stone loach and bullheads compete (Welton *et al.* 1991).

The tendency for semi-natural streams to be wider and deeper also introduces the possibility that spined loach were actually selecting for larger rivers, perhaps closer to the confluence with the Trent. It could be argued that larger rivers are more likely to provide the resources required for spined loach. However, spined loach are known to occur in very small streams (e.g. Ahnelt & Tiefenbach 1994). Unless spined loach exists in a particular form adapted to a specific set of resources linked to the size of the stream (as in Japan-see Saitoh 1990), there seems little reason why spined loach were absent in the small steams in the current study, apart from the fact that were modified.

Conclusions

The current study supports the view that spined loach are associated with more natural streams with diverse habitat structure, which have more diverse fish and invertebrate communities. The preference for unmodified streams may be linked to a) the presence of slower flow in at least some sections of natural streams b) the provision of refuges against predation in more structurally diverse habitats c) competition with stone loach, which may dominate in unmodified streams, or d) any combination of these factors. The observed habitat preferences of spined loach support the contention that fine sediments, particularly sand, with the presence of refuges (in this case emergent macrophytes, leaf litter, overhanging vegetation in the absence of submerged macrophytes) are important. However, there is a real need for a longer term study elucidating the habitat preferences of spined loach in relation to population dynamics, the impact of habitat management and seasonal changes in habitat selection as fish grow, macrophytes develop and decay, and flow regimes change (see Perrow & Jowitt 1997 for full details).

D. Management guidelines

Introduction

A number of preliminary general guidelines were provided in the report by Perrow & Jowitt (1997). In any system containing important populations of spined loach, these were to reduce eutrophication, excessive loading of fine sediments, excessive stocking of benthivorous fish and any wholesale management of river and stream channels (e.g. channelization) that cause a significant reduction in habitat diversity. More specific guidelines stemmed from the short-lived nature of spined loach and its reliance on annual recruitment to maintain populations, which suggests that the effects of various management practices used by the Agency and other organisations, such as dredging, weed-cutting and channel profiling, may be considerable. Reductions in the frequency of management, leaving unmanaged refuge areas and alternatives to routine management were suggested.

There was little scope in the current study to expand on these management guidelines apart from the general impact of modification of streams (see *Habitat relationships in streams and rivers* above).

Conclusions

From information gathered from 12 tributaries of the River Trent, it clear that modification of streams typically for land drainage and flood defence purposes, causing a reduction in physical habitat diversity, has a detrimental impact on spined loach (see *Habitat relationships in streams and rivers* above).

Unfortunately, the reasons behind this impact are unclear. Possibilities include the loss of preferred substrate, increase in flow above a tolerable threshold, loss of refuges against predation and an increase in potential competitors (e.g. stone loach). Specific, longer-term research into these relationships is required (see *Habitat relationships in streams and rivers* above and Perrow & Jowitt 1997 for full details). The impact of routine maintenance such as weed-cutting and dredging also needs to be thoroughly investigated. The impact of both is likely to be considerable (see *Habitat relationships in streams and rivers* above and Perrow & Jowitt 1997).

Acknowledgements

We are grateful to Mary Gibson for managing the project. Thanks to Tim Jacklin and Jim Lyons of the Agency and Wendy Brooks of EN, amongst others, for providing invaluable information. We are also grateful to all those site managers and landowners, too numerous to mention, who allowed access to their land.

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Appendix 1:

Terms of reference

Background

The spined loach, is a small bottom dwelling fish which is confined to the rivers and drainage channels in the Midlands and eastern England.

Although it is generally considered to be widely distributed within these areas, its threatened status within Europe has led to it being listed on Appendix 3 of the Bern Convention and Annex II of the EC Directive on the conservation of natural habitats and wild flora and fauna.

Historically there has been little systematic survey or monitoring for spined loach, and little research into its ecology. Consequently there is still a lack of detailed understanding of its distribution and habitat requirements, and the implications that different management operations might have on populations.

A research project undertaken by ECON (97) provided new and valuable information on distribution and habitat requirements. In particular, it indicated that populations were centred on three main catchments, the Ouse, Witham and Trent and that the spined loach appeared to be associated not so much with muddy, silty substrates, but with macrophytes. It also examined the fish species with which it appeared to co-exist, and found positive correlations with trout.

Results from this work were used to develop interim management guidelines and to confirm the selection of Special Areas of Conservation for the spined loach in the Ouse Catchment.

The work to date has centred on the main R. Ouse and associated ditches and dykes, and there is now a need to extend the focus of the work to look at the other two main catchments where it occurs, the Witham and Trent, and to examine its habitat preferences there. In doing this, it will be important to both test the findings from the R. Ouse catchment regarding macrophyte preferences and to extend the analysis to look at streams and rivers.

With this more comprehensive information it will then be possible to provide more definitive information on habitat requirements, management guidelines and possible river rehabilitation objectives.

Aim

The aim of the project is therefore to extend the existing work and to provide more information clarification on:

1. distribution in the Trent and Witham Catchment

2. habitat preferences/requirements in main river ditches and dykes

3. habitat preferences/requirements in streams and rivers

4. associations, therefore characterisation profiles, for main rivers ditches, dykes streams and rivers containing spined loach

5. expanded management guidelines

6. identification of characteristic/representative sites containing healthy, viable populations of spined loach in the Witham and Trent Catchments.

7. general river rehabilitation targets to enable spined loach populations to be enhanced.

Method

Initially the contractors will be expected to analyse existing information on fish distribution, habitat type and quality and water quality within the Witham and Trent Catchments to identify potentially suitable sites for spined loach.

In order to test the ideas regarding habitat preferences and management implications the contractor will also be expected to identify and sample a number of sites not considered suitable for spined loach.

Selected sites will then be surveyed using appropriate sampling techniques, either hand trawls or electrofishing apparatus to confirm the presence or absence of spined loach and to provide further details where necessary of physical chemical and biological features, to allow for meaningful analysis.

Information to be collected should include, but not necessarily be restricted to estimates of relative abundance of all fish species. Occurrence and relative abundance of the main macrophyte species. Percentage cover of substrate classes. Width/depth. Riparian vegetation. Adjacent land use. A crude scale of channel naturalness.

Information on key habitat features, water quality, spined loach and other species of fish should be collated and analysis undertaken. These should include, but not be restricted to producing length frequency plots, and analysing the relationship between site features and spined loach size classes and trout size class and spined loach size class.

Results

Results from each site should be presented in a written and tabulated format.

They should be used to illustrate the likely distribution of spined loach in the Witham and Trent Catchment, its habitat preference, and to evaluate both its requirements and the species with which it is associated.

It should discuss under different headings characterisation criteria, management guidelines and rehabilitation objectives.

Management guidelines should focus on dredging, weed cutting channel profiling and littoral margin management and channelisation in small streams.

Duration

This contract will commence 14 July 1997 and terminate by 31 December 1997.

Outputs

The output of this project will be a written report, containing appropriate figures and tables.

A draft report should be produced by 31 October, a final report by 31 December

The latter must be to the satisfaction of the nominated officer..

Project Management

The nominated officer will be Mary Gibson.

The project will be overseen by a steering group with representatives from English Nature and the Environment Agency.

The contractor will be expected to attend two meetings, one at the onset of the project, and one after submission of the draft report.

The contractor will also be expected to organise and run a one day training course for staff from both English Nature and the Environment Agency, in order to demonstrate distribution and habitat preferences of spined loach, and to facilitate discussions on management requirements. The contractor will be expected to prepare and distribute a short note on relevant aspects of spined loach ecology for this training day.

Payment

50% of the total cost of the project will be paid on receipt of the draft report.

The other 50% will be paid on receipt of a satisfactory final report.

Health and Safety

The contractor will be expected to satisfy the nominated officer that appropriate health and safety procedures are adhered to at all times during the undertaking of this project.

Appendix 2:

Details of selected sites

Sites of Nature Conservation Importance
River Witham and Adjacent Sites

SK85

Beckingham Ranges SNCI Grid Ref: SK 878554

Grassland and hay meadows on both sides of the Witham, owned by the Ministry of Defence. The site supports a rich assemblage of calcareous grassland species, along with an artificial pool with a rich marginal flora.

SK92

Easton Park SNCI Grid Ref: SK 928265

Typical large parkland with many single standing trees and woodland. The grassland is mainly improved pasture and of a low botanical interest. The Witham flows through the centre of the park.

Grange Farm Grassland SNCI Grid Ref: SK 929285

An area of unimproved pasture, marsh and swamp adjacent to the Witham with an outstandingly rich calcareous flora. The site may also have an interesting invertebrate fauna.

Stoke Rochford Grassland SNCI Grid Ref: SK 931287

An area of pasture with rough limestone grassland situated on a steep bank on the eastern side of the Witham. Some limestone species are present, but the site is generally of low botanical interest.

Colsterworth Grassland SNCI Grid Ref: SK 929228

Cattle grazed pasture to the east of the Witham. Dominated mainly by rough grasses and common herbs, the site is of a generally low interest, although does support a large population of the common butterflies.

SK93

Belton Park SNCI Grid Ref: SK 935385

Ancient parkland with areas of cattle grazed grassland and woodland. Large ornamental lakes support some marginals as well as breeding great-crested grebe. The Witham flows along the western edge of the site.

Grantham (B.R. Skn4) SNCI Grid Ref: SK 925338

A strip of land adjacent to the railway line and Witham consisting mainly of dry grassland and scrub, although the area next to the river has dense scrub with small patches of wet grassland. The site has a good assemblage of the more common grassland plant species.

SK93

Little Ponton Grassland SNCI Grid Ref: SK 928318

Large area of improved grassland adjacent to the Witham. There is a small unimproved area with meadow saxifrage and common rock-rose, otherwise unimpressive. Man orchid has been recorded here, but is probably no longer present.

Salterford Valley SNCI Grid Ref: SK 926341

Steep-sided valley, with the Witham flowing along its floor. Habitats present include aquatic, marsh, grassland, scrub and grazing pasture. Mainly unimproved, the valley is a rich botanical site. The Witham here has also been noted by Anglian Water as potentially good for aquatic invertebrates.

SK96

Witham Marshes SNCI Grid Ref: SK 967687

One of many SNCIs associated with the Witham along the Witham Valley, to the south of Lincoln. The site consists of a large area of Glyceria marsh, and is probably a good site for both aquatic and terrestrial invertebrates.

Witham Leys SNCI Grid Ref: SK 966680

A large wetland site separated from the Witham by a footpath. The lake is fringed by a dense willow copse at its northern end but supports a rich marginal flora and a wide variety of the more common breeding birds. Possibly an important wintering bird site, given the other wetland complexes close by.

Delph Drains SNCI Grid Ref: SK 965682 - 967691

A narrow drain which runs alongside the Witham, together with an area of rough grassland. The aquatic flora is most rich in the southernmost section of the drain. Kingfishers are regularly seen feeding along the drain and the adjacent river.

River Witham (Bracebridge) SNCI Grid Ref: SK 956652 - 970700

A long stretch of the Witham that flows through the wide valley to the south of Lincoln into the city. Site consists of the river itself with associated areas of rough grassland and marsh. The aquatic flora in this stretch of the Witham is quite rich and snipe can be found feeding on the marshy grassland in winter.

Bracebridge Corner SNCI Grid Ref: SK 967683

An area of damp grassland and scrub to the east of the River Witham. Scrub is largely hawthorn and birch, with some mature trees. Most of the grassland is very marshy, but of a low botanical interest.

SK97

Catchwater Drain SNCI **Grid Ref: SK 953702 - 970695**

A drain running through the centre of Lincoln, flowing into the Witham at its eastern end. Mainly of interest for its rich aquatic flora, this interest is becoming fragmented and some parts of the drain are now quite badly polluted.

Witham, South and East Delph SNCI **Grid Ref: SK 991711**

The site consists of the River Witham, the South Delph drain and the disused railway line that runs between them. Witham banks are rough grassland. The river and delph support interesting marginal and aquatic plants, and possibly an interesting aquatic invertebrate fauna.

TF07

Washingborough Junction **Grid Ref: TF 007708 - 016708**

Large area of wetland, grassland, scrub and woodland separated from the Witham by the disused railway line. The ponds and marshy areas have an interesting marginal flora. Reported as being good for dragonflies.

Greetwell Hall Wood SNCI **Grid Ref: TF 015712**

Very wet woodland on the bank of the Witham with an interesting ground flora and a strong population of the more common woodland birds. The wood become less interesting in the north, as the ground conditions become more dry. Woodcock have been recorded here.

Fiskerton Brick Pit and Bank SNCI **Grid Ref: TF 079719**

Flooded brick workings to the north of the Witham. The area of open water is fringed with common reed. Ornithologically interesting, with breeding great-crested greb, tufted duck, reed and sedge warblers and reed bunting.

TF15

Mill Drain SNCI **Grid Ref: TF 195572 - 200564**

A long drain, wide and deep in parts that flows into the Horncastle Canal close to the junction with the Witham. The aquatic vegetation is very rich, including a number of submerged species. Banks are high and consist of rough grassland. Several very large pike were observed during the last survey.

Pumping Station by River Witham **Grid Ref: TF 189583**

An area of open water at the junction of the Witham and a large drainage ditch to the south-east of Thorpe Tilney Dales. Generally unremarkable except for a large colony of arrowhead found here.

TF16

Metheringham Delph Lincs Trust Reserve **Grid Ref: TF 108622 - 155651**

An important wetland nature reserve consisting of the Metheringham Delph and banks. The drain runs into the Witham at its eastern end. The site supports a rich aquatic flora and is also important for its aquatic invertebrates.

Bardney Settling Ponds SNCI **Grid Ref: TF 115680**

A series of settling ponds belonging to the British Sugar Factory at Bardney, situated behind the southern bank of the Witham. An important site for migrant birds, much of the area consists of open water with large expanses of mud and silt which draw migrant waders in autumn and spring.

Witham Way Lincs Trust Reserve **Grid Ref: TF 116685 - 317455**

A long, linear nature reserve along the banks of the Witham from Bardney to Boston following the trackbed of the disused railway. The site is discontinuous with areas not accessible to the public. The reserve has varied habitat types and a wide range of interesting species, including many of the more common woodland and wetland birds, butterflies and dragonflies. During spells of bad winter weather, unusual birds can often be found on this stretch of the Witham. Recent visitors have included white-billed diver, Slavonian grebe and red-crested pochard.

Nocton Delph SNCI **Grid Ref: TF 100650 - 127664**

The delph is approx. 8m in width with gently sloping banks, flowing into the Witham at its eastern end. The aquatic flora is most rich at the end nearest the Witham. Possibly good for aquatic invertebrates.

TF34

Slippery Gowt SNCI **Grid Ref: TF 346416**

Sandy bank on the landward side of the Witham to the south-east of Boston. Much of the site is now a refuse tip, but an interesting dry grassland flora remains. The main interest of the site is the branched horsetail *Equisetum ramosissimum*, this is one of only two British sites for the RDB1 species.

Hobhole Bank Lincs Trust Reserve **Grid Ref: TF 365405 - 366415**

Drain and banks just to the north of the tidal Witham. Aquatic vegetation is confined to small areas and is dominated by common reed, but bank vegetation shows a strong calcareous influence. The bank scrub supports a high population density of common woodland and farmalnd birds.

Date Notified: 2.5.86

FILE REF. UCS/178

COUNTY: CAMBRIDGESHIRE

SITE NAME: LITTLE PAXTON PITS

DISTRICT: HUNTINGDONSHIRE

Status: Site of Special Scientific Interest (SSSI) notified under Section 28 of the Wildlife and Countryside Act 1981.

Local Planning Authority: Huntingdonshire District Council

National Grid Reference: TL 200 637 | Area: 128.2 (ha.) 316.8 (ac.)

Ordnance Survey Sheet 1:50,000: 153 | 1:10,000: TL 16 SE; TL 26 SW TL 26 NW

Date Notified (under 1949 Act): | Date of last revision:

Date Notified (under 1981 Act): 1986 | Date of last revision:

Other Information

This is a new addition to the Cambridgeshire Schedule.

Description and Reasons for Notification:

Little Paxton Pits is an extensive area of flooded gravel workings of varied age, with a correspondingly diverse vegetation structure. The pits are of national importance for wintering wildfowl, and an important stopping point for migrants. The invertebrate fauna is extremely rich and includes a number of national rarities.

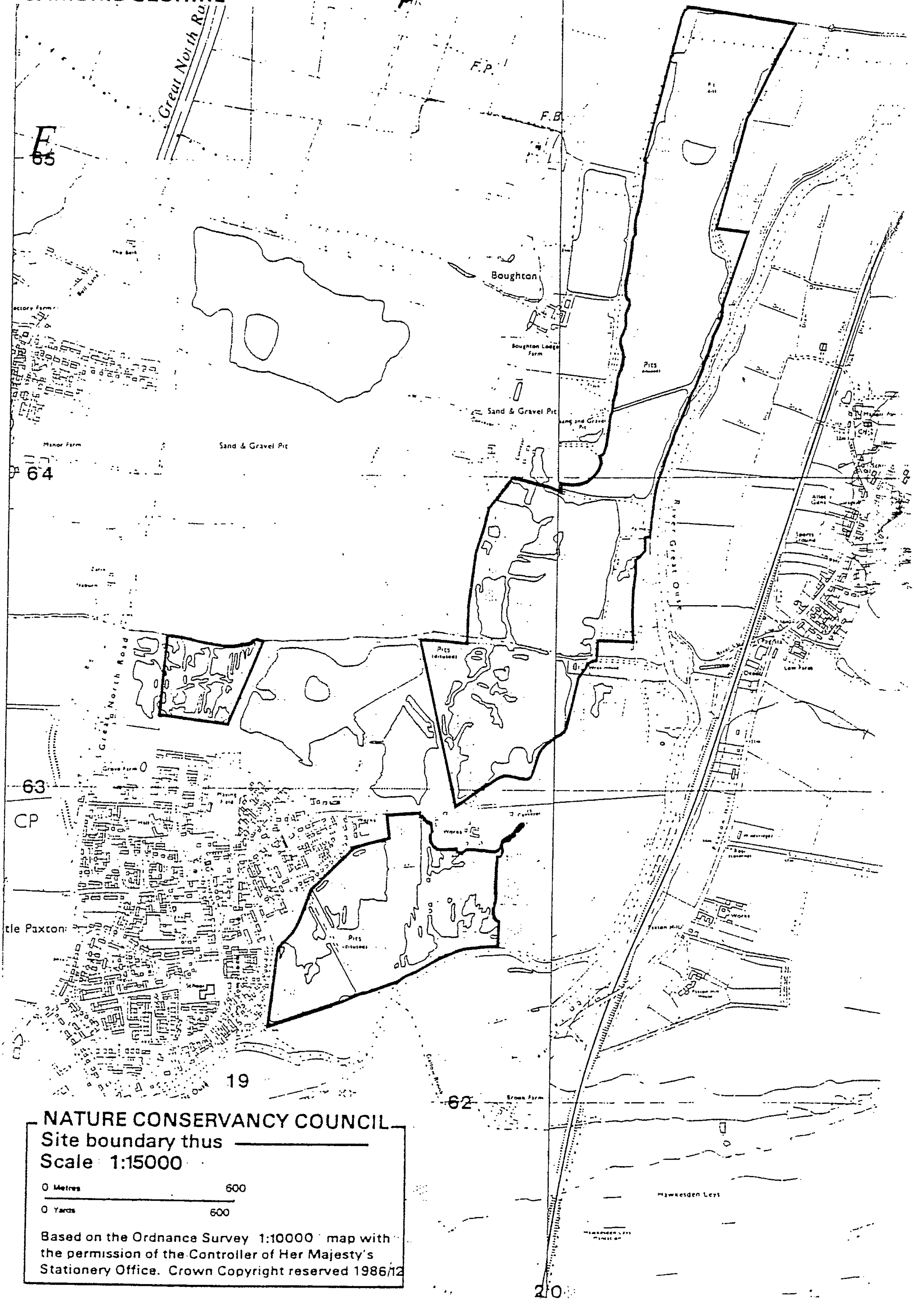
The pits vary in structure from larger, more recently flooded pits having little aquatic vegetation to smaller, older pits with broken fringes of emergent vegetation dominated by plants such as Reedmace Typha latifolia, Common Reed Phragmites australis, and Common Club-rush Schoenoplectus lacutsris. Areas of marsh support characteristic species such as Meadowsweet Filipendula ulmaria, Purple Loosestrife Lythrum salicaria and several species of sedges and rushes. Many of the older pits are surrounded by dense willow Salix carr. Amongst the more local aquatic plant species represented are Lesser Reedmace Typha angustifolia and Fringed Yellow Water-lily Nymphoides peltata.

Ornithologically, the pits are noted in particular for their use by wintering Gadwall Anas strepera. The numbers of this species here regularly exceed 1% of the British wintering population. Of additional interest is the breeding bird community. In particular the Ringed Plover Charadrius hiaticula, Snipe Gallinago gallinago, Tufted Duck Aythya fuligula, Kingfisher Alcedo atthis and Nightingale Luscinia megarhynchos have been recorded. In addition there is a small heronry.

The site also supports a particularly rich invertebrate fauna. A number of nationally rare species have been recorded including a number of flies Diptera, Spilogona scutulata, Limnophora scrupulosa, Dolichopus andulusiacus and Lispocephala falculata and the Leaf-hopper, Homoptera Idiocerus herrichi. The Earwig Dermaptera, Forficula lesnii, is present at the northern extreme of its British range.

In addition to the aquatic and marsh communities, woodland, scrub, hedges and areas of dry grassland provide further habitat of value to wildlife generally, and support a number of plant species which are local in Cambridgeshire. These include Common Spotted Orchid Dactylorhiza fuchsii, Bee Orchid Ophrys apifera, Blue Fleabane Erigeron acer, Hare's-foot Clover Trifolium arvense and Knotted Clover Trifolium striatum.

LITTLE PAXTON PITS
CAMBRIDGESHIRE



NATURE CONSERVANCY COUNCIL

Site boundary thus

Scale 1:15000

0 Metres 600

0 Yards 600

Based on the Ordnance Survey 1:10000 map with the permission of the Controller of Her Majesty's Stationery Office. Crown Copyright reserved 1986/12

COUNTY: NOTTINGHAMSHIRE SITE NAME: MOTHER DRAIN, MISTERTON

DISTRICT: BASSETLAW

STATUS: **Site of Special Scientific Interest (SSSI) notified under Section 28 of the Wildlife and Countryside Act 1981**

Local Planning Authority: BASSETLAW DISTRICT COUNCIL

National Grid Reference: SK 767 955 to SK 786 947 **Area:** 4.6 (ha) 11.4 (ac)

Ordnance Survey Sheet: 1:50,000: 112 **1:10,000:** SK 79 SE, NE

Date Notified (under 1949 Act): **Date of Last Revision:**

Date Notified (under 1981 Act): 15 September 1993 **Date of Last Revision:**

Descriptions and Reasons for Notification

Mother Drain is a drainage channel running parallel to the River Idle on the edge of the North Nottinghamshire Carr Lands. The site supports an exceptionally rich invertebrate fauna, which includes notable assemblages of dragonflies and water beetles, and a rare moth.

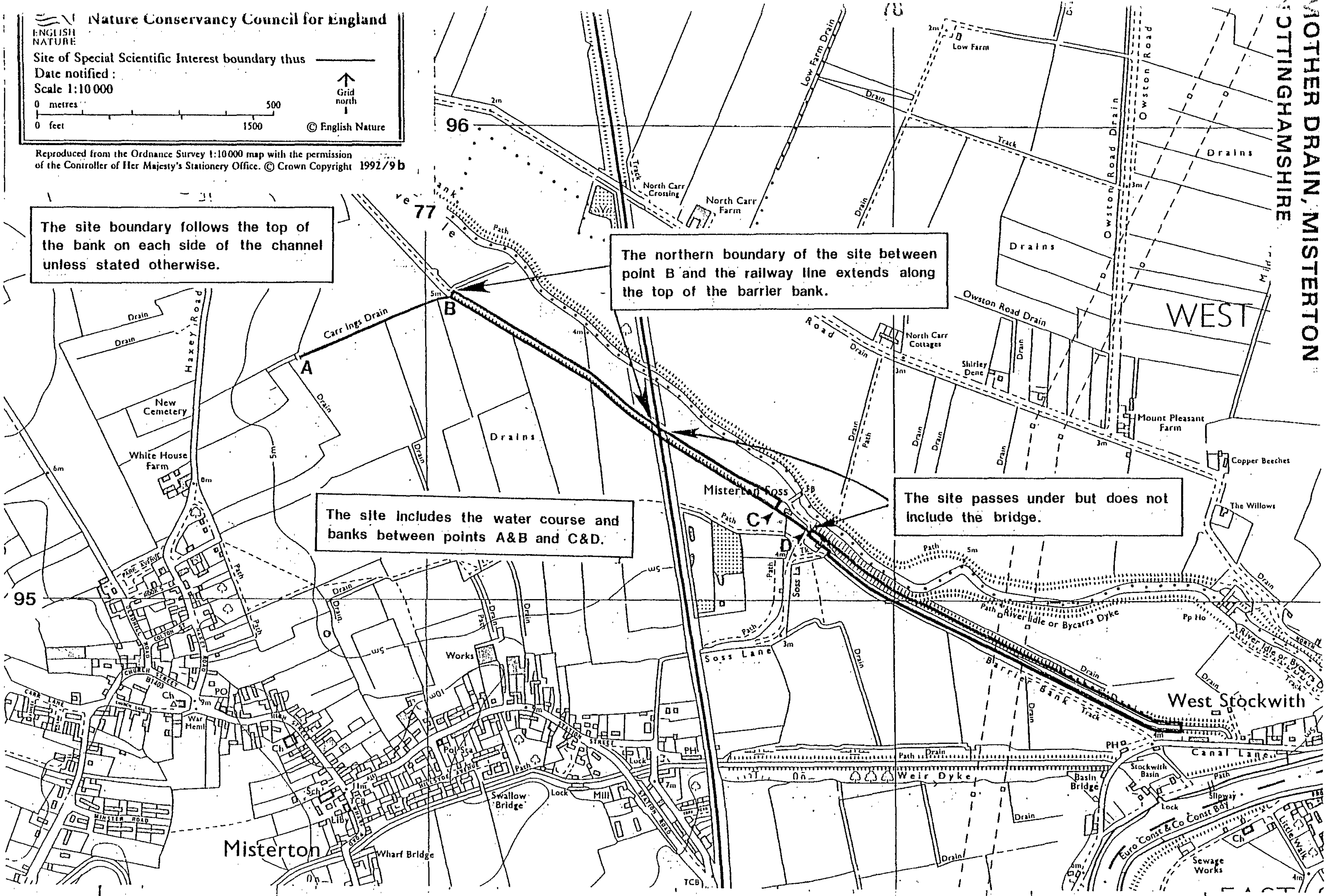
Mother Drain is situated in the alluvial flood plain of the tidal River Trent near its confluence with the River Idle. The site has affinities with both Trentside habitats further upstream in the County and also with acid fen communities of the North Nottinghamshire Carr Lands to the west. Its invertebrate interest derives from its good water quality and the botanical and structural diversity of its open water, emergent and bankside communities.

Open water communities of common aquatic plants occupy the central bed of the channel. These are flanked by stands of robust emergent species such as common reed *Phragmites australis* and greater pond sedge *Carex riparia*. The steep banks show a gradation from wet fen vegetation at the water's edge to drier tall herb and grassland communities further up the banks. The wetter areas are characterised by common meadow-rue *Thalictrum flavum*, lesser spearwort *Ranunculus flammula*, purple loosestrife *Lythrum salicaria*, common fleabane *Pulicaria dysenterica* and meadowsweet *Filipendula ulmaria*, while meadow cranesbill *Geranium pratense*, greater burnet *Sanguisorba officinalis* and common valerian *Valeriana officinalis* are common components of the drier bankside communities. In addition sand leek *Allium scorodoprasum* occurs here in its only Nottinghamshire locality.

The site supports an exceptional assemblage of dragonflies and damselflies. Fourteen species have been recorded as breeding, with a fifteenth regularly noted at the site. Three of these - variable damselfly *Coenagrion pulchellum*, hairy dragonfly *Brachytron pratense*, and black darter *Sympetrum danae* - are of nationally notable status, and a further three - banded agrion *Calopteryx splendens*, brown hawker *Aeschna grandis*, and four-spotted chaser *Libellula quadrimaculata* - are at the northern edge of their normal range in Britain.

The range and abundance of the water beetle fauna at the site is exceptional for this type of water body. It includes seven nationally scarce species, *Rhantus grapii*, *Dytiscus circumcinctus*, *Cercyon convexiusculus*, *Cercyon ustulatus*, *Chaetarthria seminulum*, *Hydraena testacea*, and *Limnebius nitidus*.

The marsh carpet moth *Perizoma sagittata*, whose larval foodplant is common meadow-rue, occurs on the drainsides. This rare species is restricted to a small number of fenland sites in the English Midlands and Mother Drain is its only known breeding locality in Nottinghamshire.


Nature Conservancy Council for England
ENGLISH NATURE
Site of Special Scientific Interest boundary thus
Date notified :
Scale 1:10 000
0 metres 500
0 feet 1500
Grid north
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MOTHER DRAIN, MISTERTON
NOTTINGHAMSHIRE
The site boundary follows the top of the bank on each side of the channel unless stated otherwise.
The northern boundary of the site between point B and the railway line extends along the top of the barrier bank.
The site includes the water course and banks between points A&B and C&D.
The site passes under but does not include the bridge.
A
B
C
D
96
95
77
Carr Ings Drain
Low Farm Drain
Low Farm
North Carr Crossing
North Carr Farm
Owston Road Drain
Owston Road
North Carr Cottages
Shirley Dene
Mount Pleasant Farm
Copper Beeches
The Willows
Misterton Soss
Soss Lane
River Idle or Bycarrs Dyke
Barrier Bank Track
West Stockwith
WEST
Canal Lane
Weir Dyke
Stockwith Basin
Basin Bridge
Sewage Works
Euro Const & Co Const Bdy
New Cemetery
White House Farm
Haxey Road
Works
Swallow Bridge
Wharf Bridge
Misterton
Station Road
Minster Road
Church Street
Drains
Drain
Track
Path

COUNTY: NOTTINGHAMSHIRE/DERBYSHIRE SITE NAME: ATTENBOROUGH GRAVEL PITS

DISTRICT: Broxtowe/Erewash

Status: Site of Special Scientific Interest (SSSI) notified under Section 28 of the Wildlife and Countryside Act 1981

Local Planning Authority: Broxtowe Borough Council, Erewash Borough Council

National Grid Reference: SK 522 341 Area: 221.2 (ha.) 546.6 (ac.)

Ordnance Survey Sheet 1:50,000: No 129 1:10,000: SK 53 SW, SK 53 NW

Date Notified (Under 1949 Act): 1964 Date of Last Revision: 1981

Date Notified (Under 1981 Act): 1982 Date of Last Revision:

Other Information:

Part of the site is managed as a nature reserve.

Reasons for Notification:

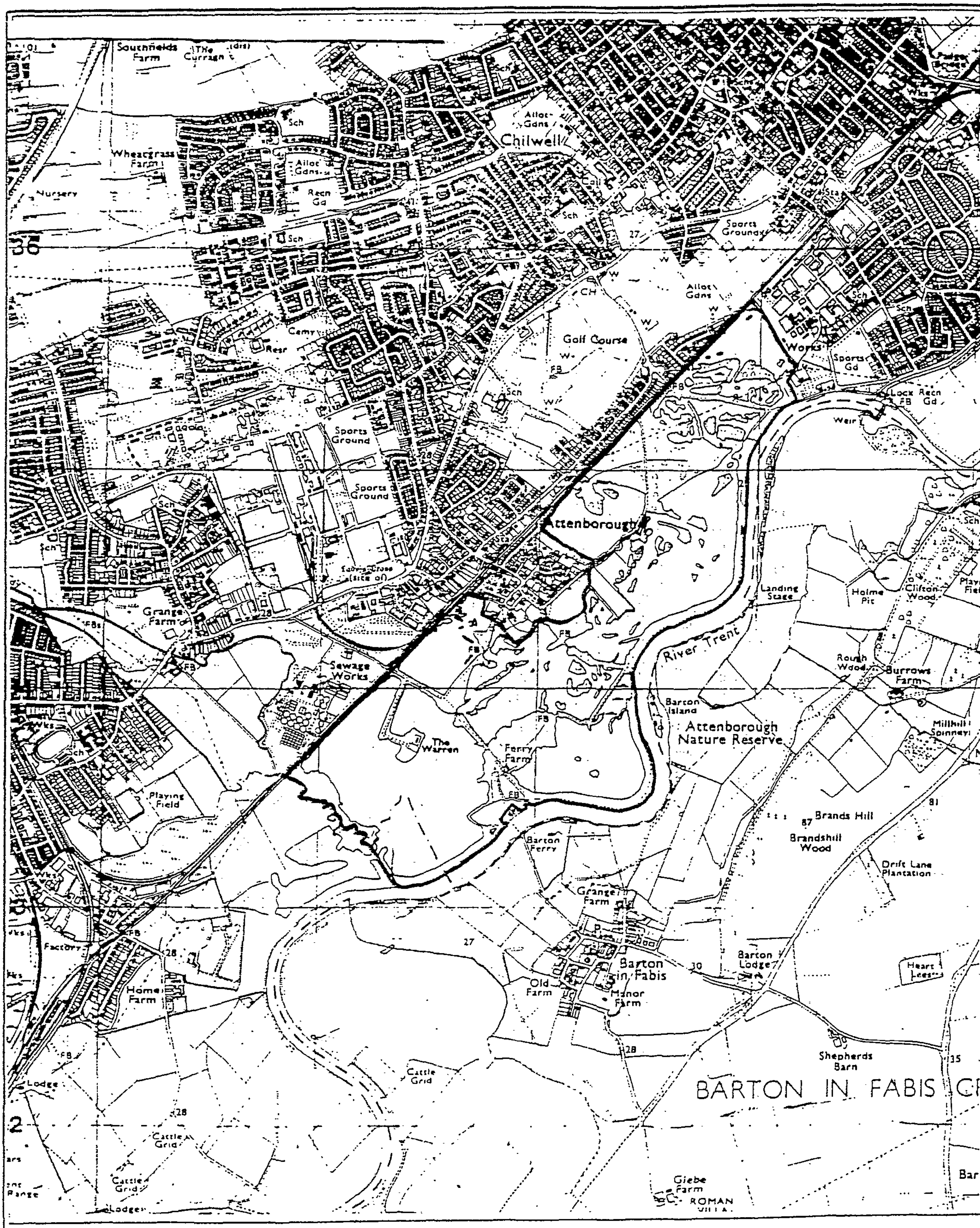
The site provides a valuable refuge for overwintering waterfowl and sustains an important breeding bird community, and is of Regional importance.

Biology:

Gravel pits of varying ages which illustrate the successional development of natural vegetation over 40 years and which possess a diverse complement of terestrial, marsh and aquatic habitats. The still water channel of the former R Erewash, together with other similar channels, contains a rich aquatic community of plants and animals, with erect bur-reed *Sparganium erectum* and yellow iris *Iris pseudacorus* common along the margins, and yellow water-lily *Nuphar lutea* abundant in the open water. To the north of Attenborough village occur substantial areas of marsh and reedswamp. These communities can be species rich, including such plants as purple loosestrife *Lythrum salicaria*, or can occur as nearly pure stands of greater pond sedge *Carex riparia*, bulrush *Typha latifolia* or common reed *Phragmites australis*. Willow scrub has developed extensively adjacent to the area of marsh and the variety of willow species reflects the presence of a former willow holt. Common osier *Salix viminalis* and purple willow *Salix purpurea* are characteristic species while a number of unusual hybrids and varieties also occur. Crack willow *S fragilis* and white willow *S alba* are typical of more mature woodland areas. Small areas of unimproved grassland also occur.

The variety of breeding bird species is exceptional and includes common tern, kingfisher, sand martin and large numbers of great-crested grebe. The pits also provide, particularly on the southern lagoons, a very valuable refuge for passage and overwintering waterfowl, being notable especially for their wintering populations of pochard and shoveler duck.

The site also includes a representative stretch of the northern bank of the River Trent.



ENGLISH NATURE Nature Conservancy Council for England

Scale 1:2500

0 100 metres

0 1000 feet

Grid North

Attenborough Gravel Pits

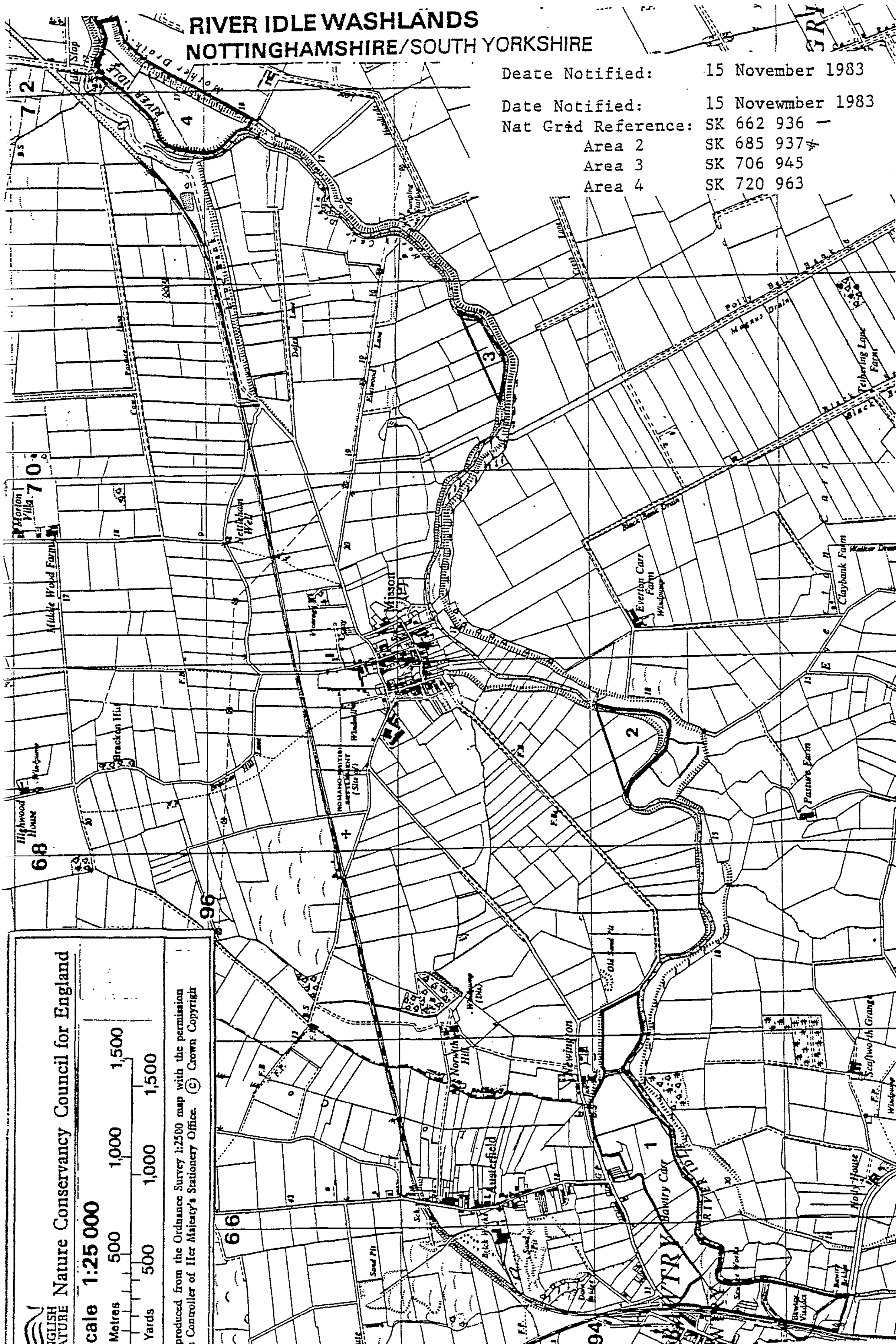
Nottinghamshire/Derbyshire

Unit, English Nature

RIVER IDLE WASHLANDS
NOTTINGHAMSHIRE/SOUTH YORKSHIRE

Deate Notified: 15 November 1983

Date Notified: 15 Novewmber 1983
Nat Grid Reference: SK 662 936
Area 2 SK 685 937
Area 3 SK 706 945
Area 4 SK 720 963



File Ref: ST/S/33

COUNTY: STAFFORDSHIRE

SITE NAME: PASTUREFIELDS SALT MARSH

DISTRICT: Stafford

SITE REF: 15 WH7

Status: Site of Special Scientific Interest (SSSI) notified under Section 28 of the Wildlife and Countryside Act 1981

Local Planning Authority: STAFFORDSHIRE COUNTY COUNCIL
Stafford Borough Council

National Grid Ref: SJ 992248

Area: 7.7 (ha) 19.0 (ac)

Ordnance Survey Sheet 1:50,000: 127

1:10,000: SJ 92 SE
SJ 92 NE

Date Notified (Under 1949 Act):

Date of Last Revision:

Date Notified (Under 1981 Act): 1986

Date of Last Revision:

Other Information:

New Site.

SITE NAME: PASTUREFIELDS SALTMARSH NOTIFICATION DATE: 9 JUNE 1986

Description and Reasons for Notification:

An inland location for a plant community of close affinity with grazed coastal saltmarshes.

Pasturefields Saltmarsh is a modified remnant of the former saltmarshes of the Trent Valley, and one of only two known extant brine spring marshes in the country. An extremely rare and vulnerable habitat important for the understanding of plant ecology and distribution and vegetational history in the British Isles.

The marsh originates from the percolation of saline surface water derived from solution of the subterranean salt-bearing rocks of the Keuper series. Evidence suggests a natural feature of great age. The spring water 'reservoir' may well have formed towards the end of the last Ice Age, 10,000 years ago. The *periglacial Midlands landscape of those times is believed to be the source of some of the original saltmarsh plant colonists.

Despite its small area (under 0.5 ha) and the degree of past disturbance the saltmarsh contains a number of halophytic plants (those largely restricted to saline habitats). The most notable of these is sea plantain (Plantago maritima), known only from one other comparable inland site in Britain. The community is classified as 'Red Fescue (Festuca rubra) Saltmarsh', and shows three distinctive plant associations reflecting differences in salinity, waterlogging and poaching. The most saline situations surround small 'pans' of standing water where there is a high cover of common saltmarsh-grass (Puccinellia maritima), with lesser sea spurrey (Spergularia marina), saltmarsh rush (Juncus gerardi) and sea arrowgrass (Triglochin maritima). On soils of intermediate salinity creeping bent (Agrostis stolonifera) replaces Puccinellia as the most abundant species with the same range but lower cover of other halophytes. Marsh foxtail (Alopecurus geniculatus) and sea milkwort (Glaux maritima) are also present.

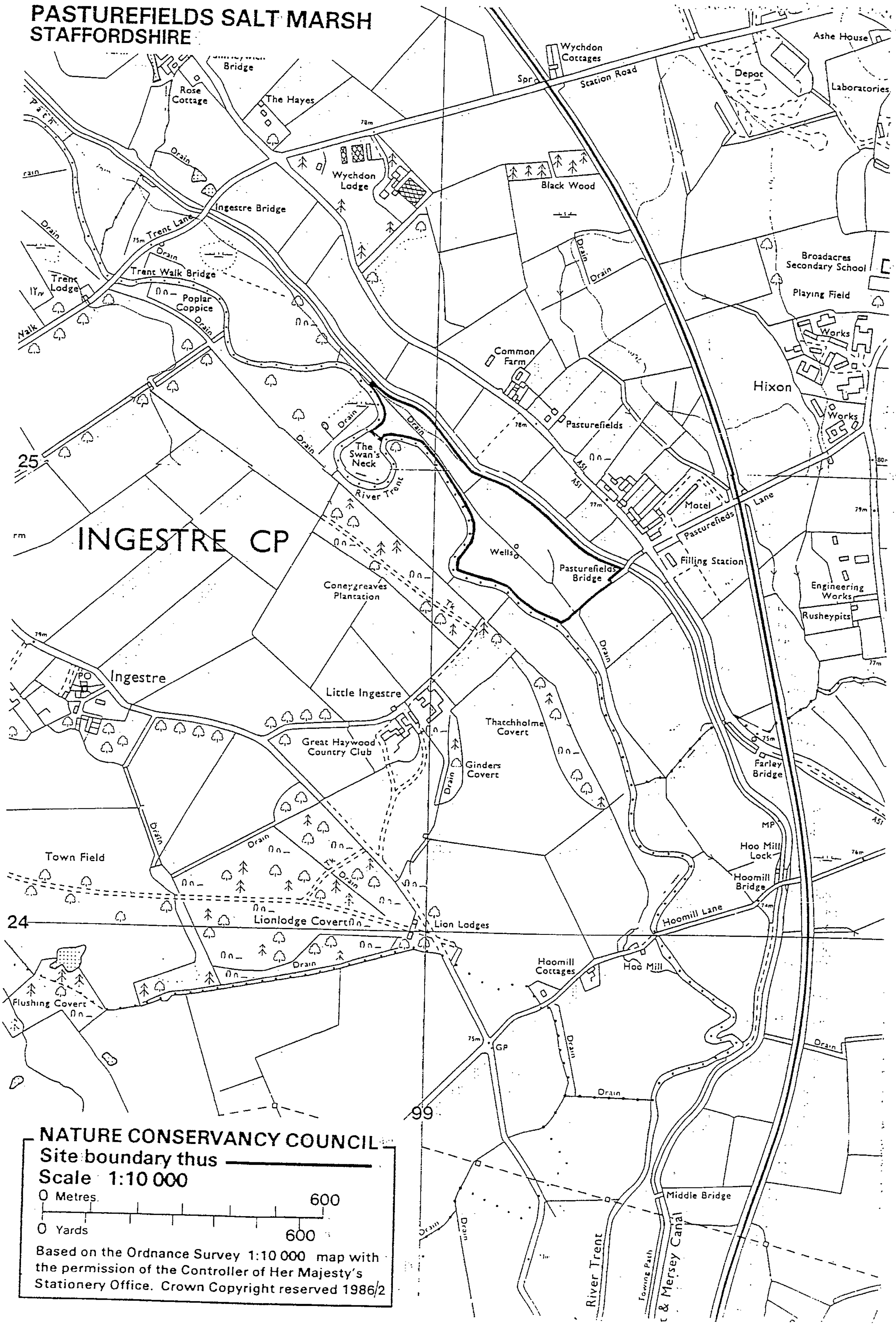
Increasing freshwater influence and livestock trampling favours a tussocky sward of red fescue and creeping bent with greater cover of ubiquitous pasture plants, eg perennial rye grass (Lolium perenne). Spear-leaved orache (Atriplex hastata) occurs sparingly.

To the east of the dividing drain there is a gradual zonation from salt marsh into rushy, wet neutral grassland of tufted hair-grass (Deschampsia cespitosa), floating sweet-grass (Glyceria fluitans), and creeping buttercup (Ranunculus repens). This in turn gives way to damp, semi-improved grassland of low floristic interest.

The site also has local importance for breeding waders - snipe (Gallinago gallinago), redshank (Tringa totanus) and lapwing (Vanellus vanellus). Over much of the lowlands these birds are now confined to scattered wet grassland localities in flood plains, a result of habitat loss through agricultural drainage.

* The tundra-like open ground at the edge of the ice sheets free from ice but subject to an arctic climate.

PASTUREFIELDS SALT MARSH
STAFFORDSHIRE



NATURE CONSERVANCY COUNCIL

Site boundary thus

Scale 1:10 000

0 Metres 600

0 Yards 600

Table 3.
Relationships between spined loach density (n m^{-2}) and a number of environmental variables in South Delph Drain and the Wicken system. Spearman rank correlation coefficients (r_s) and associated probabilities (p) are shown, where *< 0.05, ** < 0.01, * <0.001.**

	South Delph Drain		*Wicken system*	
Variable	r_s	p	r_s	p
Fish abundance (n m^{-2})	- 0.30	NS	- 0.03	NS
Fish biomass (g m^{-2})	- 0.20	NS	- 0.01	NS
No. macrophyte species	+ 0.20	NS	- 0.40	*
Macrophyte cover	- 0.20	NS	+ <0.01	NS
Filamentous algal cover	- 0.20	NS	+ 0.50	***
Invertebrate abundance	- 0.30	NS	- 0.30	NS
Sediment volume	+ 0.50	*	+ 0.40	**

Discussion

Perrow & Jowitt (1997) sampling the outer (Counterdrain/Old Bedford river) and inner (River Delph/Old Bedford) rivers at the Ouse washes showed that spined loach was only present in good numbers (c. 0.2 m^{-2}) in the outer river. Also, the general absence of 0+ fish in the inner river resulted in a poor age structure. This questioned the long-term viability of this population. Overall, spined loach therefore appeared to be associated with good quality habitat containing macrophytes and avoided thick black anoxic sediments. This pattern tended to be repeated in other habitats such as streams and lakes. Spined loach thus also tended to be associated with diverse fish communities.

The results from the Wicken system and the South Delph Drain particularly, contradict these initial findings. Here, spined loach tended to favour fine silty sediments, even if they appeared anoxic in the case of the South Delph Drain. Macrophytes were generally avoided where they were present, although filamentous algae was favoured in the lodes at Wicken. The good age structure in all sites also suggests the populations are viable (see *Establishing further SAC's* above). Peacock (1997) also recorded similar relationships between spined loach abundance and the volume of silt, gravel and algae in Wicken Lode.

There are four plausible explanations for these contrasting habitat relationships. First, that the individuals within the different populations do indeed have different habitat preferences. For example, Saitoh (1990) working in the Asahi river basin in Japan showed that several forms of spined loach (in the *Cobitis taenia* complex) inhabited distinct habitat types. The 'small form' selected small creeks and flooded fen, whereas the 'middle form' selected the main stream and its tributaries. Consequently, this suggests distinct substrate preferences. It is plausible, given the likely long period of isolation (at least 10 000 years in some cases) between some populations of spined loach within the UK and the tendency of the species to form races, subspecies or species (Lelek 1980, Saitoh & Aizawa 1987, Saitoh 1990), that the patterns observed are the result of habitat preferences by distinct types of spined loach.

Second, there is the distinct possibility that the variables monitored during sampling may not reflect the critical factors determining the distribution of spined loach. Variables such as the number of macrophyte species and invertebrate abundance were used as indicators of general habitat diversity, including the food and spawning resources available to the species. This may simply not be specific enough. In the case of food resources, for example, the rather specialised feeding mechanism in which fine substrate is pumped into the buccal cavity and small (0.2-0.75 mm - Robotham 1977) food particles are retained in mucous, means that the sediment has to contain a relatively high density of food particles for metabolic demands to be met. An obvious caveat in the approach adopted is that the food resource has not been quantified or even related to gross habitat quality indicators. The relatively diverse diet of spined loach - both animal; particularly chydorids, copepods (especially copepodites and nauplii) rhizopods, ostracods, rotifers; and plants principally desmids and filamentous algae (Robotham 1977) - suggests spined loach may easily switch between different prey items depending on their availability. Thus, the enriched sediments downstream of the STW in the South Delph Drain, are likely to have contained a high density of organic particles. In the outer river of the Ouse washes, small animals and plants associated with macrophyte debris may have formed the principal dietary component and thus the basis of habitat selection.

Third, each site in which spined loach occurs may have different limiting factors resulting in different trade-offs. For example, Perrow & Jowitt (1997) suggested the risk of predation from a number of vertebrate (especially larger omnivorous fish) and even invertebrate predators may have a significant role in determining the distribution and thus habitat preferences of spined loach. The structural complexity of dense macrophytes or filamentous algae may offer effective refuges from predation. In the absence of predators, these would not be required. The biomass of other larger fish species may thus be a reasonable indicator of predation risk, determining habitat preferences. The possibility of other fish competing for resources or more importantly changing the nature of the sediment and its capacity to support suitable food for spined loach, adds to the value of this potential indicator. Unfortunately, the hand trawl is incapable of sampling the larger species likely to comprise the bulk of fish biomass. However, if it is taken as an indicator of fish biomass, the South Delph Drain seemingly supports a low fish biomass, whereas Reach Lode and the outer river of the Ouse Washes (confirmed by other techniques - see Perrow & Jowitt 1997) support a higher fish biomass. This conceivably could account for the association with macrophytes or algae in the latter and the lack of any association with cover in the former.

Fourth, any habitat relationships may change according to season, the availability of resources or may change as the fish grows. For example, Peacock (1997) showed the habitat relationships in Wicken differed between different size classes of spined loach. For the smallest (20-40 mm), probably 0+, spined loach silt and gravel were positively selected, whereas filamentous algae was selected by larger (41-65 mm), probably 1+, spined loach. The largest spined loach (66-80 mm) did not select for any of the variables tested. Relationships with habitat variables may change as a result of predation risk, which is, greater for smaller, rather than larger fish (see above), for example. This was suggested as a possible mechanism determining the association of 0+ spined loach with macrophytes in the outer river of the Ouse washes (Perrow & Jowitt 1997). Unfortunately, insufficient data was available to determine the habitat preferences of the different size classes in the sites sampled in the current study to further elucidate habitat requirements of different size classes, particularly 0+, the success of which determines the sustainability of the population in this short-lived species. Further work on this critical issue is clearly needed (Mann 1995).

Conclusions

Spined loach may be associated with a range of substrate types including silt, in slow-flowing drainage channels. Macrophytes and filamentous algae may be selected in some situations and not others. Populations may reach reasonable density and display good age structure in a range of different habitat types. The possibility of the occurrence of distinct types of spined loach, each with different habitat requirements, and a lack of knowledge on the factors determining the distribution of different size classes of spined loach such as the abundance of food resources and predation risk (particularly from larger fish) impedes a more thorough understanding of the habitat preferences of spined loach in drains. If populations of spined loach are to be conserved or promoted in drainage channels, including within cSAC sites such as the Ouse Washes, these aspects should form the focus of further research.

C. Habitat relationships in streams and rivers

Introduction

Information from the literature (e.g. Lelek 1980, Marconato & Rasotto 1989, Ahnelt & Tiefenbach 1994), associations with fluvial fish species in community analyses (Penczak *et al.* 1991, Perrow & Jowitt 1997) and evidence from records of fish in the UK suggested that streams and rivers were an important habitat for spined loach. Given the ancestral association of the species with streams and rivers and the widespread occurrence of what was suggested to be its preferred microhabitat - a sandy substrate with a dense, yet patchy coverage of rooted, submerged macrophytes (Perrow & Jowitt 1997) - within streams and rivers, these were suggested to represent the optimal habitat type for spined loach. This required verification, however. Further, there was a clear need to clarify the relationships between spined loach and variables such as the occurrence of macrophytes and the nature of the sediment in streams and rivers. As many rivers are managed for flood defence and land drainage purposes through a suite of physical modifications (widening straightening, deepening) broadly termed channelization, there was also a need to determine the impact of such practices upon spined loach in what appeared to be their optimal habitat.

Methods

Site selection

All streams sampled were tributaries of the River Trent. The basic design was to compare the densities of spined loach and environmental variables in 6 semi-natural streams (Rivers Anker, Mease, Penk, Sence, Smite and Sow -Fig.'s 6 & 7) and 6 streams that had been modified (i.e. subject to channelization) (River's Greet and Leen and Fairham, Kingston, Knorwell and Wood Brook's (Fig.'s 8 & 9) (Table 4). The classification of streams into semi-natural and modified was conducted by Agency fisheries staff, to prevent a bias in selection by the authors. Agency contacts were Jim Lyons (JL) of Lower Trent Area and Tim Jacklin of Upper Trent Area, both in Midlands Region. One site was selected within each stream. This was the usually the site closest to the confluence with the Trent which could be sampled by wading (see below). All sites had been routinely used as sample sites by the Agency, which allowed access to the site and to water quality and biological data. A similar design had been successfully used in a study of bullhead (*Cottus gobio*) conducted for the Agency (Perrow *et al.* 1997).

PART 3 NON-MOLLUSCAN INVERTEBRATES

3.1 The southern damselfly: dispersal and adult behaviour

3.2 Strategy for the management of white-clawed crayfish populations in England and Wales

THE SOUTHERN DAMSELFLY *COENAGRION MERCURIALE*: DISPERSAL AND ADULT BEHAVIOUR

G.W. HOPKINS & K.J. DAY

CCW CONTRACT SCIENCE REPORT No. 184.

Nominated Officer:
A. P. Fowles
Invertebrate Ecologist

October 1997

ENGLISH NATURE

ENVIRONMENT AGENCY

This research was jointly funded by the Countryside Council for Wales, English Nature and the Environment Agency under the auspices of the *Southern Damselfly UK Biodiversity Action Plan Steering Group*. The Steering Group is composed of representatives from the British Dragonfly Society, the Countryside Council for Wales, English Nature, the Environment Agency and the Wildlife Trusts.

CCW CONTRACT SCIENCE

TITLE: The southern damselfly *Coenagrion mercuriale*: dispersal and adult behaviour

REPORT No.: 184.

AUTHOR: G.W. Hopkins & K.J. Day.

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G.W. HOPKINS
K.J. DAY

THE SOUTHERN DAMSELFLY *COENAGRION MERCURIALE*: DISPERSAL AND ADULT BEHAVIOUR

G. W. Hopkins & K.J. Day

Contents

1. SUMMARY

1. This report summarises field work undertaken on the dispersal behaviour of the southern damselfly *Coenagrion mercuriale*. Mark-recapture techniques were used on the two largest populations of the species in Britain, on Mynydd Preseli, Pembrokeshire, and in the New Forest, Hampshire.

2. Few teneral individuals were marked and their recapture rate was low. Of those that were caught again, the distances travelled were small. A large number (>1400) of non-teneral males and a substantial number (>400) of non-teneral females were marked at each site and it is the movement by these that is analysed.

3. At each site, non-teneral individuals of both sexes were recorded as moving relatively long distances along the streams which they inhabit, with a significant proportion of individuals moving 200 m, and some individuals further.

4. At neither site were there regular long-range dispersals across areas of unsuitable habitat. In the New Forest the longest such movement was 1.06 km by a male, but no other substantial movements were observed. In Pembrokeshire the two longest movements were by males which travelled 800m and 200m respectively, with no movements of such distance by females observed. Both sexes were regularly found in *Juncus*-dominated vegetation about 50 m away from the main breeding habitat.

2. INTRODUCTION

The southern damselfly *Coenagrion mercuriale* Charpentier 1840) is a rare species that is found in central and western Europe and North Africa (Askew 1988). The strongholds of the southern damselfly are in France, Spain and Portugal. It is declining in all other parts of its range and is reported to be in danger of extinction (van Tol & Verdonk 1988, van Helsingden *et al.* 1996). The southern damselfly is included on Apendix II of the Berne Convention and Annex II of the EC Habitats & Species Directive. It is currently recommended for full protection on Schedule 5 of the Wildlife & Countryside Act, 1981, and is on the Short List of the UK Biodiversity Action Plan (HMSO 1995). The New Forest, Hampshire, and Mynydd Preseli, Pembrokeshire, have been proposed as candidate Special Areas of Conservation (SACs) for the southern damselfly. In Britain, populations are found in Anglesey, Glamorgan, Pembrokeshire, Devon, Dorset, Hampshire and, possibly, Oxfordshire (Merritt *et al.* 1995). There are recent (post 1974) records from twenty-six $10km^2$ squares of the national grid.

2.1 Objectives

This report summarises the extensive fieldwork undertaken during the summer of 1997 on Mynydd Preseli, Pembrokeshire and the New Forest, Hampshire, to establish the dispersal capabilities and other aspects of the adult behaviour of the southern damselfly. The project specification established the aims of the project as:

- investigate the distance moved by adult *C. mercuriale* using a mark-recapture technique.
- determine the extent of the local colonies.
- estimate local population density.
- make observations on the behaviour of the adults, including roosting, oviposition, and daily activity.

2.2 Previous studies

The southern damselfly has been the subject of several research projects in recent years, concentrating on both of the study sites investigated here.

On Mynydd Preseli, Evans (1989) examined the habitat preferences of *Coenagrion mercuriale* through larval sampling. She found that larvae were most abundant in well vegetated, shallow seepages overlying thin peat. Merritt (1983) reports (for a range of sites in Devon, Pembrokeshire and the New Forest) that seepages occupied by *C. mercuriale* are neutral-alkaline (average pH = 6.7), indicating base-enrichment. During the summer months, Evans (*loc. cit.*) found larvae amongst dense vegetation, but sampling in November revealed that larvae were inactive within the peaty sediments. In Pembrokeshire, and also in Devon (Knights 1983), two distinct generations of larvae appeared to be present, supporting the comments by Corbet *et al.* (1960) that *C. mercuriale* is semi-voltine (ie. taking two years to mature to the adult stage). However, it should be noted that Corbet (1955) reared a male *C. mercuriale* in captivity from egg to adult in under one year.

In 1996 Skidmore (1996) undertook a baseline survey of the distribution of *C. mercuriale* on Mynydd Preseli candidate SAC. He confirmed that the species is widely distributed on shallow flushes on the lower-lying slopes, but also noted that several peripheral populations had become extinct in recent years. His report draws attention to the possibility of poor dispersal ability as an important factor in the conservation of the southern damselfly.

The New Forest Study Group began its interest in the local populations of *C. mercuriale* in 1982 (Winsland 1985), beginning with an examination of pH at a range of sites. Whilst average pH varied between 6.17 and 6.75 on different geological areas, suggesting local base enrichment of seepages, they concluded that "pH is not a causal factor affecting the distribution of *mercuriale* but only a single element in a complex situtation and the climate and local topography are probably the main governing factors". In subsequent years (Jenkins 1986a, 1986b, 1991) attempts were made to estimate population size at a large colony on the Crockford stream (which is also the main New Forest study site used in this project). Diurnal behaviour was studied in 1986 (Jenkins 1987) and a mark-recapture programme was undertaken in 1991 (Jenkins 1995). The latter study demonstrated that southern damselfly adults are characteristically short-lived (average male lifetime = 5.5 days, average female lifetime = 2.6 days) although some adults survived for at least 28 days. Further investigations of pH (and temperature) have also been carried out at Crockford (Jenkins 1994).

2.3 The importance of dispersal

Within the academic community the role of re-colonisation following local extinction is appreciated as being important in ensuring the persistence of many species (in jargon, the topic of metapopulation dynamics). For conservation purposes, this implies a need to ensure that species can re-colonise a locality if the population there becomes extinct. Management of rare species, therefore, should not only aim to reduce the rate at which populations go extinct, but also to increase the likelihood that sites will be recolonised - the greater the dispersal ability of a species, the greater the likelihood of re-colonisation, although this will in practice depend on the distance between sites.

Most entomological research on the siginificance of dispersal behaviour for conservation has been undertaken on butterflies and two examples illustrate the importance of these processes at two spatial scales, namely studies on the silver studded blue *Plebejus argus* and the silver spotted skipper *Hesperia comma* (Thomas 1994).

The silver studded blue lives on patches of heathland or grassland that are maintained in their early successional stages by cutting, grazing or burning. After a few years these patches become unsuitable as the vegetation matures and the butterflies must move to new patches. It appears that the chances of a new patch being occupied decreases sharply if it is more than about 150 m away. This movement between patches occurs at a relatively small scale. The second example of the importance of dispersal concerns the re-colonisation of new localities following habitat restoration. The silver spotted skipper lives on heavily grazed grassland and, with the arrival of myxomatosis, many grasslands became unsuitable and the butterflies were lost from localities. Recently, these grasslands have again become suitable for the butterfly, but whether they are reoccupied depends on how close they are to surviving populations. For a large area of restored habitat to have a 50% chance of re-colonization it needs to be within about 5 kilometres of a surviving colony.

Thus, a range of possible extinction-colonisation dynamics are possible according to the behaviour and ecological characteristics of species. It is, therefore, difficult to generalise about how species should be managed and information on dispersal behaviour should be a pre-requisite for species considered to demonstrate metapopulation dynamics (Harrison 1994). That the southern damselfly is rarely found away from water (Hammond 1977) suggests that it is a poor disperser, but few quantitative data are available to support these observations. This paper reports on a pilot study which was designed to establish dispersal characteristics and thus the potential for the species to colonise new localities within a region or to re-colonise former sites within a locality.

2.4 Site comparisons

The New Forest localities for *C. mercuriale* are typically valley mire streams flowing through the heavily grazed (by cattle and ponies) heathlands of the region. These streams are relatively discrete areas separated by dry habitats. Mynydd Preseli in Pembrokeshire is an extensive common, heavily grazed by sheep where, in contrast to the New Forest, suitable habitats for *C. mercuriale* (streams, flushes and valley mires) occur very close together.

Superficially, the main study sites in Pembrokeshire and the New Forest are similar, being small, shallow streams with abundant aquatic and emergent vegetation. Mynydd Preseli is approximately 10 kilometres from the sea. The site comprises a ridge of hills about 300-400 metres above sea level and the adjacent low-lying areas. The vegetation is characteristically oceanic, containing elements of lowland and upland bog, grassland and heath. *C. mercuriale* occupies the poorly drained lower slopes of the hills which are underlain by glacial clay, some of which is calcareous and of Irish Sea origin. The main study stream is at an altitude of 120-140 metres.

The Glanyrafon Uchaf site is heavily grazed by sheep, which appear to graze only up to the stream margins and not the aquatic or emergent vegetation. The sheep avoid entering the water and boggy margins and they only create bare mud by trampling over a small length of the stream. Most of the surrounding adjacent vegetation consists of heavily grazed gorse (*Ulex gallii*) bushes, few of which are taller than about 0.75 metres, interspersed by very short grass, with *Juncus effusus* stands in the wetter areas. There are very few taller gorse bushes, and these are widely dispersed. The study stream is exposed and little cover is provided by the topography or vegetation.

The Crockford study site in the New Forest is approximately 5 kilometres from the sea, at an altitude of about 20-30 metres. a.s.l. The stream lies in a shallow depression below the surrounding dry heath. In 1997, the site was mainly grazed by cattle. They trample the stream at a few crossing areas and graze the aquatic or emergent vegetation. In the adjacent heath there are substantial stands of gorse which can be up to almost 2 metres tall. The site is a little more sheltered than Glanyrafon Uchaf.

Detailed vegetation transects were only recorded in the New Forest, but similarities and differences are apparent. Both sites included sections of wide, wet mire vegetation, with abundant cotton grass *Eriophorum* and white beaked-sedge *Rhynchospora alba*, where the water flow is diffuse. Much of the remainder of the main Pembrokeshire stream was a narrow channel (<1m wide) with abundant *Juncus acutiflorus* and marsh St John's Wort *Hypericum elodes* . The New Forest stream eventually develops into a stream 2-3m wide, fringed with tall bog myrtle *Myrica* gale and sparse, low *Phragmites australis* reed.

2.5 Weather problems

The weather during the study was appalling. Heavy and frequent rain (this was one of the wettest Junes this century) was accompanied by high winds and low temperatures - a minimum temperature of $2C^0$ was recorded at ground level on the night of 15-16 June in the Pembrokeshire site. Weather conditions improved later in the study and July was an 'average' month. However, the Pembrokeshire study continued during the first week of August when there was substantial flooding in the county.

At both sites, temperature was recorded using a maximum - minimum thermometer placed in ground level vegetation. Temperature was recorded from 10 June in Pembrokeshire and 26 June in the New Forest.

3. METHODS

Fieldwork was undertaken between 10 June and 9 August 1997 on Mynydd Preseli and between 6 June and 31 July in the New Forest.

In Pembrokeshire (Glanyrafon Uchaf) and the New Forest (Crockford) the main study sites were streams that were previously known to support large, dense populations of *C. mercuriale*. Qualitative mark-recapture methodology was employed to allow analysis of population sizes and demography. At both sites, a section of stream was subdivided to allow an estimation of within-stream movement. To detect longer movements, other water bodies and likely sites were searched as time allowed.

Generally the methodologies were similar at both sites. Individuals were given unique marks using a combination of a single colour paint mark on the thorax and one wing was numbered using a black Lumicolor marker. The paint mark on the thorax was applied using a paintpen. Paint pens are much more convenient than using a pot of paint and a brush in the field. Good newsagents stock gold, silver and white, while other colours can be obtained from graphic and art supply shops. Size was measured as length of the forewing from base to tip, using calipers. The date and location of the first and subsequent captures were recorded. Sex and age (teneral or non-teneral) were also noted.

3.1 METHODS (PEMBROKESHIRE)

3.1.1 Mark-Recapture

On every day that the weather was suitable, between 10 June and 9 August, a quantitative capture-recapture study was undertaken, except for 22 and 25 July, and 7 and 8 August. Due to poor weather it was not possible to undertake a quantitative mark-recapture study on a number of days. This quantitative study was only undertaken if there was sunny weather, with gentle winds only, for the duration of the sampling exercise. Suitable sunny weather constituted regular periods of unbroken sunshine with no wind gusts greater than approximately 3m/s. To measure the wind a meter which measured wind gusts, rather than cumulative wind, was used, with measurements being made for a minute. In practice this weather corresponded to the weather suitable for females to fly in tandem over the stream.

During this exercise, individuals flying on the main study stream were caught randomly without bias as to whether they did or did not have a mark. This exercise started at approximately mid-day and could be completed in a maximum of three hours. The sequence in which sections were searched was varied randomly. Subsidiary sites were visited on most days of good weather and the peripheral sites were visited as time allowed. Because the stream and vegetation structure on the Glanyrafon stream was very variable, capturing individuals using a constant effort (as measured by time) protocol was inappropriate. Captures were made by slowly walking the length of the stream and capturing individuals flying in front of the worker. This protocol ensured that individuals had an equal chance of capture whatever the characteristics of the stream-site which they occupied. On a number of days when it was not possible to undertake the quantitative study individuals were nevertheless captured and marked on the Glanyrafon Uchaf stream and elsewhere.

3.1.2 Teneral Emergence

In Pembrokeshire the habitat structure of the study site was such that it was possible to monitor the daily pattern of emergence by searching two sections of stream for all emerging individuals. In these sections the stream was narrow enough, and the vegetation was sparse enough, being dominated by *Juncus acutiflorus*, to make it possible to find all emerging individuals. Thus, the counts of emerging individuals are absolute rather than a catch per unit effort measure. Sections E and F of the Glanyrafon Uchaf stream (see below) were searched each morning from 13 June until 9 August for newly emerged tenerals. Individuals were held in polystyrene cups capped with gauze until the wings and cuticle were hard enough to be marked. On all days the cuticles were hard enough to be marked by early afternoon, and on particularly warm days (e.g. 5/7/97, with a maximum temperature of 22^{0}C) by 11.00am. Searching for tenerals began on 13 June.

3.2 METHODS (NEW FOREST)

3.2.1 Mark-Recapture

The location of the main mark and recapture exercise evolved over a period of several days from 7 June, as distribution data became available. Sampling began at 9.00am each morning and continued to c. 5.30pm. Four hours were spent catching adults at each site, with twenty minutes in each section, dependant on weather conditions. All individuals were marked with a unique identification number on the left forewing, using a Staedtler Lumocolor 313 S marker pen, and marked with paint on the dorsum of the thorax. From 18 June to 26 July most marking and re-catching was done on two large sections of stream approximately 200 m apart

(Sections 1 and 6). Each of these large sections was 300 m in length and divided into 25 m sub-sections. Long distance dispersers were searched for largely on the eastern tributary, the Peaked Hill tributary (see Fig. 13), with an additional search of neighbouring sites in late July.

3.2.2 Teneral emergence

The shrubby nature of the vegetation bordering the Crockford stream meant that it was extremely difficult to detect emerging individuals without causing undue damage or to make a quantitative search, hence teneral emergence was not systematically recorded.

4. RESULTS

The data sets from both sites are massive, with over 2,600 individuals marked in Pembrokeshire and 2,900 in the New Forest, and this report should therefore be considered as a preliminary analysis of these data sets. The data was entered on the spreadsheet software Microsoft Excel 4.0, with the statistical analyses reported here performed on Minitab release 8.2. The data is currently held with Dr D.J. Thompson at the University of Liverpool.

4.1 BRYNBERIAN, MYNYDD PRESELI, PEMBROKESHIRE (SN118344)

4.1.1 The locality

The Pembrokeshire study was undertaken on Mynydd Preseli, the locality with the second largest population of *C. mercuriale* in Britain. The New Forest is believed to support the largest British population. Mynydd Preseli is an extensive area of unenclosed common that is heavily grazed by sheep. The detailed distribution of *C. mercuriale* in the area is reported by Skidmore (1996). The site is divided into a northern and southern half by the ridge of the Mynydd which is above 300 m in altitude.

Skidmore (1996) reported that there were a number of localities for the species, arranged in a west-east orientation on the north face of the common, up to an altitude of about 170 metres a.s.l. He identified three catchments on this slope, with the central one, the Glan-yr-Afon catchment, containing the largest area of suitable habitat. This region (Fig. 1) therefore comprised the core of the study area where most effort in marking and recapturing was employed. This area would be the source of most dispersers, which could move either east or west. Concentrating re-capture effort in this area would allow the detection of any dispersers moving from sites to the east or west.

The main study stream and the marked valley mire formed the areas where the quantitative mark-recapture study was undertaken. The three large subsidiary sites were the main areas where additional marking and recapture was undertaken. The *Juncus* beds were dry river courses, where small numbers of *C. mercuriale* could be found away from the main study stream. As Fig. 2 shows, however, marking was also undertaken wherever individuals were found, including a number outside the core study area.

Fig 1 The core study area

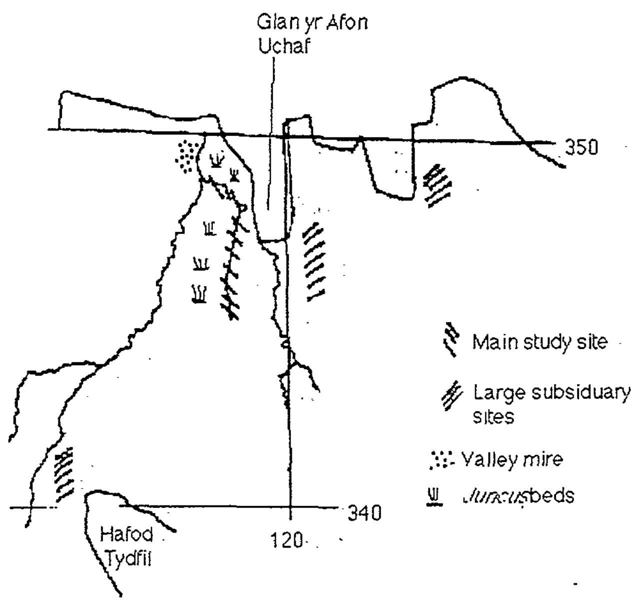
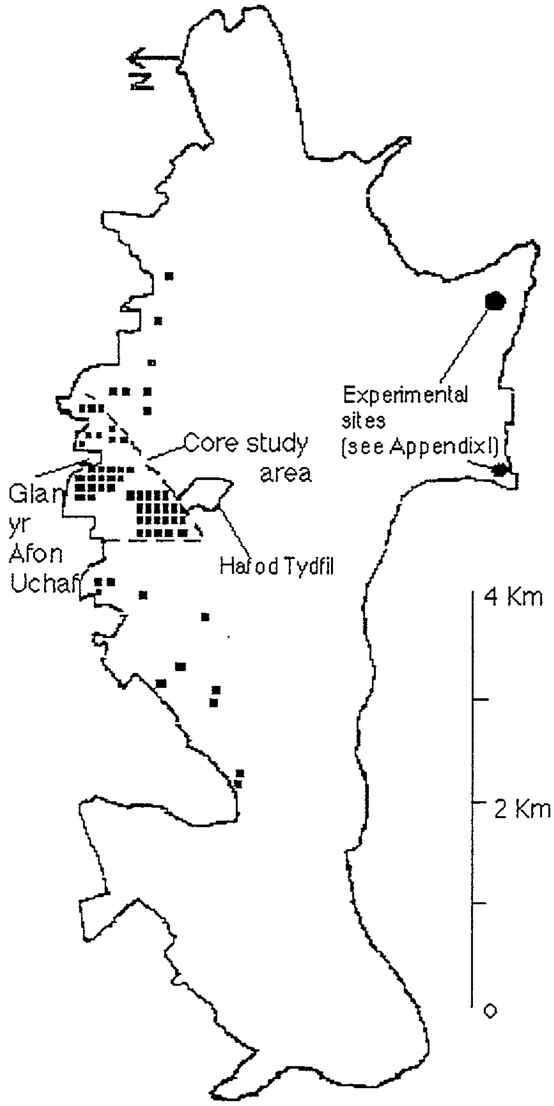


Fig. 2: Location of sampling sites (Mynydd Preseli)



4.1.2 Stream Sections

The main study stream was divided into sections, running downstream:

A to C These three sections comprised areas of very wet bog vegetation with only a diffuse water channel. The vegetation included cottongrass (*Eriophorum* spp.), white beaked-sedge (*Rhynchospora alba*), sundews (*Drosera* spp.) and purple moor grass (*Molinia caerulea*). A was 40 m long, B 50 m long and C 50 m long.

D This section held little surface water, with most of the flow being underground except after heavy rain. There were extensive stands of *Juncus* and *Molinia* and the section was 40 m long.

E From the start of this section the water flowed as a well defined channel. Here there were occasional stretches filled with marsh St Johns Wort (*Hypericum elodes*) and abundant *J. acutiflorus.* This section was 40 m long.

F This channel had abundant *Juncus* spp. and *Myrica gale*. This section was 50 m long.

G This section of channel was narrow and fast flowing (30 cm wide). There was little vegetation in the channel or surrounding it. This section was 40 m long.

H This section comprised an extensive, dense stand of *Juncus* spp and was 45 m long.

I to **K** In these sections there was little submerged vegetation with the channel variously having a gravel, muddy or rocky bed, and was approximately 0.75 m wide. Section I was 40 m long, J was 60 m long and K was 55 m long.

L This section was a slow flowing stretch of the stream which meandered before entering a small river. There was abundant growth of *J. acutiflorus*, *Hypericum elodes* and other plants. This section was 50 m long.

The mean section length is 47 m (maximum 60 m, minimum 40 m).

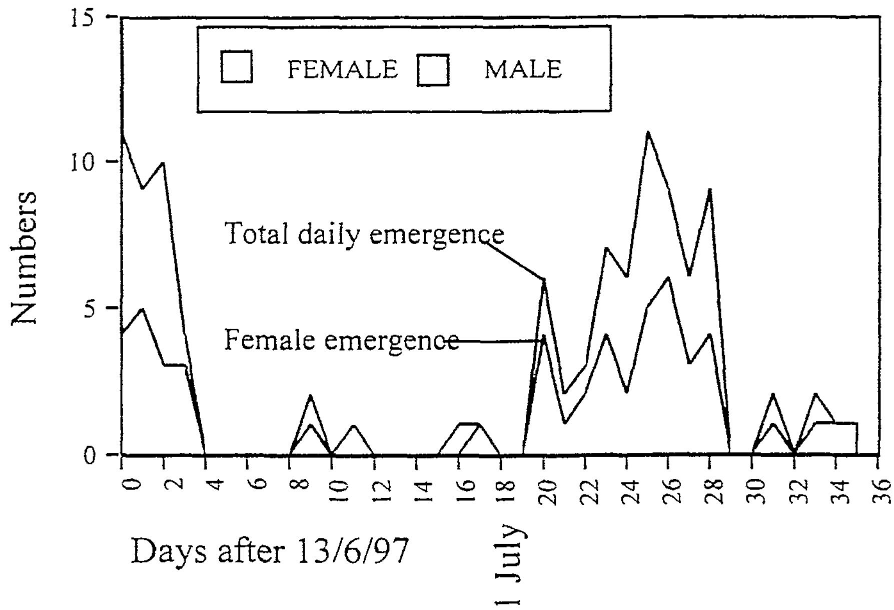
The Glanyrafon Uchaf stream is mentioned in Skidmore (1996, p.16), with sections A to F identified in his report as being above the conspicuous boulder. Skidmore found no *adult C. mercuriale* below the boulder, although he did find several nymphs amongst *Potamogeton*. However, in 1997 there were large numbers of *C. mercuriale* adults in these lower sections. The large subsidiary site near Hafod Tydfil is also mentioned by Skidmore (1996, p. 16).

4.1.3 Results

4.1.3.1 Phenology

When the study began on 10 June 1997 *C. mercuriale* adults were already flying. Tenerals were first searched for on 13 June when several were found. Subsequent emergence patterns were somewhat erratic (Fig. 3), although heavy rains and high water levels in June were presumably a major factor in inhibiting emergence or washing away any individuals that tried to do so. There is also the possibility that the apparent break in mid-period emergences is real and reflects the assumed semi-voltine nature of the life cycle noted by other authors (eg. Corbet *et al* 1960, Knights 1983, Evans 1989), with the earliest adults emerging from larvae in their second year and later individuals emerging from larvae that have managed to complete their development in a single year.

Fig. 3. Daily teneral emergence

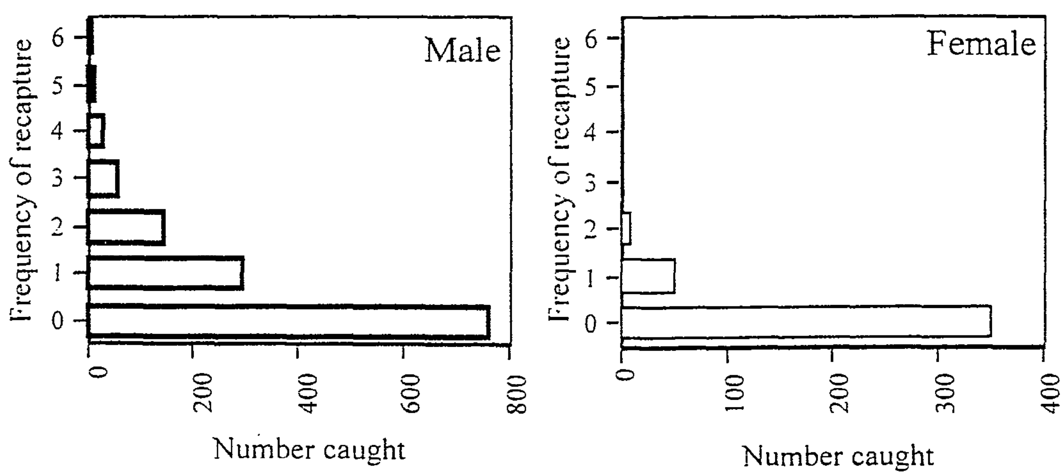


An examination of the daily ratio of males to females (not shown) provides no evidence for a bias in sex ratio or a change in the ratio over time. 53 emerging females and 51emerging males were captured , with the sex ratio therefore believed to be equal.

4.1.3.2 Mark-Recapture

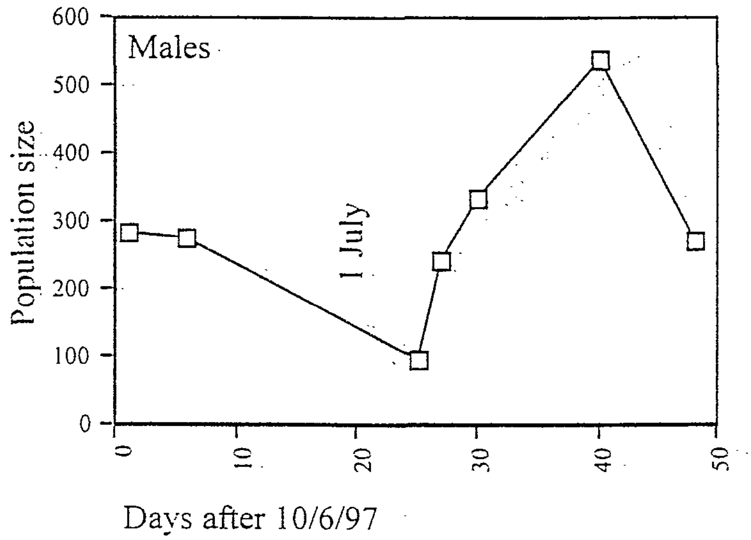
The frequency of recaptures was 40% for males (n=1287) and 10% for females (n=436) on the Main Study Site. Some males were re-captured up to six times, but the number of multiple female recaptures was much lower (Fig. 4).

Fig. 4. Recapture rates for non-tenerals on the Main Study Site.



Over the 500 or so metres of the Main Study Site, including the adjacent valley mire, a peak estimate (calculated using the Petersen estimate) for the male flying population is 500 individuals on 20 July (Fig. 5). The Petersen estimate is the simplest way of estimating population size (Begon 1979) and is used here because of that simplicity. The calculation is based on the proportion of individuals that are marked one day and are re-caught on another. Thus, if r individuals are caught one day, and on another day individuals are caught, of which m were marked, then it should be true that the population size = (r*n)/m. Further analysis is possible with more sophisticated models. The Petersen estimate is applicable to a population where there are no births and immigrations, or deaths and emigrations. None of these assumptions is likely to be true. In an attempt to minimise the potential effects of births, deaths, etc.; the population size was only estimated when sampling was undertaken on consecutive days.

Fig. 5. Estimated male population size



The mark-recapture data indicate a crash in population size over the period of bad weather in June, but this requires further analysis to establish if it is genuine and attributable to increased adult mortality or reduced teneral entry to the population.

On the Main Study Stream there was substantial movement between sections (Figs. 6 & 7). Interpretation of these results should be cautious since any movement between adjacent sections could be as little as 1 metre or over 100 metres, but nevertheless both sexes show substantial movements. The mean length of a section is 47 metres. Movements of over 250 metres along the stream were common. There is apparently no trend in the direction of movements as upstream movements were as common as those downstream.

Fig. 6. Within-stream movements by males marked in each section

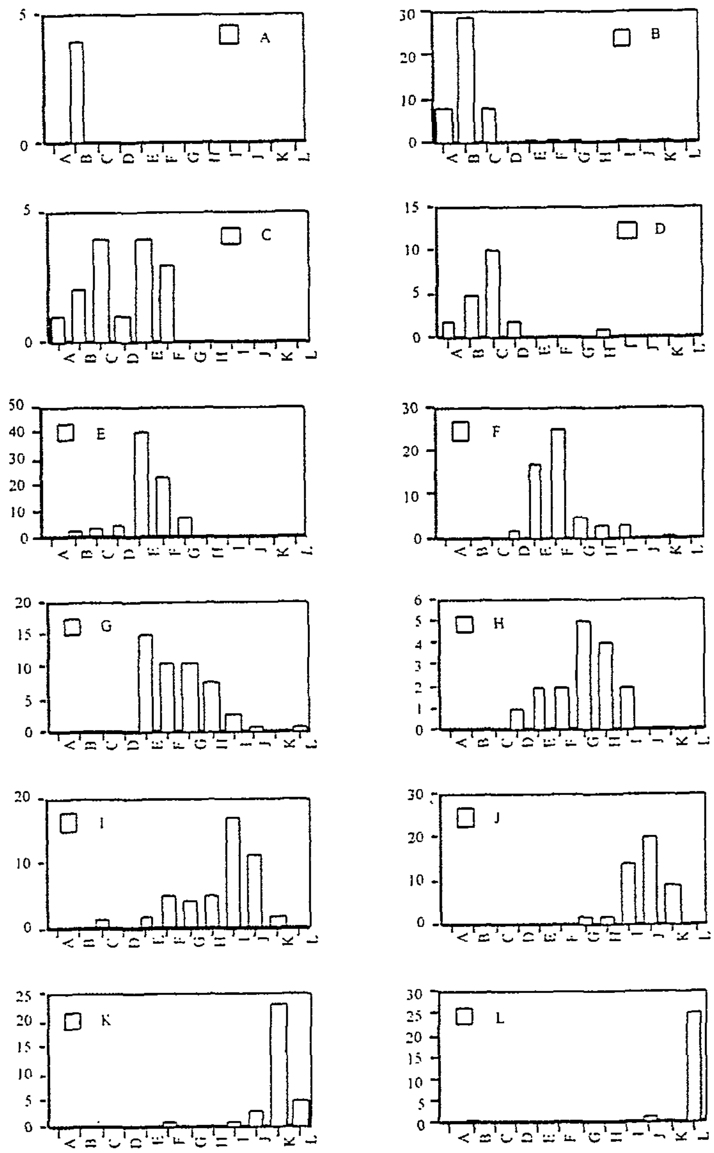
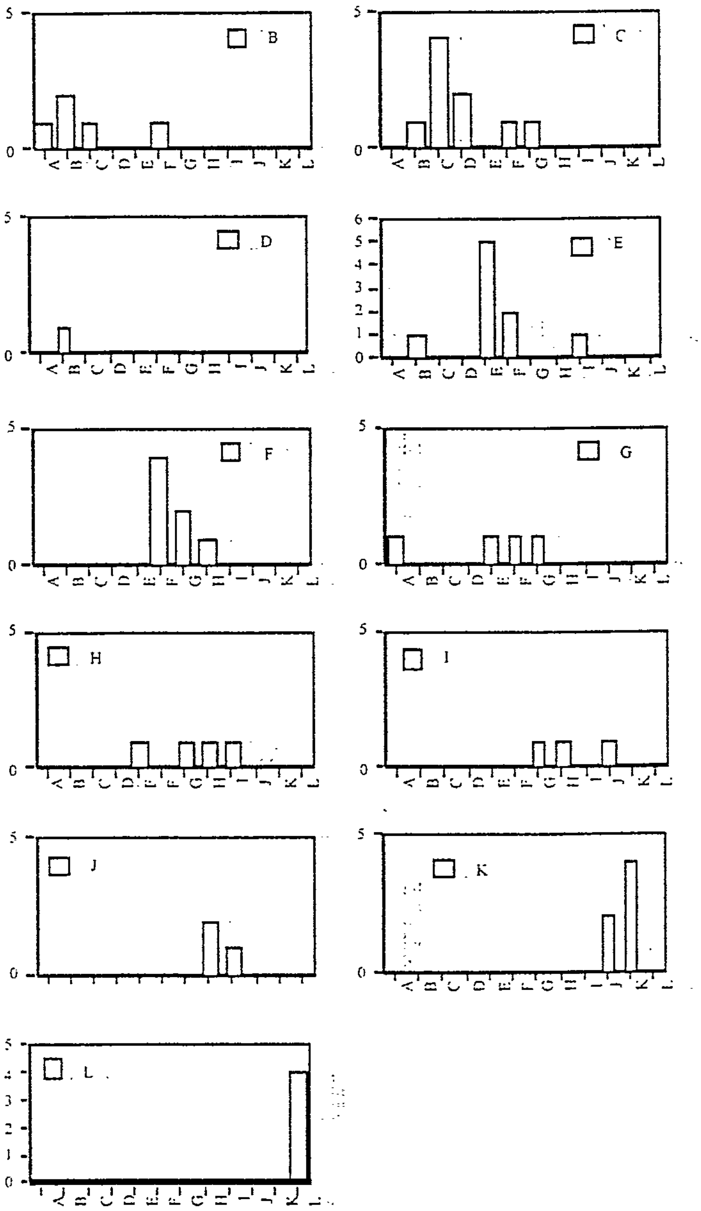


Fig. 7. Within-stream movements by females from each section.



4.1.3.3 Long Distance Movement

Movement by either sex between breeding sites was rare, with the longest observed movement being by a male (Fig. 8), which moved from near Hafod Tydfil (marked on 4 July) to the Main Study Stream (recaptured on 23 July). Few female movements were observed (Fig. 9). For both sexes, short movements (<50 m) were largely from the Main Study Site to nearby *Juncus* beds, or *vice versa*.

Fig. 8. Long distance movements by males

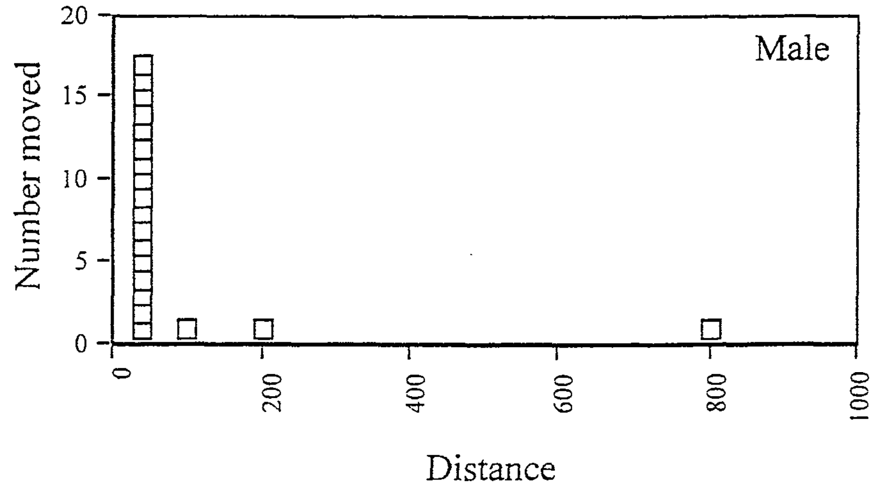
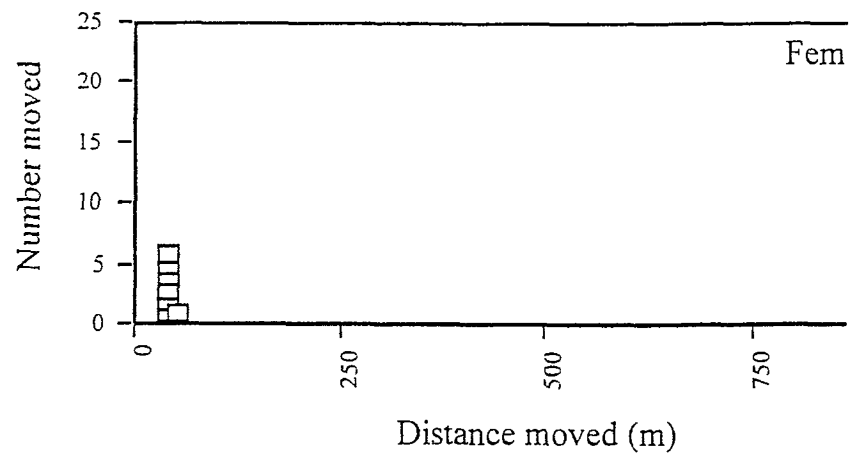


Fig. 9. Long distance movements by females



4.1.3.4 Wing length

Tenerals showed no change in wing length over time (Fig. 10), although the sample sizes are small. However, wing length of non-teneral adults caught for the first time declined through the season (Figs. 11 & 12) (Male wing length = 181-0.03x, n=1324, r^2=21.0, P<0.001; Female wing length = 20.3-0.03x, n=415, r^2=15, P<0.001).

Fig. 10. Change in teneral size over the season

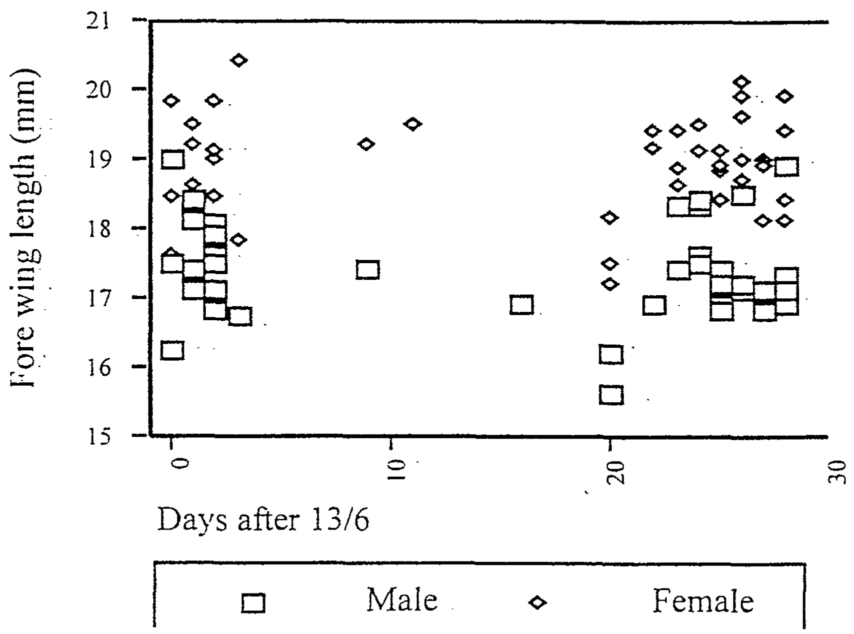


Fig. 11. Change in males (non-teneral) size over the season

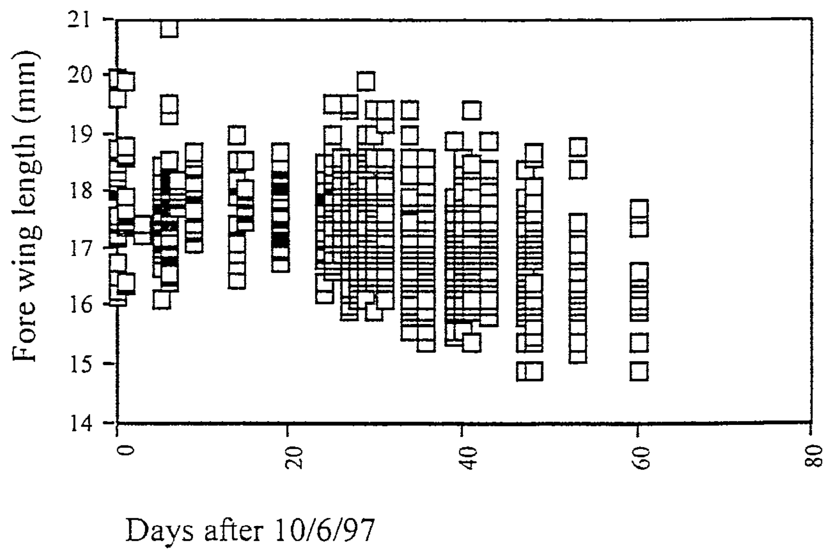
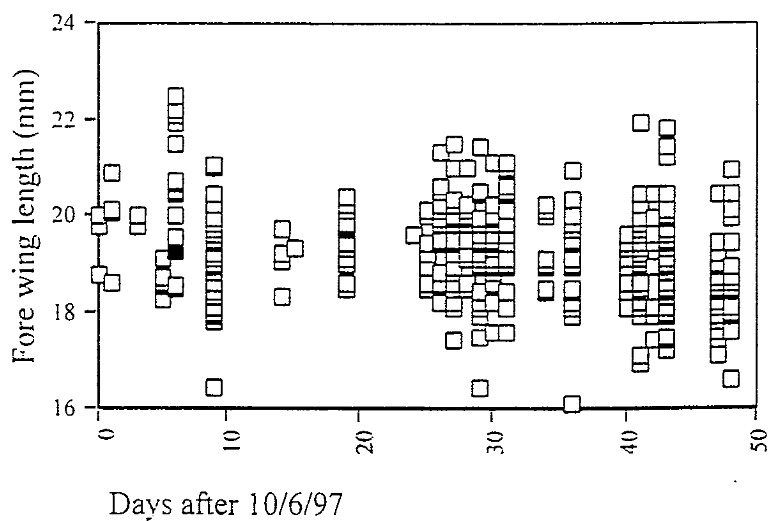


Fig. 12. Change in female (non-teneral) size over the season



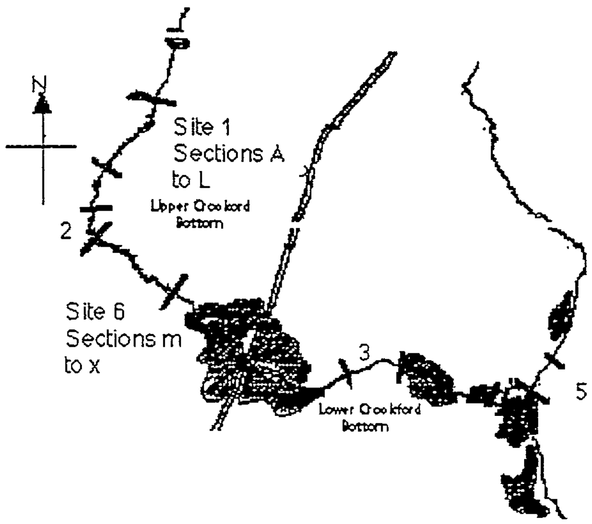
4.2 CROCKFORD, NEW FOREST, HAMPSHIRE (SZ345993)

4.2.1 The locality

The New Forest is the locality with the largest population of *C. mercuriale* in Britain. This study was undertaken at Crockford Bridge, an area of dry heathland, heavily grazed by ponies. The Upper Crockford Stream, which was the main study site, is considered to hold the largest population of *C. mercuriale* in the New Forest (Jenkins 1986a). Population counts undertaken in 1984 and 1985 indicated that over 350 adults were present during counts on peak days (Jenkins 1986a). Here *C. mercuriale* is found in a stream which flows through open valley mire and heathland. Initially fhe stream flows from north to south and then turns to flow east towards the road bridge. East of the road the stream flows through patches of scrub. For most of its length, this lower stream has scrub vegetation borderering at least one bank and there are only a small number of open 'glades' where both banks are open to valley mire or heathland (Jenkins 1986b).

As the entire Crockford site is on the same water system (Fig. 13) it was possible, if unlikely, for an individual to travel within the entire site without moving away from water. It was necessary, therefore, to make a subjective decision as to whether movements between sites involved merely moving along the water channel or across the intervening dry heath. In practice, only one long distance movement was recorded where it was thought more likely that an individual crossed the dry heath rather than moved along the water channel.

Fig. 13. Crockford Bridge study area in the New Forest



4.2.2 Stream sections

Each sub-section was 25 m long. In three sub-sections vegetation transects were surveyed and aquatic invertebrates sampled.

The references for the various sections are:
Site 1, start of sub-section A - SZ 3480 9985
Site 1, end of sub-section L - SZ 3462 9961
Site 6, start of sub-section M - SZ 3459 9939
Site 6, end of sub-section X - SZ 3483 9922

Two vegetation transects of stream section 1 were surveyed (junction sub-sections A/B) and junctions G/H) and one transect on section 2 (end of sub-section X). At junction A/B (SZ 3480 9985) the water is slow moving with *Potamogeton* sp. and *Hypericum elodes* in the water with the surrounding vegetation being species rich, including *Eriophorum, Pinguicula, Juncus conglomeratus, J. acutiflorus, Rhynchospora alba, Myrica gale,* tussocks of *Molinia caerulea,* and *Erica tetralix.*

At the junction of G/H (SZ 3470 9968) the stream is more confined, with less *Potamogeton* and *Hypericum*. The surrounding vegetation includes low *Myrica, Molinia* and *E. tetralix*.

At the end of sub-section X (SZ3483 9922) the channel is narrow with a gravelly bottom in places. *Potamogeton* and *Hypericum* are restricted, whilst *Phragmites* and other plant species not found upstream occur here. Abundant tall *Myrica* and other plants comprise the remainder of the vegetation.

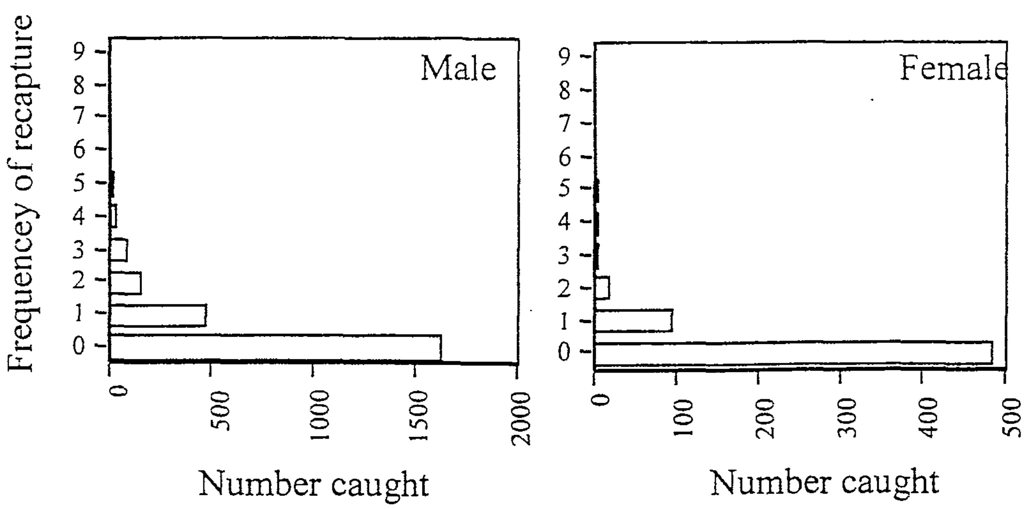
4.2.3 Results

4.2.3.1 Mark-Recapture

The analysis of dispersal included here is largely based on fieldwork carried out between 18 June and 26 July, although all long distance dispersal events are reported.

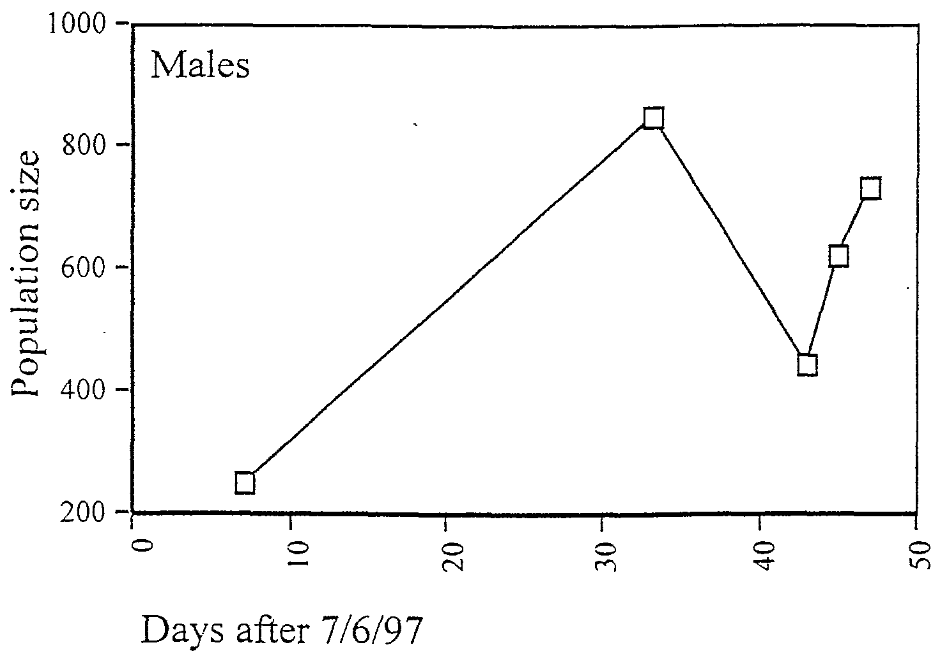
The male recapture rate on the main study site was 31% (n=2351) and for females this was 19% (n=598). One male was recaptured 9 times (Fig. 14).

Fig. 14. Recapture frequencies for both sexes in the New Forest.



The population size over a 300 metre stretch (Site 6) of the main study site peaked at approximately 800 individual males (Fig. 15) on 20 July (calculated using the Petersen estimate (Begon 1979)).

Fig. 15. Population size at site 6



Within the streams there was substantial movement between sub-sites, with a number of movements between the two main sites. The within-sites movements for the males at sites 1 and 2 are shown (Figs. 16 & 17) as are the female movements (Figs. 18 & 19). There were several movements between the two main sections, representing one female movement of 600 metres, two male movements of 600 metres and one each of 400 metres, 300 metres and 200 metres.

Fig. 16. Within-section movements: males, Site 1

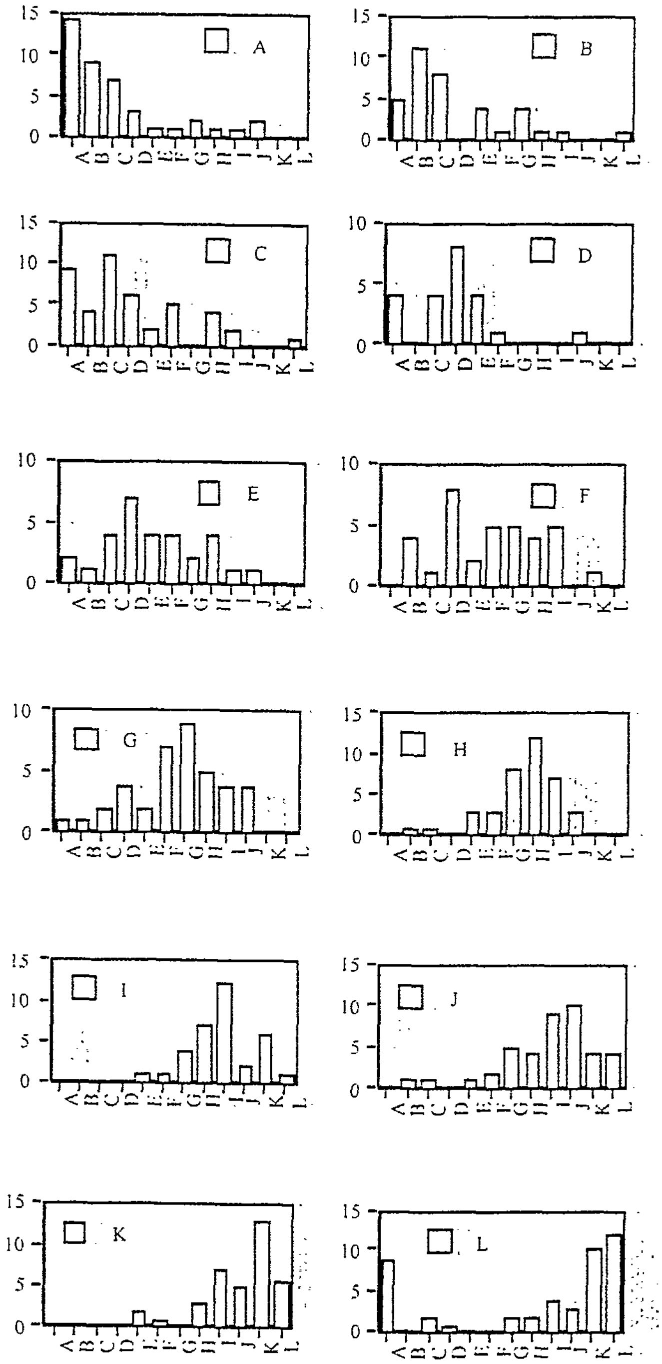


Fig. 17. Within-section movements: males, Site 6

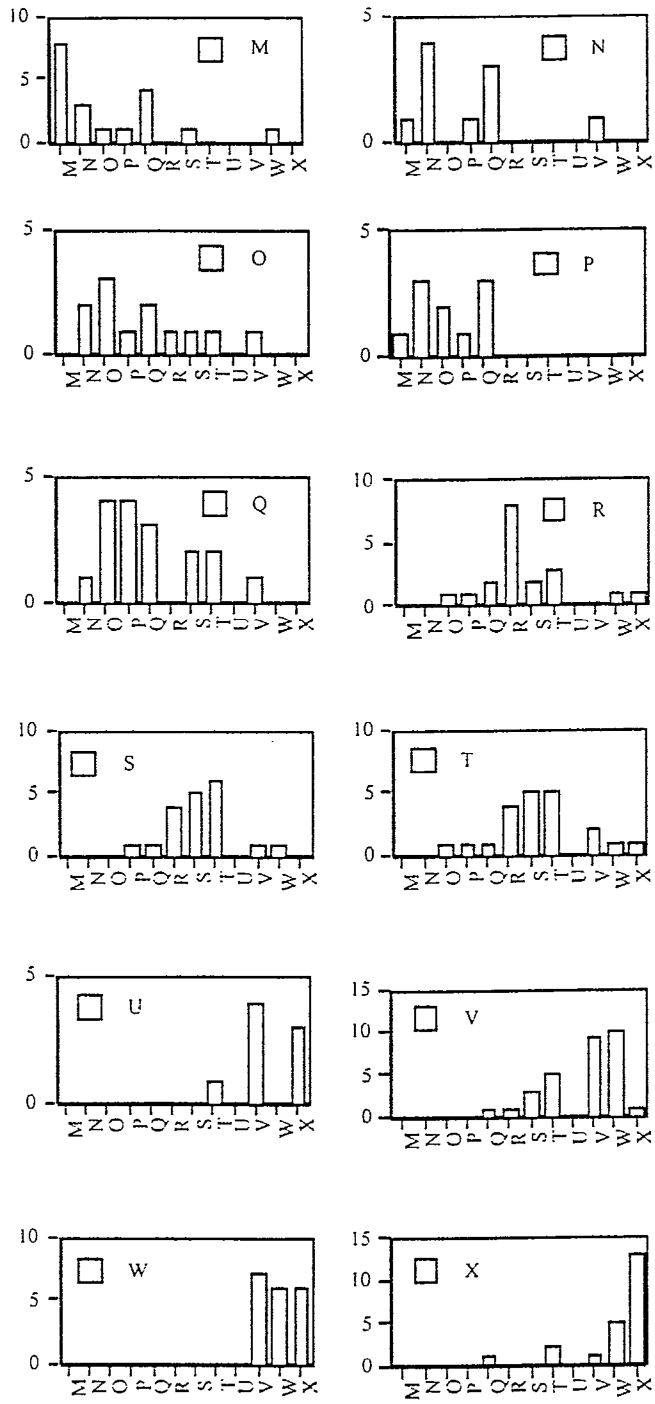


Fig. 18. Within-section movements: females, Site 1

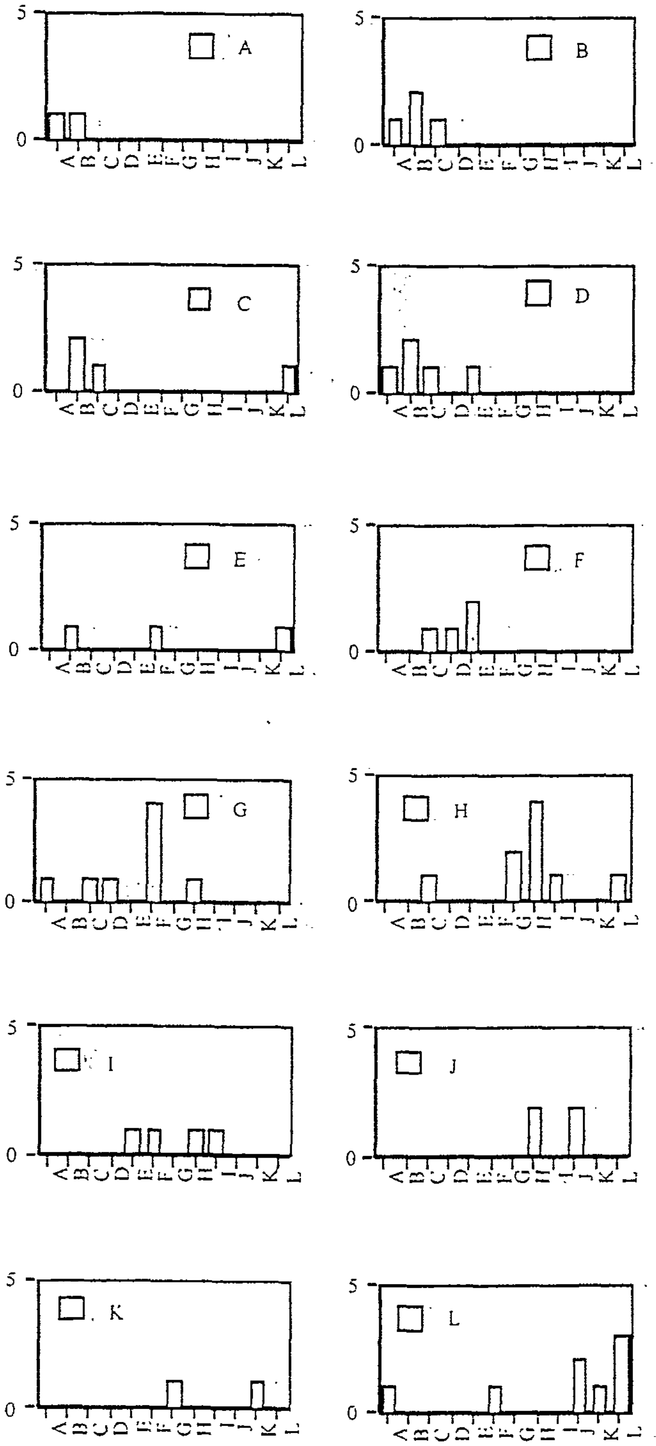
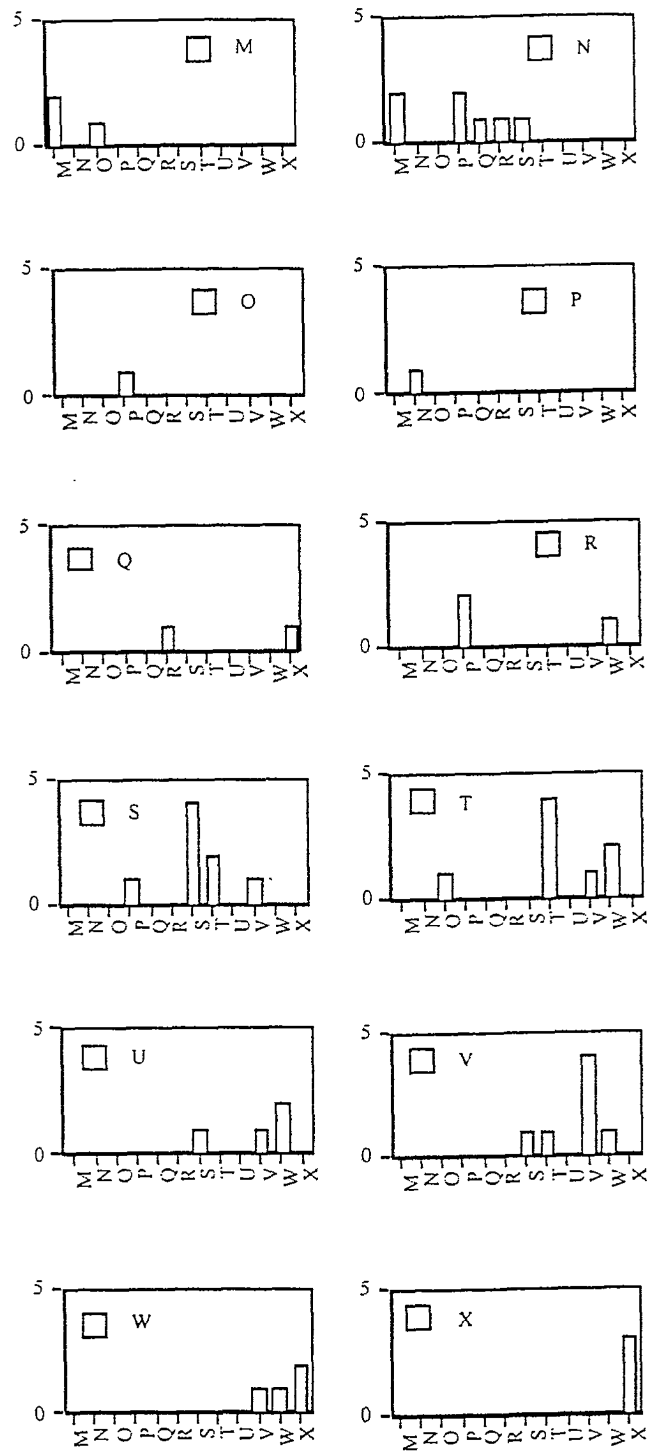


Fig. 19. Within-section movements: females, Site 6



4.2.3.2 Long Distance Movement

Only one substantial long distance movement was recorded at Crockford, with the individual male moving 1.06 km, between site 1 (marked on 9 July) and site 3 (recaptured on 16 July) (Fig. 20). Few female movements were observed (Fig. 21). A survey of other sites in the locality, within a radius of approximately 5 kilometres, revealed a number with *C. mercuriale*, but no individuals marked at Crockford were found.

Fig. 20. Long distance male dispersal

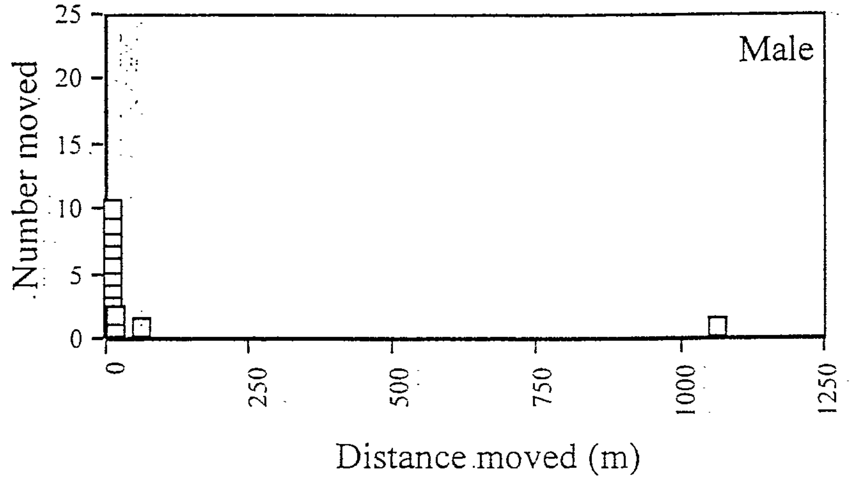
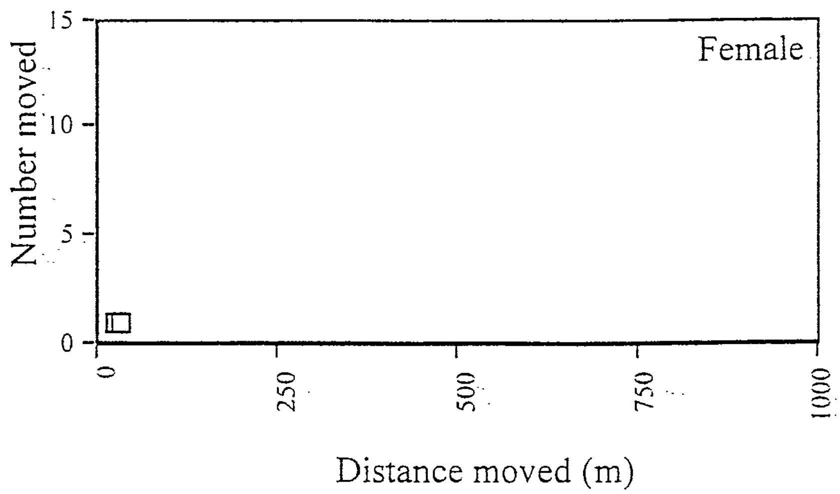


Fig. 21. Long distance female dispersal



4.2.3.3 Wing length

Adult wing length for both sexes declined over the study period (data not figured). (Male size = 17.6-.04x, n = 2345, r^2 = 47.4%, P < 0.0001; female size = 19.3-04x, n = 597, r^2 = 37%, P < 0.001)

4.3 Comparison of results

4.3.1 Phenology

The study started too late to record the start of the emergence period and tenerals were recorded during the first search on 13 June at Glanyrafon Uchaf. The last observed emergence here was on 14 July. The emergence of tenerals in Pembrokeshire was erratic (Fig. 3), and there was no clear seasonal pattern, although heavy rain may have prevented emergence in mid-June. Sex ratio was equal at emergence (50.9%: 49.1%, female: male).

Trends in adult population size are difficult to establish at present. At the moment only crude estimates of adult male population size have been made (Figs. 5 & 15), using the Petersen formula (Begon 1979). Both sites, however, show a peak of abundance in mid-July, based on a 500 m length of stream and a small adjacent valley mire in Pembrokeshire and a 300m section of stream in the New Forest.

4.3.2 Wing length

At both sites, and for both sexes, wing length declined over the season, as estimated from the sizes of individuals captured and measured for the first time.

4.3.3 Dispersal

4.3.3.1 Teneral movements

A total of 88 teneral females and 75 teneral males were marked in Pembrokeshire, and 3 teneral females and 15 teneral males in the New Forest. Recapture of tenerals was poor and no particularly long distance movements were found, hence these are not analysed further here. On most days tenerals were found to fly only short distances after emergence, flying vertically 1-2 metres and horizontally 10-30 metres; even late in the day tenerals could be found near breeding sites. On two particularly hot and sunny days (4/7/97 and 5/7/97, maximum temperatures of 19°C and 22°C respectively) in Pembrokeshire, a number (<10) of individuals were seen to fly vertically 15-30 metres and then fly horizontally out of the site.

4.3.3.2 Within-stream movements

In Pembrokeshire, approximately 1400 non-teneral males and 470 non-teneral females were marked on the main stream. The male recapture rate on the stream was 40% and the female recapture rate was 10%. Both sexes displayed substantial within-stream movement, supporting the statement by Merritt *et al* (1996) that males are not territorial. In the New Forest 2351 non-teneral males and 597 non-teneral females were marked. The recapture rate was approximately 31% for males and 19% for females. In the New Forest site the stream was longer, and several very long within-stream movements were recorded (female: 600 m; male: 600 m, 600 m, 400 m, 300 m, 200 m).

4.3.3.3 Long distance movements

Finding individuals away from the vicinity of breeding sites was a notable event at both sites. In Pembrokeshire, within the general locality of the main study site, there were many smaller breeding sites and over 350 males and 100 females were marked at these localities. In the New Forest, tributaries of the main stream and three adjacent watercourses were searched for marked adults. The topography and habitat structure of the area meant that in many cases movements between several sections of stream were easier cross-country rather than by within-stream movement.

Few movements were recorded in the New Forest, although the longest movement of the project was detected here, with a male travelling at least 1.06 kilometres (as measured for the shortest distance across country). In Pembrokeshire, no movements of this distance were found (the longest being 800 metres), but there was a greater number of shorter movements by males to nearby *Juncus* beds which ran parallel to the main study site.

4.3.4 Behaviour

At both sites, finding animals more than about 10 metres away from the stream corridor and breeding site was unusual. In Pembrokeshire, small numbers of animals could be found sheltering in *Juncus* beds that ran parallel to the study stream, but they never appeared to utilise gorse *Ulex europaeus* bushes for shelter or cover. In the New Forest, where *Juncus* tussocks were rare, adults could occasionally be found resting on gorse bushes. No localities appeared to be used by either sex preferentially. The low numbers of non-teneral females that were found is remarkable given the equal sex ration at emergence. This corresponds with previous observations on the species (eg. Jenkins 1986a) and is not entirely an artefact of the males being more brightly coloured and thus preferentially caught.

Predation was rare, the main enemies being spiders, whilst, both in Pembrokeshire and the New Forest, individuals were found trapped on sundew leaves. A teneral female was attacked and eaten by a *Pyrrhosoma nymphula* on her maiden flight in Pembrokeshire. Skidmore (1996) also reported *P. nymphula* preying on a teneral *C. mercuriale*. Birds were not seen to attack individuals.

For further notes on behaviour see Appendix 2.

5. DISCUSSION

A substantial data set on elements of the biology of adult *Coenagrion mercuriale* has been collected and a fuller analysis of this is required, as is a mathematical analysis of the quantitative mark-recapture data, incorporating weather effects and body size (as indicated by wing length) on survival rates.

The main objective of this study was to study dispersal behaviour and to quantify movement. There were substantial within-stream movements by both males and females at both sites, but very little movement away from the main study stream. In Pembrokeshire, more dispersal (<50m) was noted because of the proximity of large *Juncus* beds to the study stream, which adults used for shelter, but, nevertheless, it was remarkable how few individuals were actually found in these despite being adjacent to a large population. In contrast to the Pembrokeshire site, the vegetation surrounding the main study site at Crockford is dry heathland, which contained little *Juncus*. Likewise, perhaps more medium distance dispersal was noted because breeding sites were closer to each other at Glanyrafon Uchaf than Crockford. There are too few data on female movements to comment on any differences in the dispersal behaviour of the sexes.

While it is not yet possible to develop these data into a quantitative model of the colonisation potential of *C. mercuriale* it would appear to be limited. Longer distance colonisation would appear to be a rare event and small scale colonisation minimal. Female damselflies characteristically oviposit in tandem with a male but more information is required on the ability of a female to oviposit alone. In the New Forest, females were observed ovipositing alone between 26 and 31 July. Some dragonfly species are known to fly considerable distances in tandem and if the pair is separated during flight the mated female would be very difficult to detect. This study has shown that long distance dispersal is uncommon but more fieldwork must be undertaken to quantify colonisation potential at different distances from the core populations. If suitable sites are distributed evenly in a landscape, then as the dispersal distance increases the chances of finding the site decrease inversely with the square of the distance moved (c.f. area of a circle = 3.14 X radius squared).

Consideration should also be given to the possibility that colonisation events are more likely from individuals that have emerged in sub-optimal habitat. On Mynydd Preseli, for example, one of the '*Juncus* beds' where adults sheltered was originally thought to be a breeding site but it dried out in mid-July and was then refilled by August floods. Surviving adults from this site must have dispersed in July to find new breeding habitat in the vicinity.

For conservation purposes, approximately 50 metres would appear to be the furthest regular colonisation distance achieved by *C. mercuriale* at Glanyrafon Uchaf, and even less at Crockford. However, given the high within-stream movements observed, these distances may be increased if the landscape is suitable. Almost certainly the majority of individuals that moved between the sections of stream will have moved along the stream channel, and greater between-site dispersal may occur if there are features in the landscape to fly along, such as hedgerows or other water channels.

There are caveats to these findings however. Trivially, this is only a one year study and long range colonisation may occur only in exceptional years. As hinted above, dispersal is likely to be dependent on landscape features, and extrapolation to other sites should be undertaken with caution. A more important observation however, is the fact that both studies were undertaken largely on streams which held large, dense populations. In Pembrokeshire, many of the occupied sites on Mynydd Preseli were actually small and held few individuals - attempts were made to estimate population size on some of these, but too few animals were found to use mark-recapture estimates. Thus, given that few individuals dispersed from large populations, where only small populations occur in stable habitats in a locality even fewer colonisations will occur. It is also possible that emigration is density dependent, so where densities are low there is less pressure for individuals to move. Additionally, since many of these populations are very small, the loss of individuals from a site might only hasten the population's extinction.

6. ACKNOWLEDGEMENTS

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Members of the UK Biodiversity Action Plan Southern Damselfly Steering Group commented on early drafts of this report.

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APPENDIX 1

DOES MARKING AFFECT SURVIVAL?

The quantitative mark-recapture data can be used to establish the effects of marking on short term survival and an experiment was also performed to establish longer term effects, using males in both instances. It is not possible to test whether marking affects dispersal behaviour, but it appears not to affect survival.

Short term survival

Begon (1979) presents a method for testing if marking affects short term survival, say by the paint being toxic, blocking spiracles, or other handling effects. The test establishes if individuals marked 'today', for example, are under-represented in tomorrow's sample compared to individuals caught today and already with a mark. This test is performed only on the Pembrokeshire data for a limited number of days, for simplicity. The position of the thorax paint mark was either on the Top, or the Right or Left side of the thorax.

The 'test statistic' is the value of chi-square and if the associated 'P' value is <0.05 then there is a significant effect of marking on short-term survival. There is none.

From 16-17/6, using 'Gold-on-Top': chi-square$=0.020$, $P>0.2$
From 4-5/7, using 'Green-on-Top': chi-square$=0.003$, $P>0.2$
From 5-6/7, using 'Green-on-Top': chi-square$=0.265$, $P>0.2$
From 19-20/7, using 'Red-on-Left': chi-square$=1.329$, $P>0.2$
From 20-21/7, using 'Silver-on-Top': chi-square$=2.030$, $P>0.1$
From 27-28/7, using 'Lime-on-Right': chi-square$=0.452$, $P>0.2$
Cumulative chi-square$=4.099$, df$=6$, $P>0.2$

Longer-term survival

Two populations in Pembrokeshire were used for an experiment to test the effects of the colour mark on the thorax on longer term survival at Glynsaithmaen and Cors Tewgyll. Both of these sites are on the south side of Mynydd Preseli (see Fig. 2).

Individuals were either marked on the thorax and wing, or wing only. On the next occasion, if there were significantly fewer re-caught with a thorax and wing mark than only with a wing mark, then there was an effect on survival.

The 'test statistic' is the value of chi-square and if the associated 'P' value is <0.05 then there is a significant effect of marking on longer-term survival. There is none.

Thorax mark on 'Top', survival from 20-23/7, chi-square$=1.176$, $P>0.2$
Thorax mark on 'Right', survival from 23-27/7, chi-square$=0.44$, $P>0.2$
Thorax mark on 'Left', survival from 27/7-2/8, chi-square$=2.143$, $P>0.2$
Cumulative chi-square$=3.763$, df$=3$, $P>0.2$.

APPENDIX 2

BEHAVIOURAL OBSERVATIONS FROM CROCKFORD, NEW FOREST

1. Population densities appear to be highest in boggy areas.

2. Females are primarily seen by the water and only occasionally within the marginal areas to the stream. These females are usually in tandem. Presumable females only come to the water in order to mate.

3. Males marked in green paint on the dorsum have been observed attempting to go into tandem with each other. Thus it has been assumed that green paint is affecting the behaviour of male individuals and consequently green paint was not used subsequently. It may be possible that the green bands on the thorax of the female may be a search signal for the male.

4. Male-male competition appears to occur, this may be occuring in various ways:-
 a) Sperm competition - previously observed in similar species
 b) Male-male competition for perching places, males appear to have preferred perching places where they wait for females. It was never observed that any male attempting to displace an displaying male was successful. This may suggest that the ability to defend a perch is related to ownership.
 c) Male-male competition for females. Occasionally it was seen that a male will attempt to dislodge a male that is in tandem with a female. However, this behaviour was never seen to be successful.

5. Female choice; females appear to be able to prevent males from taking them into tandem. This is achieved by an arching of the abdomen upwards, which presumably prevents the male clasping the female, by closing the gap behind the head of the female. It is also been observed that females appear to fight males if they do not wish to enter the tandem position with the male. If a female wishes to go into tandem then this is achieved quickly and effectively with no conflict.

6. Escape responses:-
 a) When cold there is no escape response and it is possible to pick up individuals directly from wherever they are found.
 b) When cool:- i) Individual will move around the stem of its perch in order to hide it body length from the observer. ii) Upon approach to an individual it will often just fall off of its perch and into the underlying vegetation. This can actually make the insect untraceable. iii) Upon approach to an individual it may fly a short distance to an adjacent patch of vegetation.
 c) In warm weather an individual will fly away from the observer, remaining in flight for up to 10 seconds, before resting again.

7. Shelter; during periods of bad weather and during the early evening, individuals can be observed away from the stream (20-50m) in tussocks. It appears that these tussocks are used to shelter from the elements during the night and during bad weather conditions. This observation is supported by the location of individuals in the morning. They can be observed on blades of *Molinia* or *Juncus* warming themselves prior to taking flight.

8. Catch rate goes right down between 3.00 p.m. and 4.00 p.m. During this time a larger number of unattended females can be found at the stream. This may suggest that there is a trade off for males between time spent trying to mate and time spent foraging for food. If males display in the morning and early afternoon at the stream, when the potential number of receptive females is optimal, there will become a point in the day when the number of females falls to a point where it no longer pays males to remain at the stream and hence they forage for food. The presence of unattended females at the stream late in the afternoon may simply be a reflection of the lack of available males following this critical time.

9. Males appear to be located in small groups together. It can be seen that males are found on vegetation which overhangs an area of clear water. However, this observation may simply be a response to a relatively high population density and a lack of locations suitable for males to display.

10. Male and female body size (as indicated by wing length) appears to have been reducing in a geometric fashion over the course of the sampling period. This may be due to delayed density dependent competition and the way in which this relates to emergence time of the individual. Alternatively, it may be related to the time of egg laying for the emerging individual from the previous year. Both of these assumptions assume a one year life cycle.

11. Tandems occur within a window of time during the day. Optimum time appears to be between 10.00 a.m. and 2.00 p.m. However, if the morning is particularly bad then the period may became extended later into the day.

12. The last observed teneral was found on the 29/7/97.

13. On the very final day (31/7/97) a single solitary female was observed to be attempting to oviposit at the end of the day.

14. List of dragonfly species found on the Upper Crockford Bottom within sites 1 & 6:

Coenagrion mercuriale
Coenagrion puella
Ceriagrion tenellum
Calopteryx virgo
Lestes sponsa
Pyrrhosoma nymphula
Ischnura elegans

Anax imperator
Cordulegaster boltonii
Orthetrum coerulescens
Libellula depressa
Sympetrum striolatum

APPENDIX 3

AQUATIC INVERTEBRATE SAMPLES FROM CROCKFORD, 17 JULY 1997: Site 1 (sub-sections A & L) and Site 6 (sub-section X).

[Abundance categories: 1 = 1, 2 = 2-10, 3 = 11-100, 4 = 101-1000, shown in parentheses]

	Site 1 Area A (SZ 3479 9984)	Site 1 Area L (SZ 3462 9961)	Site 6 Area X (SZ 3488 9917)
TURBELLARIA: Planariidae			
Polycelis spp.	(1)	-	-
OLIGOCHAETA	(3)	(4)	(4)
ANNELIDA			
Glossiphonia complanata	(1)	(3)	(2)
Erpobdella octoculata	-	-	(1)
MOLLUSCA			
Potamopyrgus jenkinsi	(3)	(4)	(1)
Lymnaea palustris	-	-	(1)
Lymnaea peregra	(2)	-	(2)
Pisidium spp.	(3)	(3)	(3)
HYDROCARINA	(2)	-	-
OSTRACODA	(1)	-	(1)
MALACOSTRACA			
Gammarus pulex	(4)	(5)	(4)
Asellus aquaticus	(2)	-	-
Asellus meridianus	(2)	-	-
EPHEMEROPTERA			
Ephemerella ignita	(3)	(2)	(2)
Caenis luctuosa group	-	-	(2)
Caenis macruralluctuosa	(2)	-	-
Baetis niger	(3)	(2)	(2)
Baetis digitatus	-	-	(3)
Baetis rhodani	-	(2)	-
Centroptilum luteolum	(1)	-	(3)
Leptophlebia vespertina	(2)	-	-
Paraleptophlebia sp.	-	(2)	(2)
PLECOPTERA			
Nemoura sp.	-	-	(1)
Leuctra fusca	-	(3)	(3)
Leuctra geniculata	-	-	(2)
MEGALOPTERA			
Sialis lutaria	-	-	(2)
ODONATA			
Cordulegaster boltonii	(1)	(3)	(2)
Orthetrum coerulescens	(4)	(3)	(3)
Calopteryx virgo	-	-	(2)
Coenagrion mercuriale	(3)	(2)	-
Ceriagrion tenellum	(2)	-	(2)
Pyrrhosoma nymphula	-	(2)	(2)
HEMIPTERA			
Gerris gibbifer	(1)	-	-
Gerris sp.	-	(2)	(1)
Corixidae sp.	-	-	(1)
Sigara venusta	(3)	-	-
Nepa cinerea	-	-	(1)
TRICHOPTERA			
Polycentropus irroratus	(1)	(2)	(2)
Polycentropus kingi	-	-	(3)
Hydropsyche angustipennis	(2)	-	-
Hydropsyche siltalai	-	(3)	-
Hydroptila spp.	(3)	-	-
Oxyethira spp.	(3)	-	-
Limnophila (*Eloeophila*) sp.	-	(1)	-
Limnephilus lunatus	(2)	(2)	(2)
Adicella reducta	(2)	-	-

Agapetus sp.	-	(1)	-
Lepidostoma hirtum	-	(3)	-
Sericostoma personatum	-	(1)	-
DIPTERA			
Atrichopogon spp.	(3)	-	(2)
Simulidae	(3)	-	-
Simulium (*Eusimulium*) *aureum* group	-	(3)	(3)
Simulium (*Simulium*) *ornatum* group	-	(2)	-
Chironomidae	(4)	(4)	(4)
Chrysops sp.	-	(1)	-
COLEOPTERA			
Helochares spp.	(2)	-	-
Anacaena limbata	-	(2)	-
Elmis aenea	(2)	-	(1)
Oulimnius sp.	-	(2)	-
Limnius volckmari	-	(2)	-
Gyrinus sp.	-	-	(1)
Gyrinus subtriatus	-	-	(1)

Strategy for the management of white-clawed crayfish (*Austropotamobius pallipes*) populations in England and Wales

A report produced under Environment Agency R&D Project 640

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1. BACKGROUND

Britain and Ireland possess a single native species of crayfish, *Austropotamobius pallipes* (the white-clawed crayfish). It has a widespread distribution in England, Ireland and Wales but, with the exception of one introduced population, is absent from Scotland. Since the 1970s a number of non-native crayfish species have been introduced for aquacultural and culinary purposes. These species have all found their way into the wild and at least two now form such extensive populations in England that they are being harvested (Rogers & Holdich, 1995). The introduction of non-native crayfish species poses a threat to the survival of the native crayfish as they are usually superior competitors and some can carry a fungal disease, crayfish plague (*Aphanomyces astaci*), to which *A. pallipes* is totally susceptible (Holdich, Rogers & Reader, 1995a). Similar problems affect mainland European populations of *A. pallipes* and other native European crayfish species (Holdich, 1996). Britain and Ireland probably possess the most extensive remaining populations of *A. pallipes* in Europe and there is a need to try and protect them from the impact of introduced crayfish and crayfish plague.

Since the threats to the survival of the native crayfish were highlighted (Holdich, 1991; Holdich & Reeve, 1991; Holdich, Rogers & Reader, 1995a, b) there have been a number of changes in legislation (see Alderman & Wickins, 1996; Holdich & Rogers, 1996; Environment Agency, 1997) to try and protect and conserve the remaining British populations and to try and manage populations of non-native crayfish and crayfish plague (Alderman & Polglase, 1988; Alderman, 1993). Such protection and management measures are now being built into the Local Environment Agency Plans (LEAPS) as a result of *A. pallipes* being one of the species highlighted in the UK Biodiversity Action Plan Steering Group Report (DOE, 1995). However, in order to carry out such measures a detailed knowledge of the distribution of native and non-native crayfish is required as is a means of accurately identifying such crayfish.

Distributional information is available through a national database at the ITE Biological Records Centre at Monks Wood of all crayfish records. Help with determining the species present in Britain and Ireland can be obtained through identification leaflets (National Rivers Authority, 1994; Environment Agency, 1997).

This document aims to provide guidance on the most appropriate management strategy for crayfish populations in each catchment in England and Wales, based on the most recent data available on the distribution and status of both native and non-native crayfish populations and outbreaks of crayfish plague. It incorporates many new records sent in by a range of individuals and organisations to the Crayfish Study Group at Nottingham University between 1994-1997, as well as the results of a number of detailed surveys of selected catchments recently undertaken by Nottingham University.

On the basis of all post-1989 records, catchments have been classified into one of 5 categories that reflect the most appropriate management in relation to crayfish populations.

2. CRAYFISH DISTRIBUTION

The distribution of *A. pallipes* in Britain and Ireland based on all records since 1970 is shown in Figure 1. This shows the minimum potential distribution. The maximum potential distribution could be somewhat greater as there are many areas which, despite having apparently suitable habitats, have never had recorded populations of *A. pallipes* in recent times, e.g. the chalk streams of the South Downs in England. Since the early 1980s many populations of *A. pallipes* have been eliminated, particularly by crayfish plague (see below), and in England and Wales the distribution is now less extensive as shown for post-1989 in Figure 2. Extensive surveys in recent years have, however, shown that *A. pallipes* populations are particularly strong in the north of England. New populations continue to be found and these will make a difference to the crayfish status of particular catchments; for instance, in May 1997 *A. pallipes* was reported from a West Somerset stream in a catchment area where no crayfish had been reported before (M. Frayling, pers. comm.) (note that this record has not been included on Figs 1 and 2).

Of the non-native crayfish only two have extensive distributions: the North American signal crayfish, *Pacifastacus leniusculus*, and the narrow-clawed or Turkish crayfish, *Astacus leptodactylus*.

The signal crayfish, introduced into Britain in the 1970s, now has a widespread distribution either on crayfish farms or as wild populations as reflected by the post-1989 distribution shown in Figure 3. The signal crayfish is much larger, more fecund, and more aggressive and invasive than the native crayfish. It can also carry the crayfish plague fungus. Prior to 1990 its distribution was even greater but many crayfish farms have proved unviable and some signal populations have died out. However, as with *A. pallipes*, new populations continue to be reported and these may result in a change to the status of catchments in the future. In addition, the new legislation mentioned above, which bans the farming of signal crayfish in much of Britain, may lead to a further reduction in its distributional range. Establishments where it is being processed for human consumption, e.g. restaurants, fish markets and hotels are exempt from the ban but MAFF (1996) have produced a leaflet giving guidance on how best to dispose of surplus stock.

The narrow-clawed (Turkish) crayfish, also introduced into Britain in the 1970s, has a less extensive distribution than the signal crayfish, being mainly confined to the south east of England (Figure 4). As with the signal crayfish, it is much larger, more fecund and invasive than the native crayfish but, like the native crayfish, it is susceptible to the effects of crayfish plague. The new legislation mentioned above bans the keeping of this crayfish over the whole of Britain except for established farmed populations.

The other species of non-native crayfish found in Britain have a very limited distribution at present. The new legislation bans the keeping of the crayfish mentioned below over the whole of Britain except for established farmed populations. The noble crayfish, *Astacus astacus*, from mainland Europe is only known from the Chew Valley in the Mendips where it occurs on a farm and in the wild. The noble crayfish grows to a larger size and is more fecund than the native crayfish but, like it, is susceptible to crayfish plague. The red swamp crayfish, *Procambarus clarkii*, originally from Louisiana (USA) but mainly reaching Britain via the aquarist trade, has only become established at one site on Hampstead Heath in London. However, individual specimens, sometimes carrying eggs, have been found in the wild in other parts of England. The red swamp crayfish is a fast-growing, highly fecund, invasive species, which can carry the crayfish plague fungus. Its rapid spread in mainland Europe is causing great concern. The spiny-cheeked or striped crayfish, *Orconectes limosus*, originally from North America but now very common in mainland Europe, has yet to be confirmed as present in Britain, although it is rumoured to be. It has similar characteristics to the red swamp crayfish, including the ability to carry the crayfish plague fungus. Various Australian crayfish belonging to the genus *Cherax* have been introduced into Britain from time to time. No wild populations have developed. The tropical red claw crayfish from Queensland, *Cherax quadricarinatus*, has been given an exemption from the new legislation, and can be kept in closed, heated aquaria.

3. CRAYFISH PLAGUE

Crayfish plague outbreaks have been occurring in Britain and Ireland since the early 1980s. Details of these outbreaks are given in Holdich *et al.* (1995a). Figure 5 shows those catchments thought to have been affected. In some cases, although mortalities occurred, they were not positively identified as being due to crayfish plague, but there is a strong suspicion that they were. Reynolds (1988) gives details of the Irish outbreak. Appendix A summarises the details of the mortalities known to have occurred in England and Wales. No mortalities thought to be due to crayfish plague have been reported since 1993.

The crayfish plague fungus can only thrive in live crayfish. Crayfish carrying the fungus may be transported from one water body to another by man, e.g. anglers, and predators, e.g. otter, mink, rats, birds. However, its spores can be carried on any damp surface, e.g. fishing equipment, boots and fish, as well as via water. Consequently, the spread of this very virulent disease is extremely difficult to control. Outbreaks of crayfish plague can occur in any native population without warning and often the source of the disease is never identified. Although there is no way of controlling the disease, precautionary measures such as thoroughly drying or disinfecting equipment can reduce the chance of viable spores being transported.

Although Figure 5 shows those catchments which are thought to have been affected by crayfish plague, there is a good chance that some of them are now free from the disease as all the native crayfish have been eliminated, i.e. there may be no host for the fungus. However, the potential for further outbreaks is high in some catchments because of the presence of signal crayfish. There are a number of proposals in LEAPS to reintroduce native crayfish but this must be done with a great deal of caution and a thorough testing of the waters with 'canary' populations, i.e. specimens held in cages, before large numbers are reintroduced.

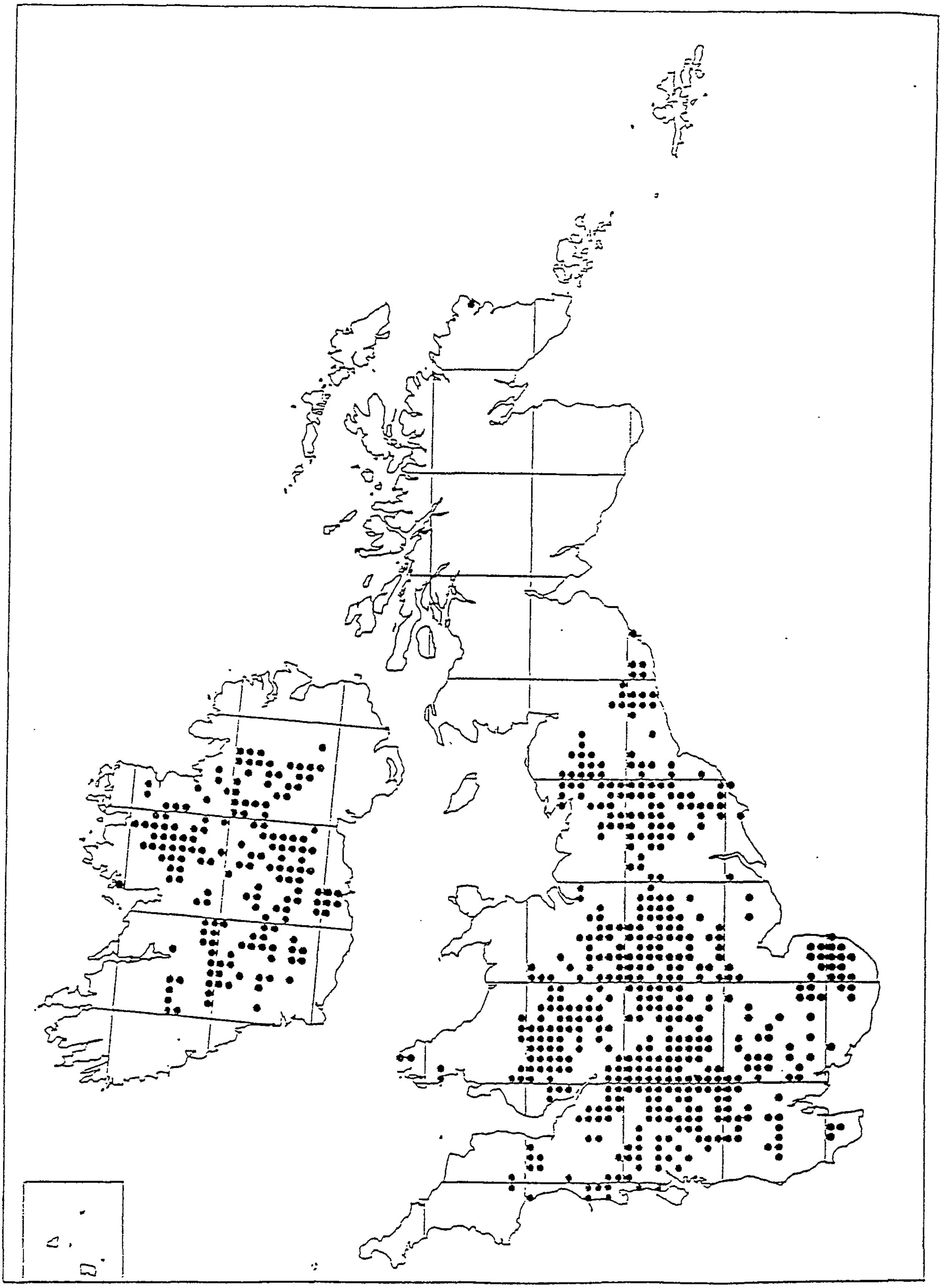

Figure 1 Distribution (10-km square) of *Austropotamobius pallipes* in Britain and Ireland based on all records for 1970-1996 inclusive.

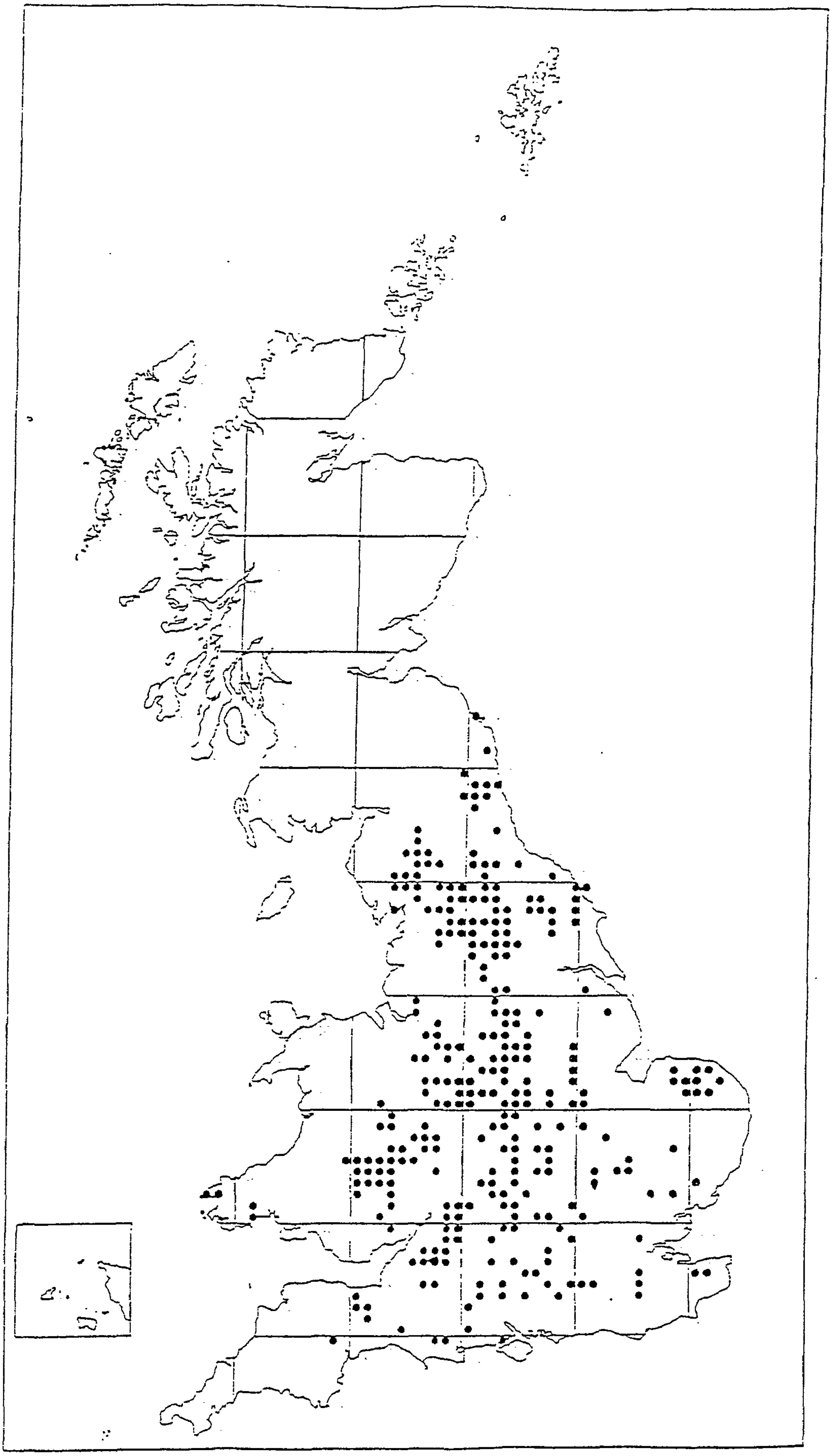

Figure 2 Distribution (10-km square) of *Austropotamobius pallipes* in Britain based on records for the period 1990-1996 inclusive.

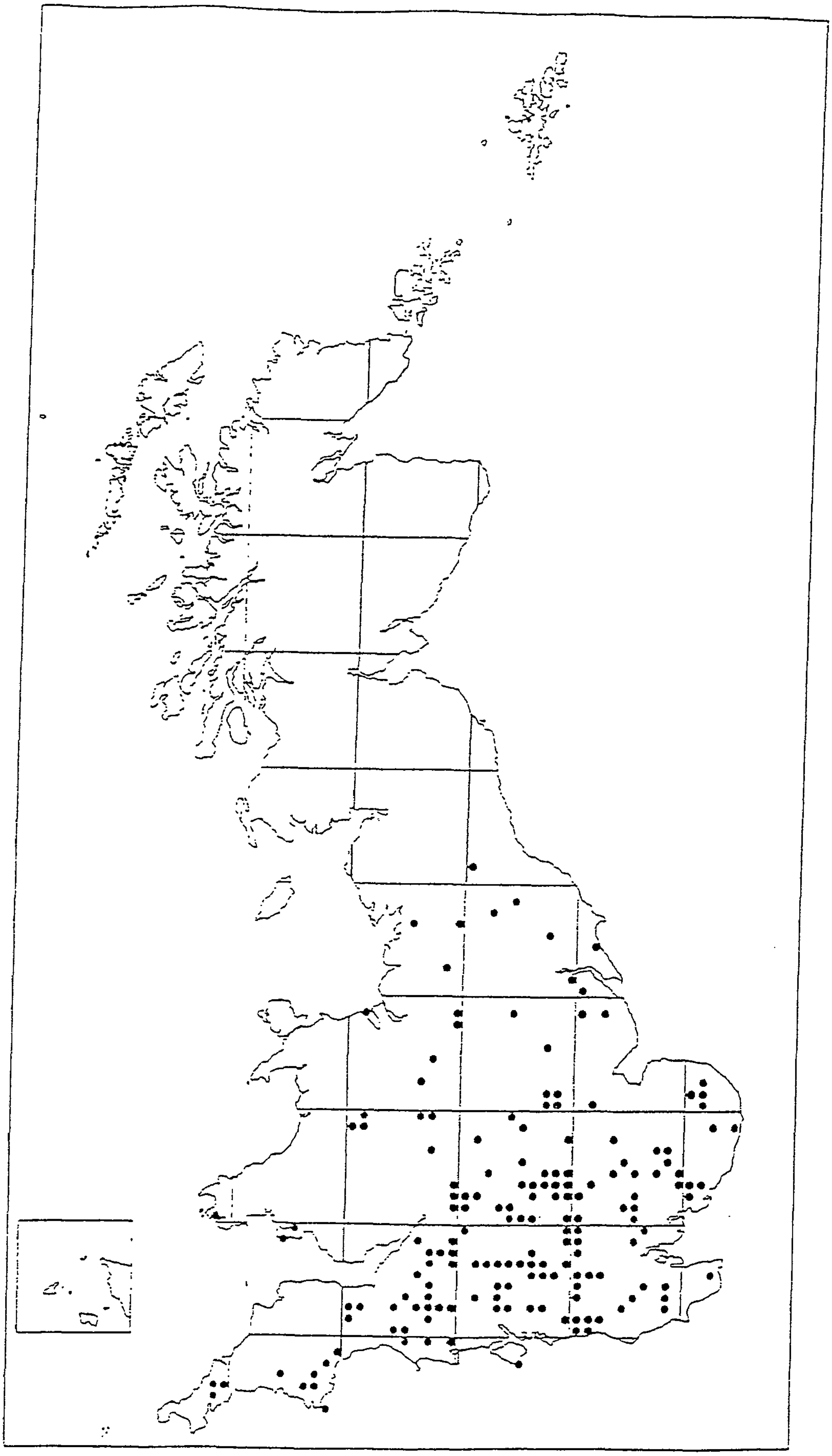

Figure 3 Distribution (10-km square) of *Pacifastacus leniusculus* in Britain based on records for 1990-1996 inclusive.

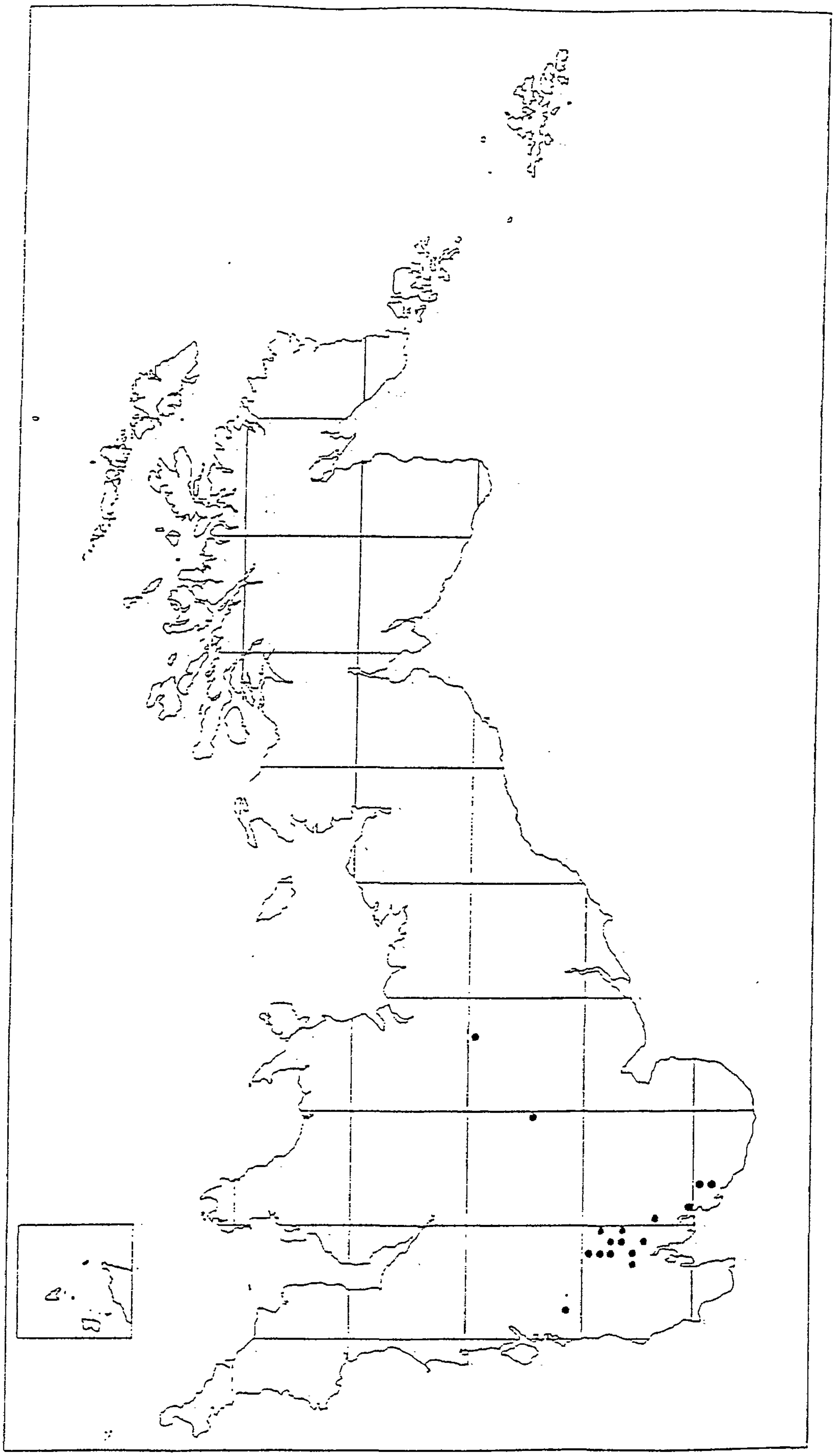

Figure 4 Distribution (10-km square) of *Astacus leptodactylus* in Britain based on records for 1990-1996 inclusive.

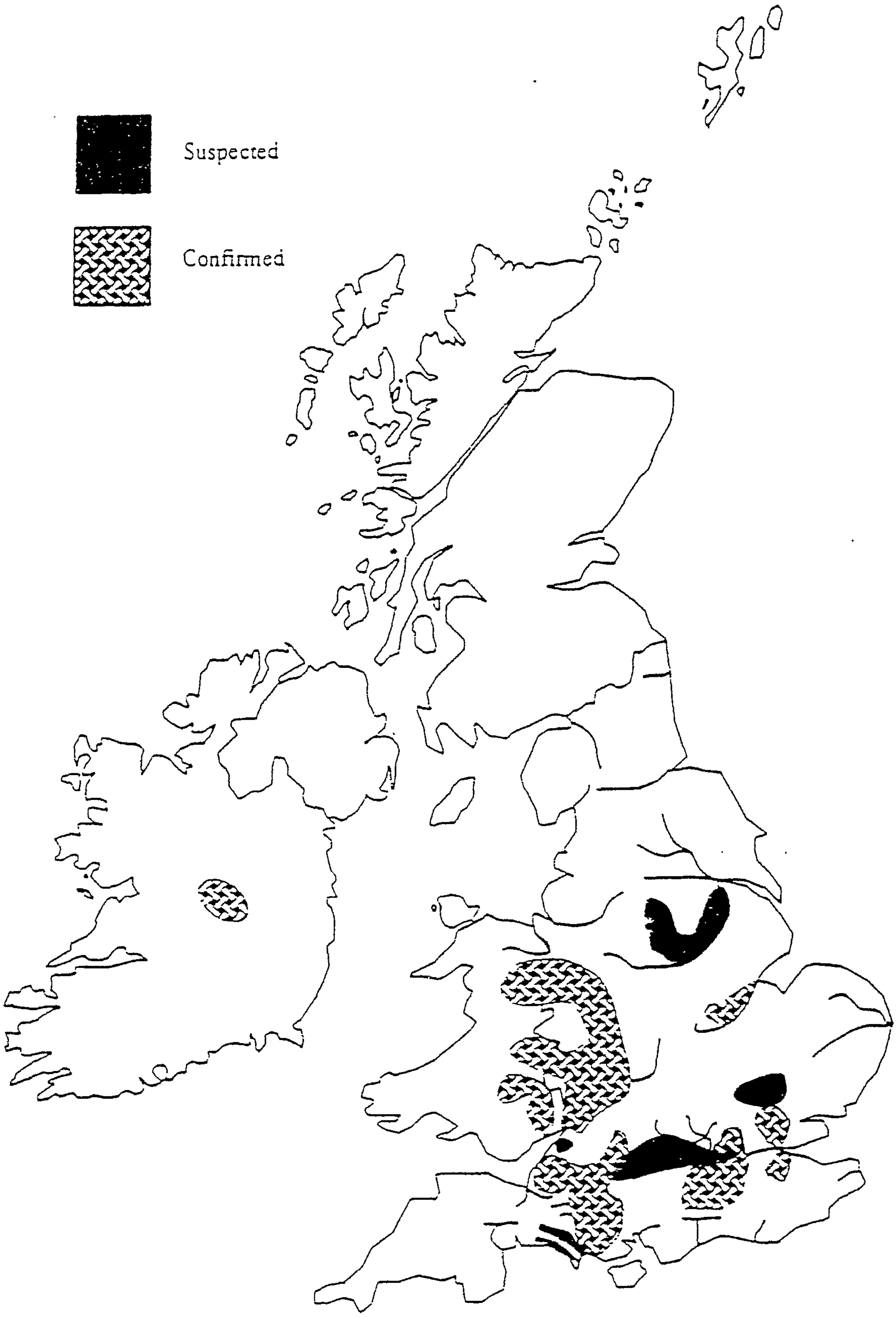

Figure 5 Catchments in Britain and Ireland which have suffered mortalities of *Austropotamobius pallipes* thought to be due to crayfish plague.

4. DESCRIPTION OF STRATEGY

In order to categorise catchments, crayfish records for each catchment were examined for the presence of the native crayfish, *A. pallipes*, and the non-native crayfish, *Astacus astacus*, *Astacus leptodactylus* and particularly for *Pacifastacus leniusculus*. Previous confirmed or suspected outbreaks of crayfish plague were not considered as none are currently known to be extant, although they are listed in Appendix B.

On the basis of the information available one of the following categories A-E has been allocated to each catchment in England and Wales (see Appendix B) and a recommendation given for their management. The colours on the left relate to those on Figure 6.

(Blue) **A** Catchments without non-native crayfish but known, often widespread and abundant, populations of native crayfish.

Recommendation: *Where practicable, conserve existing native crayfish populations and take proactive steps to avoid the introduction of non-native species, including strong objections to any planned crayfish farms.*

(Brown) **B** Catchments where there is a limited spread of non-native crayfish (including crayfish farms) and a relatively widespread distribution of native crayfish.

Recommendation: *Where practicable non-native populations should be contained or eradicated. The native crayfish populations should be conserved and proactive steps taken as in category A to prevent further spread of non-native populations.*

(Yellow) **C** Catchments where is a widespread occurrence or local abundance (including crayfish farms) of non-native crayfish and a limited distribution of native crayfish.

Recommendation: *Where practicable the spread of non-native crayfish should be controlled and the native crayfish populations conserved.*

(Red) **D** Catchments where there are no known native crayfish populations but populations of non-native crayfish are present (including crayfish farms).

Recommendation: *Where practicable the spread of non-native crayfish should be controlled. Survey work should be carried out to ascertain if native crayfish are absent, as the absence of records may be due to a lack of recording effort.*

(White) **E** No known crayfish records.

Recommendation: *Monitoring should be continued as non-native crayfish may spread from adjacent catchments and native crayfish populations may have gone unrecorded. Survey work should be carried out to ascertain if native crayfish are absent, as the absence of records may be due to a lack of recording effort.*

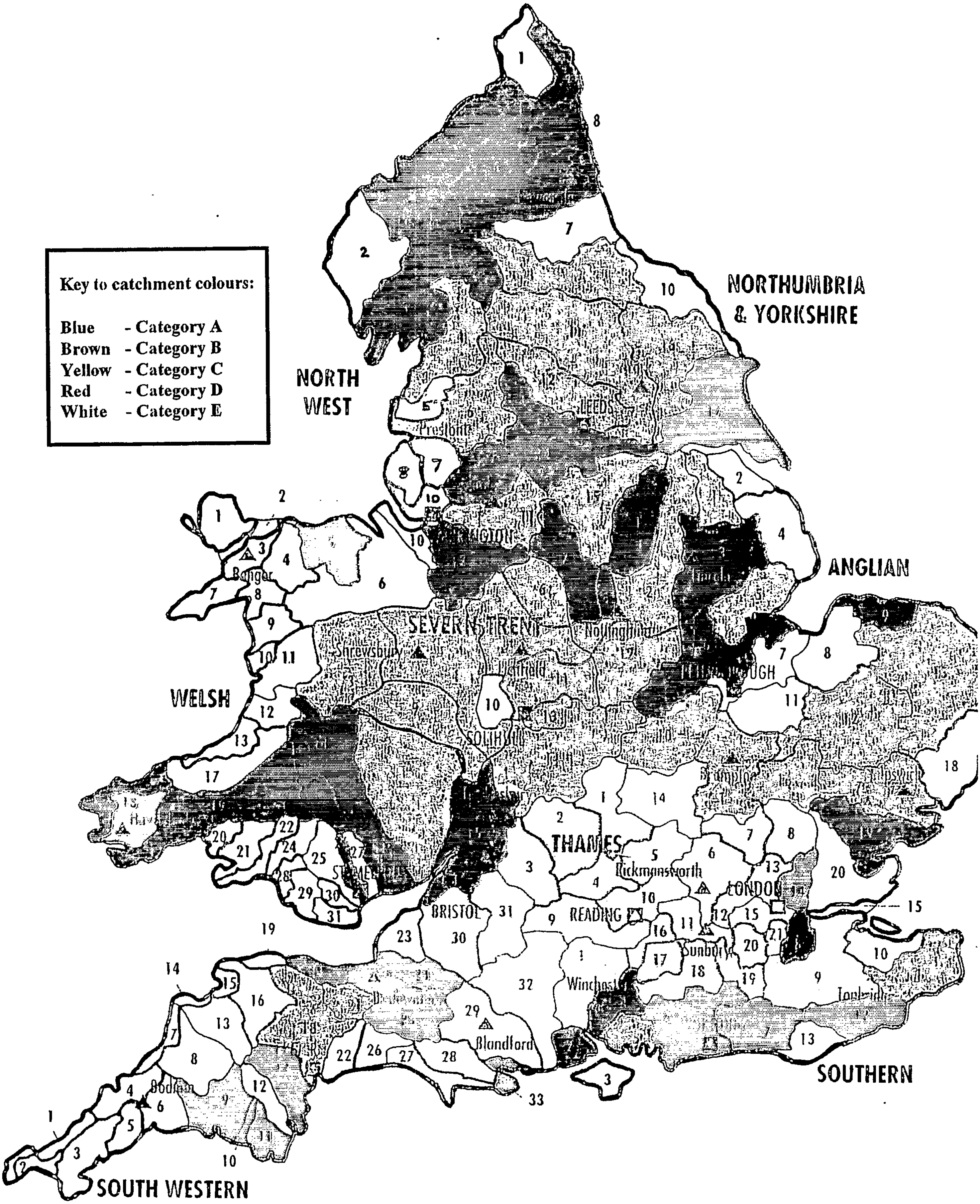

Figure 6 Categorisation of catchments in England and Wales by their crayfish status. See page 10 and Appendix B for further details. Catchments are those defined by the Environment Agency.

Most catchments in England and Wales have either native or signal crayfish or both except in the west, i.e. west Wales and south west England. There is, however, great variation in the density of records and crayfish populations. For instance, on the River Ure (part of catchment 11 in the Northumbria &Yorkshire Region), there are hundreds of records and crayfish are regularly found; in contrast, on the Rhymney (catchment 26 of Welsh Region), there are only occasional records at a few points. In some catchments crayfish may only be represented by a single record, such as Hull & Coast (catchment 17 in the Northumbria & Yorkshire Region), Clwyd (catchment 5 in the Welsh Region), and West Somerset rivers (catchment 20).

The authors take the view that all native crayfish populations are worth conserving but at a practical level some will be easier to protect than others.

The most important native crayfish populations to conserve are those in Category A catchments, where no non-native crayfish are present but many healthy native populations exist. The highest level of conservation should be afforded to these populations, which are particularly prevalent in the north of England. Conservation measures include designating sites as SSSIs, and making sure that man-made operations (such as dredging, macrophyte clearance, removal of tree roots and boulders) do not interfere with crayfish habitat. Maintenance of water flow is particularly important. Above all, any occurrences of non-native crayfish should be contained and eradicated if possible (see below).

The second most important native crayfish populations to conserve are those in Category B catchments. In this category native populations are widespread but non-native (usually signal) crayfish have a limited distribution, although they can be locally abundant on and in the vicinity of crayfish farms.

Category C catchments, where there is a widespread occurrence of non-native crayfish, are mainly located the south of England. The spread of such populations should be prevented in order to protect the remaining native crayfish populations. However, there are so many populations of non-native crayfish in these catchments that their control will prove very difficult.

There are catchments (Category D) where, despite the fact that there are no records for native crayfish, non-native crayfish (usually signals) have become established. Signal crayfish are known to be more adaptable to environmental conditions than native crayfish (Holdich *et al.*, 1995a), including saline environments (Holdich *et al.*, 1997). However, as these catchments often border catchments with native crayfish, and unrecorded native populations may occur in the catchment itself, then non-native crayfish should be prevented from spreading further. Most of the catchments in this type of category are located in the south of England.

Category E catchments contain no records for either native or non-native crayfish. Often this is due to unsuitable conditions, e.g. water chemistry and/or type of river. Most of the catchments in this category are located in western Wales and south west England. However, the fact that there are no crayfish in these catchments at present does not mean they could not occur in the future or perhaps have not yet been discovered.

Crayfish plague outbreaks occurred frequently in the 1980s. In more recent years there have been very few - none having been reported since 1993. There are no known instances of native European crayfish developing resistance to the disease so the decrease in outbreaks is more likely to be due to other factors or random chance. There is the possibility that the disease is becoming less prevalent as signals carrying the disease are culled or predated. Of course in some catchments where the native crayfish has been eliminated the niche has either been taken over by non-native crayfish or remains vacant. There are some instances where crayfish have been successfully reintroduced or have recolonised the area (Holdich *et al.*, 1995a). There is no known way of preventing the spread of crayfish plague other than by eliminating the crayfish species which carry it.

It is worth giving further consideration to two management issues that are fundamental to the crayfish policy adopted in LEAPs.

- *Eradication of non-native crayfish species*

  This should be considered as an option to protect the native crayfish, particularly in Category B catchments. However, no research has been funded in Britain to see if this is feasible. Control of such populations is probably a more viable option, particularly by intensive trapping over a sustained period as has been done for *A. leptodactylus* (Holdich *et al.*, 1995a). However, even control is difficult unless it is carried out at regular intervals as juvenile crayfish are rarely caught by trapping. Signal crayfish in particular are able to survive out of water for months in their burrows so attempts to eliminate lacustrine populations by draining down and then refilling have failed as the time interval was not long enough - a least a year is required.

- *Restocking, or even stocking areas where native crayfish have not previously been recorded*

  Restocking of waters previously affected by crayfish plague has only been tried in the Bristol Avon catchment and this has been highly successful (M. Frayling, pers. comm.). Large numbers of animals of a mixed age structure are required for restocking and may be difficult to acquire. In this context attempts are being made to cultivate crayfish using local stock to restock the River Itchin, where native crayfish are though to have been eliminated by crayfish plague in the 1980s (A. Hutchings, pers. comm.). In both these cases, local stock has been used but in other cases this might not be possible. Studies by Grandjean *et al.* (1997a) have shown by the mitochondrial DNA technique that *A. pallipes* in Britain are very similar to those in France, suggesting that British populations may have been derived from French stock. Also, this may have been relatively recently as little genetic variation has been found between British populations (Grandjean *et al.*, 1997b). Although both these studies were fairly conclusive, further work is needed using a greater range of samples and additional techniques before one can say that reintroductions can be made using stock from non-local populations.

It should be noted that the provisional categorisation of catchments in the draft version of this report prompted some disagreement over the status of certain catchments from local Agency staff. The nature of these conflicting opinions, and the decisions made by the authors in the final categorisation, are given in Appendix C.

5. CONCLUSIONS

Very few catchments containing native crayfish in England and Wales are currently safe from the threat of non-native crayfish. Even those in the north of England could easily be threatened by an illegal introduction or an outbreak of crayfish plague. It should be noted that a number of signal crayfish populations are thought to be developing north of the border in Scotland, close to England's densest native crayfish populations.

The distribution of crayfish in Britain is not static and consequently for any conservation and management plans to succeed there needs to be continuous monitoring of the situation. The information provided here will need updating every year if managers are to be provided with the correct information.

The new legislation involving the setting up of prohibited areas for crayfish farming should reduce the risk of the disease being transferred into areas possessing good populations of native crayfish. However, whilst crayfish plague outbreaks have declined in recent years there is no room for complacency.

The categorisation of the crayfish status of catchments in England and Wales provided in this document should assist managers in deciding what further measures need to be taken to protect and conserve populations of native crayfish. However, the status of catchments is bound to change if monitoring is carried out. One problem managers appear to have is with the actual Agency categorisation of catchments given to the authors as a framework, which has been highlighted by their responses to the initial draft of this document. The next update of the strategy therefore needs to review the catchment boundaries used with a view to providing greater discrimination where necessary.

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Appendix A - Confirmed and suspected outbreaks of crayfish plague in England & Wales

River/lake	Date	Catchment	Confirmed
R. Lee (Herts)	1981-82	Thames	Yes - MAFF
R. Sherston (Bristol Avon)	1981-82	Avon	Yes - MAFF
R. Blackwater (Surrey)	1982	Thames	Unconfirmed
R. Wey (Alton-Farnham)	1983	Thames	Yes - MAFF
R. Avon (Hampshire)	1984	Hamp. Avon	Yes - MAFF
R. Kennet (Berks)	1984	Thames	Unconfirmed
R. Frome (Dorset)	1984	Dorset Frome	Unconfirmed
R. Stour (Dorset)	1984	Dorset Stour	Unconfirmed
R. Colne/ Misbourne (London)	1985	Thames	Yes - MAFF
R. Darent (Kent)	1986	Thames	Unconfirmed
Dowles Brook (Forest of Wyre, Kidderminster)	1987	Severn	Yes - MAFF
By Brook (Bristol Avon)	1990	Bristol Avon	Yes - MAFF

Appendix A (continued)

River/lake	Date	Catchment	Confirmed
Somerset Frome/ Mells River (Bristol Avon)	1990	Bristol Avon	Yes - MAFF
R. Ise (Kettering)	1990	Nene	Yes - MAFF
R. Camlad (Newtown)	1990	Severn	Yes - MAFF
Tributaries (Herefordshire)	1990	Welsh Wye	Unconfirmed
R. Arrow (trib. of R. Lugg, Eardisland)	1990	Welsh Wye	Yes - MAFF
R. Wye (Buxton, Derbyshire)	1990-91	Derbys. Wye	Unconfirmed
R. Derwent (Derbyshire)	1990-91	Derbys. Wye	Unconfirmed
R. Clun (Welsh border)	1991	Teme/Severn	Yes - MAFF
R. Blyth (Northumbria)	1992	Blyth	Unconfirmed
Wycombe/Wye/ Wycombe Dyke	1992	Thames	Yes - MAFF
Avening Brook (nr Stroud)	1993	Glos. Frome	Unconfirmed
R. Bradford (nr Alport)/R. Lathkill	1993	Derbys. Derwent/Wye	Unconfirmed
R. Tillingbourne (nr Dorking)	1993	Thames	Unconfirmed

Appendix B - Crayfish management by catchment

For definition of categories A-E see main text. Also shown are confirmed (++) and suspected (+) outbreaks of crayfish plague by catchment (see Appendix A for further details).

ANGLIAN REGION

B	1	Ancholme
E	2	Grimsby Area
A	3	Upper Witham
E	4	Louth Coastal
B	5	Lower Witham
A	6	Welland
E	7	Lower Nene
E	8	North Norfolk rivers
A	9	Stiffkey, Burn & Glaven
B ++	10	Upper Nene
E	11	Old Bedford River
B	12	Ely Ouse
B	13	Yare
C	14	Upper Ouse
B	15	Bedford Ouse
B	16	Cam
B	17	Gipping & Stour
E	18	Alde, Blyth & Deben
A	19	Blackwater including Colne & Chelmer
E	20	Crouch & Thameside

NORTHUMBRIA & YORKSHIRE REGION

E	1	Till
A	2	Aln
A	3	Coquet
A	4	Wansbeck including Lyne
A +	5	Blyth
A	6	Tyne including Ouseburn
E	7	Wear
E	8	Northumbria Area Coast
B	9	Tees, Leven & Skerne
E	10	Esk & Coastal streams
B	11	Swale, Ure & Ouse
B	12	Nidd & Wharfe
A	13	Aire
A	14	Calder
B	15	Don, Rother & Dearne
B	16	Derwent
D	17	Hull & Coast

NORTH WEST REGION

A	1	Eden & Estuary
E	2	Derwent & Cumbrian Coast
A	3	Leven & Morecombe Bay
B	4	Lune
E	5	Wyre
B	6	Ribble
E	7	Douglas
E	8	Alt & Crossens
A	9	Irwell
E	10	Mersey Estuary
B	11	Mersey Basin
A	12	Weaver

SEVERN-TRENT REGION

A	1	Idle, Maun & Torne
B	2	Trent - Dove to Humber
B ++	3	Severn - Upstream of Perry
B ++	4	Severn - Perry to Teme
B	5	Upper Trent, Sow & Penk
B	6	Dove & Churnet
A +	7	Derwent
A	8	Erewash
B ++	9	Teme
E	10	Stour
B	11	Tame & Anker
B	12	Soar
B	13	Blyth, Cole & Bourne
B	14	Warwickshire Avon
A +	15	Severnside

SOUTHERN REGION

C	1	Test
A	2	West Hampshire
E	3	Isle of Wight
A	4	Itchen
B	5	Meon & East Hampshire
D	6	Arun
D	7	Adur & Ouse
A ++	8	Darent
C	9	Medway
E	10	North Kent
B	11	Stour
D	12	Eastern Rother
E	13	Cuckmere

SOUTH WESTERN REGION

E	1	Hayle & Red River
E	2	Cober & South Cornwall
E	3	Fal
E	4	Gannel & Camel
E	5	Parr, Crinnis & St Austell
E	6	Seaton, Looe & Fowey
E	7	North Cornwall Coast, Strat & Neet
E	8	Upper Tamar & tributaries
D	9	Tamar Estuary, Tavey, Lynher, Plym & Yealm
D	10	Erme
D	11	Avon
E	12	Dart
E	13	Torridge
E	14	Abbey River & Clovelly Stream
E	15	Taw & Torridge Estuary
E	16	Taw
D	17	Teign
B	18	Exe
D	19	North Devon Coastal & Lyn
A	20	West Somerset Rivers
B	21	Tone
E	22	Sid & Otter
E	23	North Somerset Rivers
D	24	Brue, Sheppey & Hartlake
D	25	Isle, Yeo, Cary & Parrett
E	26	Lim & Axe
C	27	West Dorset Streams
C +	28	Frome & Piddle
C +	29	Dorset Stour
C ++	30	Lower Bristol Avon
C ++	31	Upper Bristol Avon
C ++	32	Hampshire Avon
D	33	Poole Harbour

THAMES REGION

C	1	Cherwell
C	2	Thames - Buscot to Eynsham
C	3	Upper Thames to Buscot
C	4	Thames - Eynsham to Benson
C	5	Thame
C ++	6	Colne
C ++	7	Upper Lee
C ++	8	Middle Lee
C +	9	Kennet
C	10	Thames - Benson to Hurley
C ++	11	Thames - Hurley to Teddington
C	12	Brent & Crane
C ++	13	Lower Lee
D	14	Roding
C	15	Thames Tideway & Estuary
C	16	Loddon
C +	17	Blackwater
C ++	18	Wey
C	19	Mole
C	20	Wandle, Beverley Brook & Hogsmill
C	21	Ravensbourne

WELSH REGION

E	1	Cefni & Braint
E	2	Menai Strait
E	3	Gwrfai, Seiont, Ogwen & Llyfni
E	4	Conwy
D	5	Clwyd
E	6	Dee
E	7	Dwyfor & Erch
E	8	Glaslyn, Dwyryd & Artro
E	9	Mawddach & Wnion
E	10	Dysynni
E	11	Dyfi & Len
E	12	Rheidol, Ystwyth & Clarach
E	13	Aeron, Arth & Wyre
A	14	Upper Wye
B ++	15	Lower Wye
A	16	Nevern, Gwaun, Solva & Pembroke Coastal Rivers
E	17	Teifi
D	18	Cleddau
A	19	Tywi & Taf
E	20	Gwendraeth, Fach & Fawr
E	21	Llwchwr & North Gower Rivers
E	22	Tawe & South Gower rivers
A	23	Usk
E	24	Neath
E	25	Taff
A	26	Rhymney
E	27	Ebbw
E	28	Afan & Kenfig
E	29	Ogmore
E	30	Ely
E	31	Thaw

Appendix C - Responses from Agency Regions to draft report

Only four Environment Agency Regions responded to an initial draft of this document and one was to report (M. Frayling) a new, and important record which changed the status of one catchment (catchment 20 in South Western Region).

For South Western Region (E. Rothero), it has been suggested that the R. Frome and the R. Piddle in catchment 28 (South Western Region) should not be classified together as the rivers do not meet until the tidal, saline zone. In addition, the former contains native crayfish and the latter signal crayfish. However, this catchment is defined by the Agency not the authors. Also in the same Region, West Dorset Streams are categorised as C and it has been suggested that they should be Category B. However, signal crayfish are so dense in the R. Nadder that there is no hope of their eradication and, although signal crayfish are not widespread it is better to retain the catchment as a C.

For Anglian Region (K. Potter), it has been pointed out that no specific mention is made of the R. Wensum which is a native stronghold in the Region, and that it has been included in the R.Yare catchment. However, this is the way the catchment is defined by the Agency not the authors. The fact that we have included the North Norfolk Rivers and the R. Stiffkey, R. Burn and R. Glaven as separate catchments is questioned. It is suggested that these three rivers are in the North Norfolk Rivers catchment; this is not so, and again this is the way the Agency defines the catchments.

Thames Region (J. Bywater) disagrees with the authors designation of all the catchment as Category C. The R. Roding was given a Category C, but as no native populations appear to have been recorded this has been changed to a Category D. The R. Cherwell and R. Evenlode should remain as Category C, and not changed as suggested to Category B and A respectively, as there is a lot of crayfish farming activity in the area and a major harvester and supplier has his facilities between the two rivers. The R. Ver cannot be changed to a Category B as it is in the Lower Lee catchment, not a separate Agency catchment. It is suggested that the R. Colne be changed from Category C to B, however, the authors consider it should remain as Category C because there are known signal crayfish records and there are very large narrow-clawed (Turkish) crayfish populations in Aldenham Reservoir and Tykes Water. It has also been suggested that the R. Ash and R. Rib are upgraded from Category C to Category A/B. However, as these rivers are included in a catchment where signal crayfish exist they should retain their original categorisation. A suggestion that the R. Wey be put in Category A as only native crayfish have been found in this catchment is not well founded. Signal crayfish also occur in the catchment, e.g. in the R. Tillingbourne, where there has been a recent (1993) suspected crayfish plague outbreak. Consequently it should retain its Category C status.

PART 4 PLANTS

4.1 Genetic studies of the English club-rushes *Schoenoplectus triqueter*, *S. lacustris*, *S. tabernaemontani* and their hybrids

4.2 Species Recovery Programme: ribbon-leaved water-plantain

Genetic studies of the English club-rushes *Schoenoplectus triqueter*, *S. lacustris*, *S. tabernaemontani* and their hybrids

A Report produced under Environment Agency R&D Project i640

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April 1998

ROYAL BOTANIC GARDENS KEW

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EXECUTIVE SUMMARY

The potential for hybridisation of triangular club-rush with related club-rushes is a major concern for proposed attempts to re-establish the species at historical locations (Nicholson 1998). The Environment Agency therefore comissioned a small project to investigate the genetic relationships between the principal club-rush species involved and their hybrids. The work was funded by Agency R&D Project i640, an umbrella project for species management in aquatic habitats.

Schoenoplectus samples were studied using DNA sequencing and genetic fingerprinting (AFLPs) to test hypotheses concerning the origin of hybrids of *S. triqueter.* Sequencing did not turn out to be a suitable tool for this group of plants as the locus studied was heterogeneous in the parents. As a result of this, further studies were focused on genetic fingerprinting. In these studies, three primer combinations (which are a means of amplifying the fingerprint 'bands' produced by AFLPs) were used, giving 183 bands. Using this technique we were able to identify the six putative hybrids from the Tamar as hybrids between *S. triqueter* and another entity closely related to, but not identical to, the individual of *S. tabernaemontani* provided by the Environment Agency. The results support the hypothesis that these hybrids are probably derived from hybridisation between the same two parent plants.

Unfortunately, the samples of *S. lacustris* and the two putative hybrids from the Arun were collected too late in the season for intact DNA to be successfully extracted. Fingerprinting will be undertaken on *S. lacustris* and the Arun hybrids using fresh material collected this spring by the Environment Agency. An updated report will then be produced in which the parentage of the hybrids will be addressed more definitively (this report will be sent directly to Peter Nicholson of South West Region, since Project i640 has now ended and reported). Areas of possible future work are discussed.

1. BACKGROUND AND OBJECTIVES

In Britain, the triangular club-rush, *Schoenoplectus triqueter* (L.) Palla, now only occurs in SW England and W Ireland, although it was previously more widespread. Hybrids of this species occur where the populations overlap with the common club-rush, *S. lacustris* (L.) Palla and the grey club-rush, *S. tabernaemontani* (C.C. Gmel.) Palla (= *S. lacustris* subsp. *tabernaemontani* (C.C. Gmel.) Syme). The hybrid names *S.* x *carinatus* (Sm.) Palla and *S.* x *kuekenthalianus* (Junge) D. H. Kent are used for the hybrids with *S. lacustris* and *S. tabernaemontani*, respectively (Stace, 1997).

In England, the triangular club-rush is now only known to occur at one site on the River Tamar, and there are six clumps of hybrid club-rushes known at sites on the Tamar, close to the triangular club-rush site. In addition, *S. lacustris* and *S. tabernaemontani* occur in the same region. Both hybrids are believed to have occurred on the Tamar, although *S.* x *carinatus* is now considered very rare or extinct there. Hybrids, thought to be *S.* x *kuekenthalianus*, also occur on the Rivers Arun and Medway (Stace, 1997).

The Environment Agency commissioned a study to examine material from the Tamar of *S. triqueter* and the hybrids and of *S. lacustris* and S. *tabernaemontani* from the same area and of hybrids from the River Arun. The request was made late in the growing season, and we undertook to carry out this work with the caveat that some or all of the samples might not be suitable for DNA analysis, due to DNA degradation in senescing tissues as the plants approach dormancy. This can cause problems for genetic fingerprinting, as the techniques are very sensitive to DNA quality.

The aims of the work were:

1. to establish the parentage of the hybrids from the Tamar and Arun;

2. to establish whether the hybrids on the Tamar were derived from one hybridisation event.

We investigated the use of two molecular techniques, one based on DNA sequencing and the other on genetic fingerprinting. Preliminary sequencing studies showed that this technique was not appropriate for use with this group of plants as the locus under study (the internal transcribed spacer of nuclear ribosomal DNA, commonly abbreviated to ITS) was present in several versions, resulting in heterogeneous sequences. Genetic fingerprinting can be used in these cases to circumvent this problem and therefore we used that technique for the main part of this study.

Genetic fingerprinting involves the production of a set of fragments which reflects the genetic constitution of an individual. These fragments can be visualised as bands in gel electrophoresis using radioactivity, silver staining or fluorescent dyes to label the DNA. One of the first methods of genetic fingerprinting was restriction fragment length polymorphisms (RFLPs). However, this technique is not appropriate for use with rare species or small populations since it requires relatively large amounts of DNA and, hence, also a large quantity of leaves.

In the nineteen nineties, genetic fingerprinting techniques incorporating the technology of the polymerase chain reaction (PCR) were developed, thus allowing fingerprinting studies to be carried out with much smaller quantities of DNA and consequently reducing the initial amount of plant material required, an added benefit when dealing with rare and endangered plants. Several fingerprinting techniques using PCR have been developed. One of the first of these was random amplified polymorphic DNAs (RAPDs), and this has been now quite widely used with cultivated and wild species. However, the technique suffers from lack of reproducibility. In 1995, another technique called 'amplified fragment length polymorphisms' (AFLPs) was developed by Keygene Inc. (Zabeau & Vos 1993; Vos *et al.* 1995) and is the most sensitive fingerprinting technique currently available suitable for use with rare and endangered taxa. The technique has several advantages over other currently used fingerprinting methods:

1. it is fast (the technique has been automated);

2. it requires relatively small quantities of DNA, thus making it suitable for work with rare species;

3. it provides 10-100 times more markers and is thus more sensitive than some other fingerprinting techniques (e.g. RAPDs);

4. it is highly reproducible.

For these reasons, we chose to use AFLPs to investigate genetic diversity in the samples of *Schoenoplectus*. This study is similar to that used with *O. simia* (Qamaruz-Zaman & Fay, 1997) and *Cypripedium calceolus* (Fay & Cox, 1997).

2. MATERIALS AND METHODS

2.1 Plant materials

The plant material used in this study is listed in Table 1. All DNAs were extracted from leaf material dried in silica gel using a modified 2xCTAB (cetyltrimethyl-ammonium bromide) procedure followed by purification on a caesium chloride gradient.

Table 1. Plant materials used in this study.

Species/hybrid	Field notes	DNA No.
S. triqueter	Site 3a, R. Tamar	5655
S. lacustris	Exe catchment, R. Clyst at tidal weir	5656
S. tabernaemontani	Exe catchment, R. Clyst at tidal weir	5657
hybrid	Site 1, Calstock, R. Tamar	5658
hybrid	Site 2, Calstock Bridge, R. Tamar	5659
hybrid	Site 3, cottage sites	5660
hybrid	Site 4, right bank, houseboat, R. Tamar	5661
hybrid	Site 5, R. Tamar	5662
hybrid	Site 6, Island, Morwellham, R. Tamar	5663
hybrid	TQ50261102, R. Arun, South Stoke	5664
hybrid	TQ50251117, R. Arun, Houghton Bridge	5665

2.2 Genetic Fingerprinting

AFLPs were conducted according to the AFLP™ Plant Mapping Protocol of PE Applied Biosystems Inc. (ABI). Three primer combinations (a means of amplifying fingerprint 'bands') were used for all individuals. The fragments were separated on acrylamide gels using an ABI Automated Sequencer. Only amplified fragments with sizes ranging from 50-500 base pairs (bp) were included in the analysis as bands outside this size range cannot be accurately sized. Gel analysis was carried out with Genescan 2.0.2 and Genotyper 1.1. The bands were scored as either present (1) or absent (0) for all individuals, resulting in a binary matrix which was analysed using the UPGMA (Unweighted Pair-Group Method using Arithmetic Averages) method of cluster analysis.

3. RESULTS AND DISCUSSION

3.1 DNA extraction

High quality DNA was obtained from the material of *S. triqueter*, *S. tabernaemontani* and the six hybrids from the Tamar. Due to the lateness in the season at the time of collection, we encountered problems obtaining DNA of sufficiently high quality for use in the fingerprinting study from the samples of *S. lacustris* and the hybrids from the Arun.

3.2 Genetic fingerprinting

In all, 183 bands were scored, ranging in size from 50 to 485 base pairs. These bands were of seven types, and these types and their relative frequencies are shown in Table 2. Examples of the fingerprint traces are shown in Figure 1, illustrating some of these types of bands. The dendrogram derived from the cluster analysis is shown in Figure 2.

Table 2. The types of bands and their relative frequencies.

Type of band	Number	Percentage
Common to both species + hybrids	63	34.5
Common to *S. triqueter* + hybrids	45	25
Common to *S. tabernaemontani* + hybrids	34	19
Only found in hybrids	19	10
Only found in *S. tabernaemontani*	19	10
Only found in *S. triqueter*	2	1
Common to both species but not in hybrids	1	0.5
Total	**183**	**100**

The level of variation in these fingerprint traces was appropriate to the questions being asked and allowed us to distinguish between the species and the hybrids and to detect genetic variation between the individual hybrids.

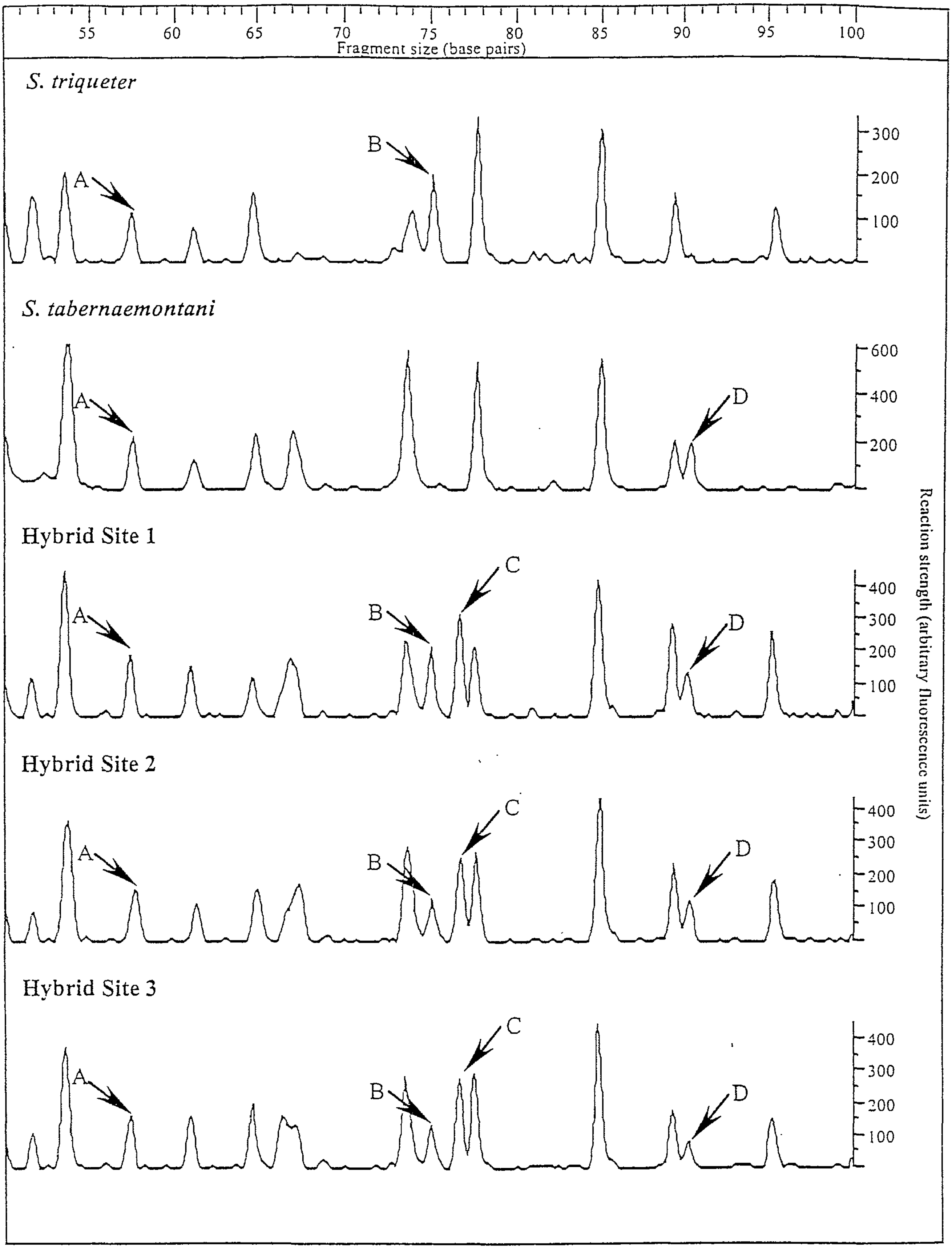

Figure 1. Representative AFLP traces illustrating some of the different types of bands found in the club-rush samples studied.

A - Bands present in all individuals
B - Bands shared by *S. triqueter* and the hybrids
C - Bands unique to the hybrids
D - Bands shared by *S. tabernaemontani and the hybrids*

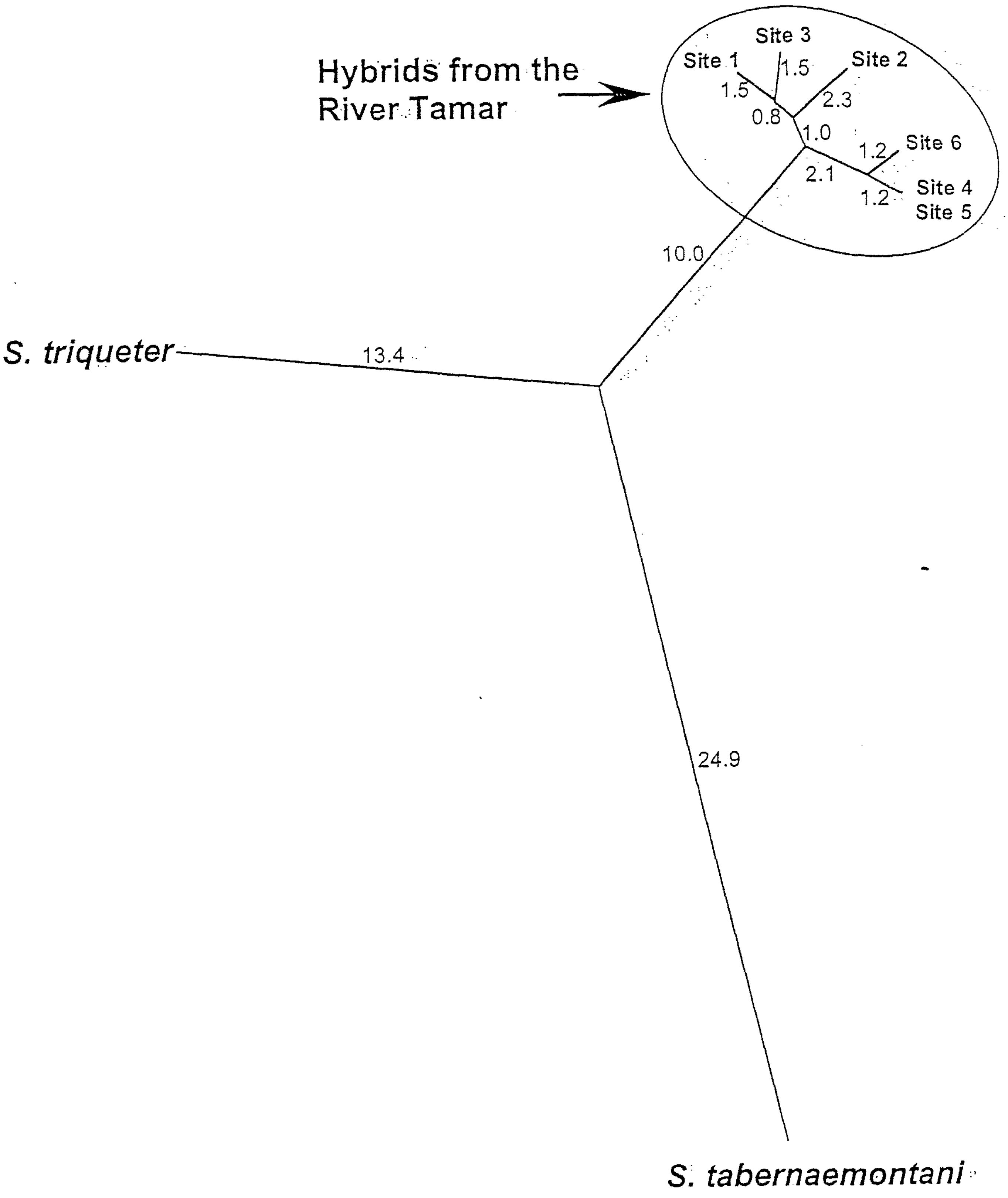

Figure 2. Relationships of *Schoenoplectus* hybrids to each other and to two of the three putative parents. Numbers besides branches are genetic distances expressed as percentages.

Out of the 111 bands found for the individual of *S. triqueter*, only three (2.7%) were not shared with the hybrids. This is indicative of a very close relationship between this individual and the hybrids, and this individual of *S. triqueter* could be a representative of the original parent genotype.

The relationship with the genotype of *S. tabernaemontani* sampled is less close. Of the 117 bands found for that species, 20 (17%) were not shared with the hybrid. This genotype of *S. tabernaemontani* is unlikely to be the parent of the hybrids. Without a sample of *S. lacustris* to compare with that of *S. tabernaemontani* and the hybrids, it is not possible to rule out *S. lacustris* as the parent (see Section £££ below).

The hybrids formed a closely related group (see Figure 2), but they are not genetically identical to each other. In total, 161 bands were present, of which 142 (89%) were present in all six individuals and 19 (11%) were present in only some individuals. The best hypothesis from these results is that the individuals are the result of one original hybridisation event. The hybrid individuals at Sites 4 and 5 were genetically indistinguishable.

4. FUTURE WORK

Fingerprinting studies will be undertaken on a sample of *S. lacustris* and the two hybrids from the River Arun when freshly collected samples are received from the Environment Agency this spring. This should clarify whether *S. lacustris* or *S. tabernaemontani* is the second parent of the Tamar hybrids and establish the parentage of the Arun hybrids. When this work is complete, a revised version of this report will be submitted to the Environment Agency (Peter Nicholson, South West Region).

In addition to this work to be carried out under the original contract, the following additional studies are recommended to further clarify the relationships of this group of club-rushes.

1. Samples of the hybrids from the Medway should be fingerprinted for inclusion in the analysis.

2. A range of individuals of *S. triqueter* from Ireland should be fingerprinted to identify the level of variation which could be expected in a 'healthier' population of *S. triqueter*, and to investigate the degree of relatedness of the English and Irish genotypes.

ACKNOWLEDGEMENTS

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SPECIES RECOVERY PROGRAMME:

Ribbon-leaved Water-plantain (*Alisma gramineum* Lej.)

Report to English Nature

Co-funded by the Environment Agency under R & D Project i 640

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May 1998

1. INTRODUCTION

The Ribbon-leaved Water-plantain (*Alisma gramineum* Lej.) was first found in Britain in 1920 at Westwood Great Pool, near Droitwich, Worcestershire. It has also been recorded at three other sites(in Lincolnshire, Cambridgeshire and Norfolk), albeit for only a few years. The species is widespread in Europe, much of Asia and North America, although in Europe it is uncommon throughout its range. It is on the 'short list' of the UK Biodiversity Action Plan (UK BAP) and Schedule 8 of the Countryside Act. An Action Plan has been drawn up for its conservation (UK Biodiversity Steering Group 1995).

In 1991, as part of its Species Recovery Programme, English Nature began a three year a three year programme of research on *Alisma gramineum* with the Institute of Terrestrial Ecology, the results of which were presented in a series of reports (Wells et al 1992, 1993, and 1994). These studies demonstrated that *Alisma gramineum* is a short-lived perennial with no means of vegetative reproduction. It relies totally on a long-lived seed bank and copious seed production for survival. Some degree of disturbance appears to be favourable for its survival ; establishment occurs in open habitats and plants do not grow where competition from either marginal or submerged aquatics is high.

In view of the national and international importance of this species, English Nature decided to continue with monitoring at Westwood Great Pool and to investigate how the site could best be managed for its survival. Work was also begun on raising this plant from seed and attempting to introduce it to suitable localities(see Wells 1996).Observations were also made on plants growing in tanks to find out more about the general biology of the species. This report describes the work carried out in 1997.

The Environment Agency now has important obligations to the species under the UK BAP, and has consequently co-funded this research over the past year under R & D Project i640.

2. HABITAT, POPULATION SIZE AND PERFORMANCE AT WESTWOOD GREAT POOL.

Westwood Great Pool was visited on 1 August 1997 by the author and S E Wells and the whole of the northern shore searched for *Alisma gramineum.* Water levels were about 15 cm below those encountered at the same time last year. This was the result of low winter and spring rainfall combined with the fact that the bank of this artificial lake was leaking(according to the bailiff). There was evidence, in the form of copious amount of dead algae and other vegetation, that water levels had been higher earlier in the year but had receded considerable since then leaving a broad band of decaying vegetation. These areas were mostly clear of any marginal vegetation and in general presented a hostile environment for seedling establishment. On areas where this dead vegetation was absent, seedlings of a variety of species had established, including Epilobium hirsutum, *Juncus articulatus, Persicaria lapathifolium, Ranunculus scleratus, Rumex maritimus,* and *Salix fragilis.* Neither *Elatine hydropiper* or *Chara spp.* were present in the bays, despite their abundance in 1991-3.

Particular attention was given to the two areas in the northern bay which had been cleared of vegetation in August 1996 using earth-moving equipment. Most of these scrapes were dry as a result of the fall in the water level in the Pool and supported an open vegetation (cover <10%) of seedlings and young plants of *Chenopodium rubrum, Juncus articulatus, Myosotis spp., Rumex maritimus, Scutellaria galericulata,* and *Typha latifolia* .. Two plants of *Alisma gramineum* were found in the most easterly bay: (1) with thirteen leaves in a basal rosette and an inflorescence just emerging from the leaves; and (2) a smaller plant with eight leaves but no sign of an inflorescence. Both plants were growing in about 16 cm of water.

No other plants or seedlings of *Alisma gramineum* were found around the shores or in the surrounding vegetation, despite searching for more than three hours.

It was unfortunate that low water levels in the Pool coincided with the year in which the scrapes were made as this did not provide suitable conditions for the germination of *Alisma.* This should not cause too much alarm, as the seed bank is extremely long-lived and open conditions should be present next year in areas where *A.gramineum* was plentiful in 1993; of more concern is the suggestion that the clay wall of the Pool is leaking as this could lead to a permanent lowering of the water-table and the loss of suitable habitat for *Alisma.*

3. MONITORING PERFORMANCE OF PLANTS INTRODUCED TO BASTON FEN LINCS.

Eleven two-year old plants of *A.gramineum*, grown from seed collected at the Blue Gowt Drain, Skirbeck, Lincolnshire in August 1992 and kept in cold storage until required, were planted in about 30 cm of water on 17 July 1996 at Baston Fen. Plants were marked with red-tipped canes. As was noted in last years report, all plants survived and seven of the eleven plants produced inflorescences in August and September. Plants appeared vigorous and, despite the presence of cattle grazing in the Fen during the autumn, plants appeared to have escaped damage from them and also from a family of swans which nested nearby.

Water levels rose considerably during the winter and when the site was visited on 25 January 1997 it was completely flooded and neither the plants nor canes were visible . Water levels gradually fell over the next two months and when the site was next visited on 20 May 1997 the *Alisma* plants were covered by about 45-50 cm of water. Because of the depth of water and the angle of the sun, it was difficult to see the plants clearly, despite the fact that the water was clear. Nevertheless, I am fairly certain that some of the plants had small leafy rosettes at this time but had made little growth.

On the next visit to the site, on 21 August 1997, the plants were still in deep water (42-65 cm) but with emergent leaves and inflorescences. Although 11 plants were planted in July 1996, there were now 16 good-sized plants in roughly the same position as planted, so it is reasonable to assume that the additional plants probably arose from seed shed last year. Twelve of the 16 plants had inflorescences, 4 remaining vegetative with only a rosette of leaves. Some plants were robust with more than 12 leaves, these large plants all bearing inflorescences. One plant had 5 flowering shoots but most had between 1 and 3 flowering shoots.(see Appendix 1 for details of plants). Some inflorescences had freshly opened flowers, others were still in bud while a few had young fruits still on the inflorescence branches. Flowers were present both above and below the water.

It was not possible to count the seed production from this colony but on the basis of counts made of plants elsewhere I would estimate that many thousands of seeds were produced here in 1997. Whether this seed(strictly fruits) is consumed by water fowl is unknown but it should be worthwhile looking next year in other parts of the Fen for seedlings or young plants of *Alisma gramineum.*

Some invasion of the planted colony of *A.gramineum* by *Glyceria maxima* has taken place so in order to contain this encroaching plants were pulled out and removed on 1 October 1997.

4. OBSERVATIONS ON PLANTS IN EXPERIMENTAL TANK.

In order to study the general biology and phenology of *A.gramineum*, 20 seedlings were planted up into 3" plastic pots and stood in a fibre glass tank on 24 July 1996. Pots were stood initially in water which was 30 cm deep, the tops of the pots being covered by about 14 cm of water. Rainfall has increased the depth of water covering the pots and for much of 1997 water has been 40 cm deep in the tank. Details of the behaviour of plants in 1996 were presented in last years report (Wells 1997). This report is concerned with what happened in 1997.

(1) Phenology

Leaves were first seen emerging from the over-wintering bud(turion) on the largest plants on 27 April and by mid-May all 20 plants in the tank had rosettes of leaves visible. Leaves grew quickly and were completely submerged (water depth 35-41 cm). Inflorescences were first seen emerging from the centre of rosettes on 23 July (plants 5 & 6); by August 14, 19 of the 20 plants in the tanks had produced inflorescences.

Inflorescences grew extremely quickly, stems emerging above water from one to eight days after first being observed at the base of the plant. Growth rates of individual flowering stems varied from 1.5 to 15.0 cm per day, the highest growth rates being associated with the largest plants. Four out of 19 inflorescences produced never emerged above the water surface but still produced flowers and fruits.

Flowers opened as early as 7.30 am and remained open until at least 16.30 pm on some days but there was a good deal of variation in this characteristic among flowers on different plants. There was no evidence to support the statement in Clapham, Tutin and Warburg (1962) that flowers open between 6 and 7.15am. Flowers opened under water as well as on aerial branches. Flowers are caducous (they fall off at an early stage)and last for only one day.

Ripe fruits were observed on two plants on 10 August but on most plants ripe fruits were present from mid-September onwards. Some of these fruits were shed into the water in September and October but some remained on dead inflorescence stalks until January 1998.

(2) Perennating organ (turion).

By the end of October most of the above soil plant material dies down(a few translucent leaves may remain) and the plant overwinters as a bud. On 6 November a small plant was selected which had flowered in the tank, and a bud was dissected . The bud consisted of 6 green leaves, each about 2 mm long tightly wrapped around the terminal meristem and presumably protecting it. The plant at this time of the year consists of the dead current years shoot and inflorescence, dying roots and the laterally placed bud or turion. The ability of the plant to produce leaves quickly in the following year(as noted earlier) is clearly related to the fact that the leaves are formed in the previous year and remain green throughout the winter in a protected bud. Whether this bud is swept away in water currents and roots again at a new site is not known, but is apossibility.

(3) New plants

Seed produced in 1996 by the plants in the tank sank to the bottom of the tank or onto soil in the pots and germinated in April 1997. Numerous small plants, mostly with two leaves were observed from early May onwards and have continued to grow through 1997. This clearly demonstrates that at least some germination can occur from seed shed only a few months previously and that it is not necessary for the seed to lie for years waiting for the pericarp to rot before germination can take place.

5. GROWING PLANTS FOR FURTHER INTRODUCTIONS

Twenty small plants, consisting of an over-wintering bud and the current years roots, were removed from the holding tank and. potted into 3" pots on 6 November. A potting mixture consisting of about 50% John Innes No2, 45 % Levington compost and 5% coarse sand was used . Plants were placed in plastic trays filled to a depth of about 6" with rainwater and stood outside. These plants will be used for further introductions in 1998.

6. INVESTIGATION OF SITES FOR FUTURE INTRODUCTIONS

(1) A meeting was held with Mr Roger Beecroft, ecological consultant for the landowner of the newly created "lakes" at Kingfisher Bridge, Cambs.(NGR 52/548731). The possibility of using one of the lakes as a site for introducing plants of *Alisma gramineum* was discussed. The idea was warmly welcomed and potential sites selected. It is planned to introduce about 20 plants there in 1998, provided the water-levels remain suitable now that water control devices have been installed. It was felt prudent to see how these worked in practice before carrying out any planting.

(2) A further meeting was held at Welches Dam, Cambs. (NGR 52/471859) with the RSPB site manager, Cliff Carson, to select a site for an introduction. The drain in which the *A.gramineum* had been found in 1972 had recently (in August) been cleaned out and it might be sensible to wait and see if the plant re-appeared from a seed bank before re-introducing the species. This was agreed and the intention is to survey this drain later in the year to see if the plant is present. If we are unable to find the plant, it is our intention to proceed with an introduction on the Ouse Washes.

The reasons for selecting the localities described above as potential sites for introducing *Alisma gramineum* may be summarised as follows: (1) the sites contain a range of habitats similar to those in which the species occurs in the wild; (2) the owners of the sites (Mr Green and the RSPB respectively) have indicated an interest in the project and are pleased to co-operate; (3) both sites are managed primarily for conservation and have staff skilled in habitat management ; (4) the sites are near enough to the consultant responsible for this project to enable visits to be made for monitoring and general observation with a minimum of expenditure.

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Appendix 1: Performance of *A.gramineum* at Baston Fen, Lincs. 21 August 1997.

Plant No.	Water depth (cm.)	No. leaves	No. inflorescences	Notes
1	42	7	0	
2	53	10	2	Partly grazed
3	55	10	2	Large, branched
4	48	10	1	Partly grazed
5	nd	3	0	
6	nd	3	0	
7	>65	nd	4	Still in bud
8	65	5	0	
9	65	5	5	Bud & fruit
10	65	12+	2	
11	65	6	1	In flower & bud
12	65	12+	2	In flower
13	65	12+	3	In flower, submerged
14	65	nd	2	Bitten off
15	65	nd	1	Bitten off
16	65	nd	2	