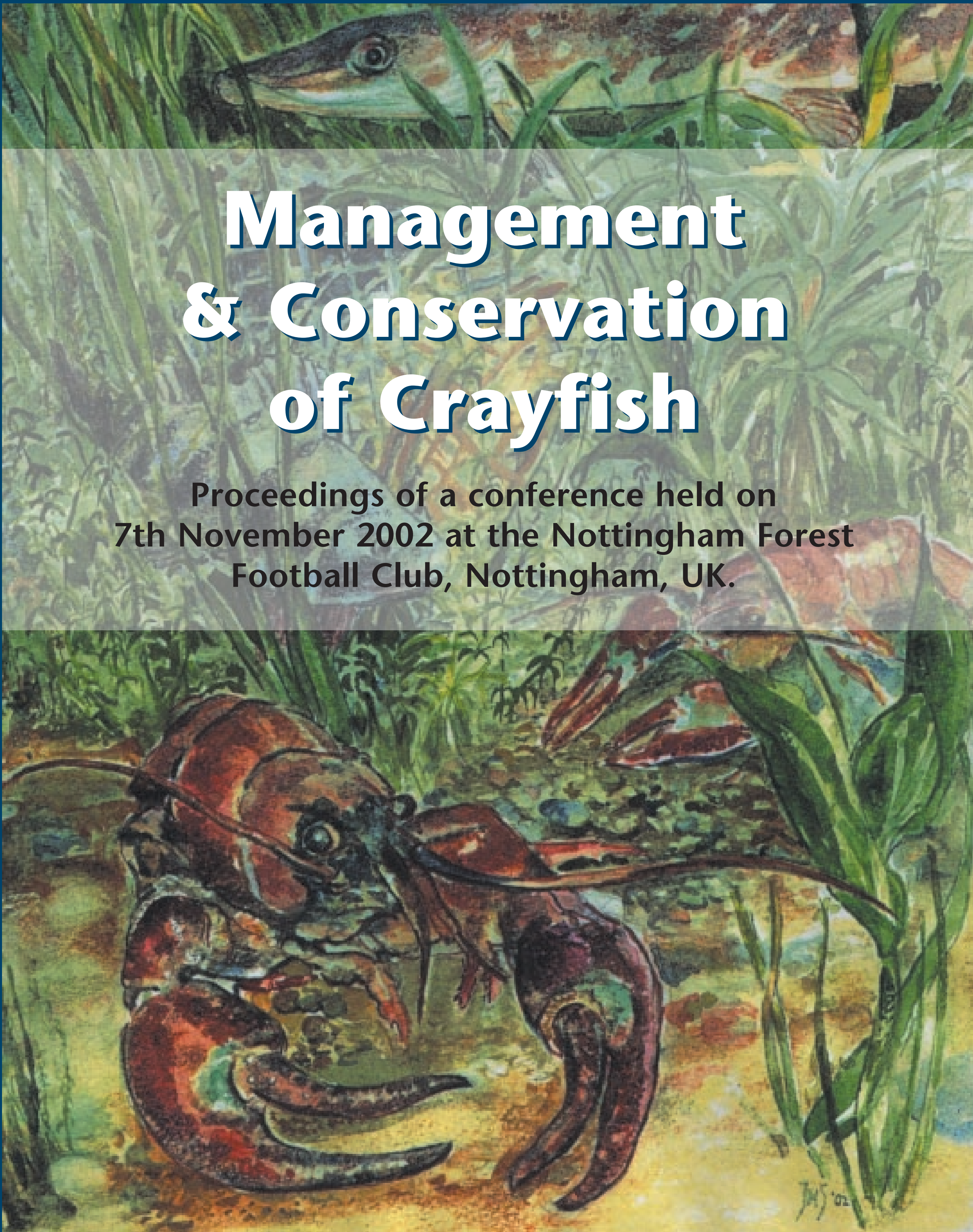

Management & Conservation of Crayfish

Proceedings of a conference held on 7th November 2002 at the Nottingham Forest Football Club, Nottingham, UK.

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Management & Conservation of Crayfish

Proceedings of a conference held on 7th November 2002 at the Nottingham Forest Football Club, Nottingham, UK

Edited by

David M. Holdich (EMEC Ecology)

&

Peter J. Sibley (Environment Agency)

May 2003

Supported by:
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Editorial

This conference was a follow up to the one held in Leeds in 2000 and is a testament to the continued interest in both indigenous (native) and non-indigenous (alien) crayfish in the British Isles.

Over 120 delegates attended from a wide range of organisations, as far a field as Germany, the Czech Republic and Croatia, and a further 40 had to be disappointed due to space considerations. A large number of high quality posters were presented and kept delegates occupied during tea breaks and over lunch. The conference dinner, held the night before at the Lobster Pot Restaurant, was a great success, and many shellfish, including crayfish, were consumed.

On the day of the conference Peter Sibley made the opening and closing remarks and acted as Master of Ceremonies. A wide range of papers were presented and David Holdich, David Fraser, Jonathan Brickland and Richard Jennings chaired the four sessions respectively.

The edited proceedings include the majority of papers presented at the conference, as well as some of the posters, and an additional one on legislation. The editors considered this to be an important topic and, as a number of issues were raised during the discussions, it was decided to include a review of current and planned legislation. Also included are a distribution update for mainland Britain and a bibliography of biological and ecological studies on crayfish in the British Isles. Some short communications have been included within the main body of the volume as they were thought to add weight to the views on management and conservation of the indigenous white-clawed crayfish.

Organising committee:

Peter Sibley (Environment Agency)
Jonathan Brickland (British Waterways)
David Holdich (International Association of Astacology)
Richard Jennings (Environment Agency)
Julie Bywater (Environment Agency)
David Fraser (English Nature)

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Jim Lyons, Pete Sibley and David Holdich for taking the conference photographs.
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Jeanette Sibley for the conference painting and the colour plate on the title page.
The children of Class 1 (2001/2), Flintham Primary School, Notts for the crayfish drawings.
Nottingham Forest Football Club for providing the facilities and looking after us on the day.
Alastair Picken, Pam Mardon, Phil Harding and Helen Watkinson for their help with publishing these proceedings.

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All papers submitted to the editors were reviewed by at least two persons.
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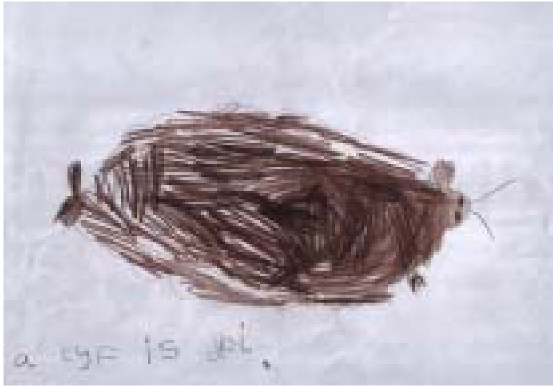
Liz Watson	David Rogers Associates
Willie Yeomans	Clyde River Foundation

Crayfish drawings courtesy of Flintham Primary School, Notts

"The crayfish is nice" by Ella Sibley



"A crayfish is brown" by Amy Richardson

"The crayfish is nippy" by Abbey Rose

An orange crayfish by Jonathan Pollard

A yellow crayfish by Aimee Black

"This crayfish is naughty" by Charlotte Weaver

"The crayfish is very nice" by Oliver Spencer

Two colourful crayfish by Evie Russell

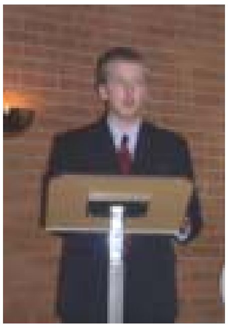
Picture gallery

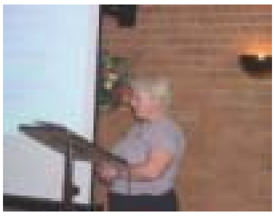







Pre-conference relaxation at the Lobster Pot

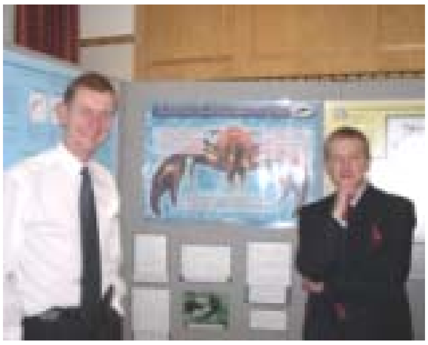



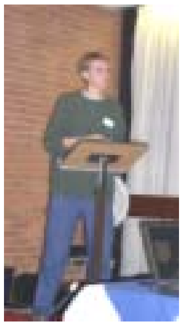


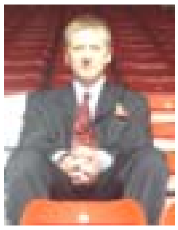
Speakers and audience at the opening sessions

Picture gallery



Management & Conservation of Crayfish





Nottingham Forest F.C.
7th November 2002

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SECTION 1. MONITORING AND RECORDS

CRAYNET : PROGRAMME AND POTENTIAL

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ABSTRACT

CRAYNET is a specialist network of workers, funded by the European Commission, on crayfish as biomonitors of environmental health and biodiversity. It arose from discussions during the planning phase of the EU-supported European Crayfish Conference, held at Poitiers in Sept. 2001. That meeting included both scientists and managers, and discussed practical problems of a deteriorating aquatic environment and loss of biodiversity, with the continued decline of community-controlling (keystone) species of European indigenous crayfish. Eight workshops identified key areas where information was lacking. The network was set up with 7 members, later expanded to 12 from 11 countries, co-ordinated by Catherine Souty-Grosset.

The proposal was funded because it contributes to several priority aspects of EU programmes and covers a species (*Austropotamobius pallipes)* and habitat (charophyte meadows in hardwater lakes) listed in the Habitats Directive. While the network is membership-based, it will encourage broad consultation through the website and specific thematic meetings, on *Austropotamobius pallipes* (in June 2003), *Astacus astacus* (September 2003), and *Austropotamobius torrentium* (September 2004). Important outcomes will be an electronic database for distribution of European crayfish (native and introduced), and an atlas containing the distribution of each species, and of its habitat preferences, with an appendix summarising the state of the art in research in each country. The website will document all meetings and other discussions, and the network will put out management and conservation guidelines for each species.

Keywords: *Astacus astacus, Austropotamobius pallipes, Austropotamobius torrentium,* distribution, exploitation, conservation

INTRODUCTION - ENVIRONMENTAL BACKGROUND TO CRAYNET

Aquatic environments are strongly affected by changes in the terrestrial environment, whether from natural or anthropogenic causes, such as industrialisation or agricultural practices. Monitoring of freshwater communities may therefore also provide a measure of changes on land. Water quality is often monitored through assemblages of bioindicator species, chiefly macroinvertebrates. Such assemblages vary, however, from place to place; few species are found throughout a wide range of habitat across Europe, and so most systems of water quality biomonitoring are national rather than international in scope (e.g. AFNOR, 1992 (IGBN); Hawkes, 1998 (BMWP/ASPT); Grandjean *et al.,* 2000 (IGBN); McGarrigle *et al.,* 2002 (Q)).

A promising alternative approach is to examine the cumulative effects on biodiversity of a widely distributed community-controlling (keystone) species. Freshwater crayfish species are among the largest and longest-lived of freshwater or land invertebrates. Their keystone impacts on community structure and biodiversity have received some attention (e.g. Momot *et al.,* 1978; Hanson *et al.,* 1990; Matthews *et al.,* 1993), and at natural densities crayfish will play a key role in maintaining biodiversity of lentic freshwater systems. Crayfish distribution has been well monitored in several European countries (e.g. Holdich, 2002, this volume; Sibley *et al*., 2002; Sibley, this volume). Because crayfish management implies not only restoration of the species but also of their habitat, several disciplines in biology (ecology, genetics, behaviour) and environmental chemistry are involved. A number of studies have elucidated crayfish habitat requirements (e.g. Foster, 1993; Smith *et al.,* 1996; Holdich & Rogers, 2000; Broquet *et al.,* 2002; Peay, this volume; Watson & Rogers, this volume).

The three main species of crayfish native within the European Union in 2002 (*Astacus astacus, Austropotamobius pallipes* and *A. torrentium*) have some biological and biogeographic differences; they also differ in their conservation status and consequent socio-economic impact. Fishing and aquaculture are permitted for the now declining *A. astacus* (e.g. Westman, 1999; Skurdal *et al.,* 2002) but no longer for *A. pallipes* that is now protected across Europe under the EU Habitats Directive. However, the less-known *A. torrentium* is not uniformly protected. Nevertheless, all three native species are recognised as keystone dominants in certain ecosystems. They are still widespread and even abundant in some countries, despite the ravages of crayfish fungal plague introduced in the 18^{th} C, the introduction of non-indigenous species of crayfish such as *Cherax destructor*, *Orconectes limosus*, *Orconectes immunis*, *Pacifastacus leniusculus* and *Procambarus clarkii* that are superior competitors (e.g. Capelli & Munjal, 1982), and the effects of human activity. ICS are under constant threat from these factors, and their continued survival in some countries is uncertain (Holdich, 1999; Holdich, 2002).

Because of traditionally high levels of European interest in the crayfish for recreational fishing, their decline has been noted by all European countries (Gherardi & Holdich, 1999; Skurdal & Taugbol, 2001) and is usually attributed to the deterioration of habitat and water quality and to epizootic fungal disease introduced by alien (American) crayfish (Holdich, 2002, this volume). The native species are becoming restricted to fragmented habitats and may be endangered, and their disappearance will inevitably impact on other aquatic biota. For this reason restockings and introductions have become important management tools (e.g. Reynolds & Matthews 1995; Reynolds, 1998; Reynolds *et al.,* 2000). The habitats to be restocked must still be suitable for crayfish in terms of water quality, morphological structures and substrate type (Holdich & Rogers, 2000; Kemp & Hiley, this volume), and free of crayfish plague, and the genetic suitability of materials used for restocking must be ascertained (Grandjean *et al.,* 1997; Souty-Grosset *et al*., 1999; Gouin *et al*., 2001). Habitat restoration and works mitigation may be necessary (Peay & Rogers, 1999; Peay, 2000).

In 1999, a group of 15 European crayfish workers submitted a research proposal « CRAYMAP » to the Fifth Framework Programme, to examine how best to use crayfish as bioindicators and keystone species in aquatic environments. While not funded, this proposal received favourable assessment, and some partners have since individually carried out local aspects of the proposal, under national or regional funding.

Two years later, in September 2001, one partner (Catherine Souty-Grosset) hosted an EU-sponsored international meeting in Poitiers, France, of crayfish researchers and managers, defined as farmers, fishermen or scientists monitoring and licensing fisheries, or those responsible for environmental quality or conservation at local regional or national level. The meeting discussed practical problems of a deteriorating aquatic environment and loss of biodiversity due to changes in land-use, with the continued decline of the controlling (keystone) species of European indigenous crayfish. At the same time, introduced American crayfish are aggressively invading (Gherardi & Holdich, 1999), aided by changes in land-use and lowered water quality. However, as alien crayfish now constitute a valuable resource in some European countries, for instance Finland, Spain and Sweden, sound sustainable strategies are needed for the wise utilisation of crayfish in Europe, without endangering the future for the native species (Reynolds *et al.,* 2002; Skurdal *et al.,* 2002). Some management and legislative problems are worsened by the lack of precise official statistics and accessible information for all of Europe (Edsman, 2000).

Delegates at the Poitiers Crayfish Conference emphasised the lack of co-ordinated research efforts across Europe, and urged the establishment of guidelines for best practice at a European level. These are essential to standardise the monitoring of crayfish stocks in their various habitats and to use these to monitor biodiversity; current changes in land-use, water quality and recreational fishing must also be considered. Discussions were conducted between researchers and managers from different countries, about their choice of strategies and assessments of these methods. A range of conference workshop topics were suggested to examine current concerns of European scientists, with the underlying themes of crayfish as keystone species controlling ecosystem biodiversity and acting as powerful bioindicators for water and environmental quality.

DEVELOPMENT OF CRAYNET PROPOSAL

Poitiers workshops

Recommendations from the Poitiers workshops formed the basis for the network proposal. The major workshop themes, now published in Souty-Grosset & Grandjean (2002), are briefly summarised below.

<u>Monitoring in conservation management of indigenous crayfish populations</u>

Fundamental to any conservation and management strategy for populations of indigenous crayfish species (ICS) is a knowledge of where the crayfish are located, size of the populations, threats to their survival, particularly from non-indigenous crayfish species (NICS) and crayfish plague, and constant monitoring of these factors over time. Delegates agreed on the need for an atlas of the distribution of crayfish in Europe.

<u>Control and management of alien species</u>

There is a limited programme of current research and relatively few practitioners, which in turn yields relatively little hard data on which decisions can be based. It was agreed that attempts to control alien populations are not always practicable using currently available techniques. However, where vulnerable populations of native crayfish are clearly at risk, attempts to reduce this level of threat are necessary.

Interactions between natives and aliens

The introduction of NICS into natural habitats leads to negative and positive effects exerted by NICS towards the habitat, and the replacement of ICS by NICS. NICS can feed on macrophytes, invertebrates and juvenile vertebrates, and can also destroy microhabitats needed by other species for reproduction or shelter. NICS are often more competitive than ICS, e.g. through faster acquisition of a shelter, and reproductive interference may also occur (Holdich, 1999). However, the overall impact on the invaded habitat has been poorly explored in the field. Positive effects from NICS may be found at a local level, such as the occupation of vacant niches within "stressed" habitats, the re-appearance of rare birds and mammals finding a new abundant prey, and the increase of income within local fish markets using NICS as a resource (Akefors, 1999).

Protection of natives in a plague situation

This workshop highlighted an apparent knowledge gap between academic science and the practical advice needed by regional authorities and managers in direct contact with water users. Questions from managers included: how long can crayfish plague live in water? What treatments are available for crayfish plague? Do all signal crayfish carry crayfish plague? Are there resistant European native crayfish? Improved communication between scientists and managers is vital. Information is also needed for crayfish farmers, fishermen and the general public, on how crayfish plague works and how to protect against spreading the disease.There is an urgent need for a European code of practice for management and controlled reintroductions.

Management: restockings and introductions

Restocking of habitats with native crayfish species is now a very important management and conservation option. However, restocking criteria related to habitats, stocking material and procedures have only been developed for individual situations. If crayfish are to be introduced to a new location their possible impact on other endangered species already inhabiting the target water body must be assessed, as well as the genetic composition of the restocking material. Crayfish farms are now a major source of restocking material, but if wild stocks are used, they may suffer over-exploitation. There has been no general comparison of restocking projects across Europe. Agreement is needed on the number of individuals, age structure and sex ratio used for restocking and on time-scale of the restocking. Compilation of guidelines for restocking was recommended as an effective conservation strategy for European native crayfish.

Management: habitat restoration

Sustainable habitat for crayfish involves many factors, including water quality and quantity, temperature, substrate, channel structure and habitat composition. Predators, disease and the absence of non-native species must also be taken into account, and appropriate habitat restoration is necessary such that native species move back to the restored habitat, whether new sites, sites where crayfish populations exist at low density, or linking patches. Before restoration, mitigation of works or physical modifications of the river bed and banks may first be needed.

National and European legislation controlling crayfish

Crayfish legislation varies among European countries and between different administrative levels, depending on history, culture and importance of recreational fishing. Primary interests may be gastronomic, patrimonial (heritage), economic or ecological; further, political and financial power may affect or distort planning decisions. Recommendations were to attempt to integrate *Astacus astacus* and *Austropotamobius torrentium* into the Habitats Directive, Annex 2; and to highlight sanitary risks from live importations of crayfish.

Education as a key to crayfish conservation

Native aquatic animals, especially crustaceans, may be a focus of educational strategies. The conservation message can be effectively presented in TV material, websites, postcards, stamps and leaflets. Children and schools are receptive to educational material such as posters and information packs, while universities, colleges and natural history societies can provide more specific knowledge. Crayfish require a clean habitat, and so tie in well with people's concerns about their environment - landscape, air and water quality. Crayfish problems of disease or environmental deterioration require publicity aimed at specific user groups and at the general public, who could usefully be involved in monitoring programmes.

Further development of proposal

These workshops led to further discussions, and the Poitiers meeting decided the main conclusions should be progressed through a European network, with the aims of linking science and management to economic development as well as with conservation. An open forum discussion in August, 2001 at IAA 13 (the 13th International Association of Astacology International Symposium in Perth, Australia) also led to resolutions passed on two connected issues, crayfish as flagship/ keystone species, and maintenance of biodiversity.

Catherine Souty-Grosset agreed to co-ordinate the development of a network proposal under the fifth Framework programme of the EU, which was submitted in 2001, as: EU Proposal number: EVK2-2001-00350; "CRAYNET: European Crayfish as keystone species - linking science, management and economics with sustainable environmental quality."

DESCRIPTION - HOW CRAYNET WORKS

Approach

All European species of native crayfish are recognised or believed to be keystone dominants in certain ecosystems. While they may show biological and biogeographic differences and also differ in their conservation status, solutions from one species may be applicable to another, and a general strategy for conservation of native crayfish species in Europe is needed. A useful outcome would be harmonisation of regulations for crayfish conservation and exploitation within the EU.

Work is needed to clarify how crayfish can be used as bioindicators and to assess what conservation measures are needed. Future work should decide which management strategies may be implemented for each catchment area. In this context, international collaboration between researchers and the circulation of scientific knowledge among administrators is of the utmost importance. CRAYNET is a good opportunity for fruitful convergences of scientific efforts, and emphasises the importance of contacts among scientists, managers and administrators, with a view to creating the right conditions for long-term collective responsibility for the natural heritage.

Structure and workplan

CRAYNET is based on comparisons of three species of traditional importance across Europe (see below). The network will bring together European scientists, managers, environmental authorities, fishermen and other stakeholders; will base its three meetings around the three main species of traditional importance across Europe; and will disseminate its findings through a website and publications.

Strand 1

The white-clawed crayfish *Austropotamobius pallipes* (Lereboullet) **(AUP)**, occurring along a western and southern axis in Europe (see Holdich, this volume). The network of partners involves France, Ireland, Italy, U.K and Spain, further links to be established with Slovenia and Switzerland.

Strand 2

The noble crayfish *Astacus astacus* (L.) **(ASA)**, ranging across northern Europe from west to east (see Holdich, this volume). Network partners include Norway, Sweden, Germany, Poland, Finland; links will be established with Hungary, Estonia, Latvia and Lithuania.

Strand 3

The stone crayfish *Austropotamobius torrentium* (Shrank) **(AUT)** with smaller populations restricted to circumalpine areas (see Holdich, this volume). Network partners will be France, Austria and Germany and links will be established with Switzerland, Czech Republic, Slovenia, Yugoslavia/Serbia, Bosnia Herzegovina.

Participants

CRAYNET involves 12 partners in 11 European countries, representing both researchers and managers. Associated colleagues will be kept informed of developments and invited to appropriate thematic meetings: other researchers, managers and stakeholders will also be kept informed.

Network partners are: University of Poitiers, France (co-ordinator); University of Dublin, Ireland; University of Firenze (Florence), Italy; Technical University of Braunschweig, Germany; Institute of Freshwater Research, Drottningholm, Sweden; University of Innsbruck, Austria; Norwegian Institute of Nature Research, Norway; Muséum National Histoire Naturelle, France; David Holdich, UK; University of Szczecin, Poland; Crayfish Information Centre, Finland and University of Leon, Spain. Invited partners for some meetings will include Portugal, Hungary, Estonia. Lithuania, Latvia, Switzerland, Czech Republic, Slovenia.

Meetings

Four participatory meetings are planned over 30 months, linking from science to management in order to emphasise knowledge-based management strategies. Edited proceedings of each will be published in BFPP (formerly the *Bulletin Français de la Pêche et de la Pisciculture* and now subtitled *Knowledge and Management of Aquatic Ecosystems*). The final aim is to synthesize and to bring together recommendations for optimal strategies at a European scale and to identify necessary lines of research.

Thematic meeting 1: *Austropotamobius pallipes* **AUP: Ireland**

Organised by partners from Ireland and Italy.

Objectives: to define the status of *Austropotamobius pallipes* as a cultural heritage and endangered species. The aim is to bring together researchers and managers with partners from Ireland, Italy, France, UK, Spain, Portugal, Germany, plus Slovenia and Switzerland, to develop recommendations for optimal strategies at a European scale and to identify necessary research, for a common approach to management techniques.

Thematic meeting 2**:** *Astacus astacus* **ASA: Norway**

Organised by partners from Norway, Sweden and Germany.

Objectives : to concentrate on biological and socio-economic aspects of the status of *Astacus astacus*, its wise and sustainable use. The aim is to gather researchers and managers with some participants from Poland, Finland, Estonia, Lithuania and Latvia.

Thematic meeting 3**:** *Austropotamobius torrentium* **AUT: Austria**

Organised by partners from Austria and Germany.

Objectives: to define the current status of *Austropotamobius torrentium* with special consideration of the importance of land-use and habitat deterioration, and to build a database for this under-recorded species. The aim is to gather researchers and managers and some partners from circumalpine regions (France, Italy, Hungary, Switzerland, Slovenia, also Czech Rep., Croatia, Bosnia-Herzegovina, Jugoslavia).

Final Conference **Firenze (Florence), Italy**

Organised by Italian partners; the final conference will gather all the main partners and participants in the three previous meetings and will include seminars and roundtable workshops for preparing and improving the guidelines for crayfish management.

Database and atlas of European Crayfish

In European countries six indigenous crayfish species and at least five introduced species may be found (Holdich, this volume). CRAYNET will compile an atlas and database based on records for a 3 or 5-year period, to be updated regularly depending on resources. This scheme will be based and organized from the Natural History Museum (MNHN) in Paris in consultation with David Holdich and other experts.

The Atlas will contain :

Generalized distribution of each species and areas at risk from crayfish plague.
Description of each species and its habitat preferences.
Detailed distribution of each species in each European country.
Notes on the distribution of and threats to each species for each country.
Status of crayfish research in each country

The Database of crayfish records for Europe may be interrogated at various levels by registered personnel. The level of interrogation could be set by each country, e.g. some countries may not want details of certain species known for commercial reasons.

Website

A European website (http://labo.univ-poitiers.fr/craynet/) will be devoted to the work and exchanges of the thematic network CRAYNET. This will be the first basic tool to link research and management to economic development and to present educational information for the general public. It will also include various documents harmonizing common European strategies for stake-holders, including management guidelines and leaflets for the public. The website will describe all meetings and provide registration forms, news from exchanges, state of data gathering for Atlas, reports and so on. Links will be made with other sites, such as MNHN Biodiversity, Crayfish NEWS IAA, Natura 2000 sites.

Proceedings

Edited proceedings of each meeting will be published in the journal BFPP *Knowledge and Management of Aquatic Ecosystems*, edited by E. Vigneux (Conseil Supérieur de la Peche), which has already produced several volumes dedicated to crayfish. The first such issue of BFPP - *Spécial écrevisse : aperçu des problèmes astacicoles, informations générales* (vol. 281) appeared 20 years ago (Vigneux, 1981). Since 1997, Catherine Souty-Grosset has developed a forum for researchers through a series of further special issues on European crayfish species in BFPP, with most papers in English. The first volume (BFPP **347**, 1997) covers the current level of scientific knowledge of the genus *Austropotamobius*. Volume 2 (BFPP **356**, 2000) examines management strategies for the two native species *Austropotamobius pallipes* and *Astacus astacus*, while problems of introduced species, and their impact on natives, are the subject of Volume 3 (BFPP **361**, 2001). The most recent, Volume 4 is entitled: "*Knowledge-based management of European native crayfishes: proceedings of the Poitiers Conference*" (Souty-Grosset & Grandjean, 2002).

Summary of expected deliverables**:**

Edited papers from Poitiers 2001 (BFPP).
Study of European legislation on water quality and fisheries.
Electronic database for European crayfish distribution and production of an Atlas.
GIS maps of crayfish distribution with water quality.
Recommendations on harmonising national and regional regulations and for improving EU legislation.
European guidelines for biomonitoring protocols for crayfish as indicators of biodiversity.
Meetings with stakeholders; leaflets and video on management.

DISCUSSION

Contribution to the EU Fifth Framework Programme

To succeed, the CRAYNET proposal needed more than just scientific input. Its contributions to several priority aspects of the *EU Fifth Framework Programme on Energy, Environment and Sustainable Development* are summarised below.

Key Action 2 Global change, climate and biodiversity

The proposal examines global environmental processes such as loss of habitats and of biodiversity in terms of two major European regions (west, north) and two main aquatic habitats (lakes and streams). Emphasis is given to three widely distributed native invertebrate (crayfish) species with keystone effects on ecosystem structure and diversity. They are traditionally important, and receive national protection in many states (Taylor, 2002). *A. pallipes* is protected under the Berne Convention and is listed in Annex 2 of the Habitats Directive. Further, an important habitat for all crayfish species – charophyte meadows in hardwater lakes – is a Priority Habitat protected under the Habitats Directive.

Action Line 2.2 (rational methods for the conservation of biodiversity)

An important underlying question is how best to maintain and to monitor freshwater structure and biodiversity in a changing Europe (Priority Action 2.2.3 Assessing and Conserving Biodiversity). Monitoring European native crayfish populations as indicators of biodiversity is a potentially important tool in environmental management. CRAYNET will develop indicators of biodiversity based on crayfish abundance, and methods to understand and quantify drivers, mechanisms (e.g. keystone species) and dynamics of biodiversity between species (crayfish populations) and ecosystems (aquatic habitats), species survival in fragmented habitats, and critical thresholds for the loss of biodiversity, in the context of invasion by alien species. CRAYNET involves interdisciplinary links to generate management programmes aimed at conserving our aquatic heritage (e.g. Convention on Biological Diversity, European Biodiversity Strategy). These can be incorporated into catchment-based responses under the Water Framework Directive.

CRAYNET will thus emphasise knowledge-based management strategies and a common European approach to management techniques. It will also develop research-management-development links through rural agencies and involve European regional programmes such as INTERREG and LEADER Plus.

How CRAYNET will further other EU policies

CRAYNET aims to address problems of wide interest among European people – their concerns about the deterioration of the aquatic heritage, together with the evident loss or reduction of key species such as trout, otter and crayfish. All three animals are seen as symbols of a balanced environment. CRAYNET aims to demonstrate the usefulness of crayfish, as important and easily monitored freshwater species, as a general biomonitor for water and aquatic habitat quality. By studying European crayfish across their entire distributional ranges, we hope their utility as a European standard will become apparent. Reintroduction strategies and protocols will be constructed and tested, and with evaluation of alternative scenarios for European development (agricultural, industrial, recreational) suggestions will be made for legal harmonisation of regulations for crayfish conservation and exploitation.

The proposal could provide widescale benefits in the form of basic management tools, useful at a European level. These could include inputs to Common Fisheries Policy (recreational fishing, aquaculture), Environmental Policies (Water quality standards) and Common Agricultural Policy (habitat bioindicators and biodiversity survey). Community Small Firms policy may be addressed through encouraging cooperative research with SMEs. Some transnational implications are also covered by Conventions such as Cross-border Pollution of Waters and Trade in Endangered Species (CITES).

Habitat restoration will also contribute to Community Social Objectives and employment, through
economic multiplier effects. Finally, crayfish fisheries have potential for development - the direct value of the annual catch in Sweden alone is currently 11 million Euro. The enhancement of crayfish stocks will also increase and diversify opportunities for traditional-style recreational fisheries, bringing small-scale socio-economic benefits and stability to local communities.

Managing the occurrence and re-establishment of crayfish as biomonitors will thus have a positive influence on improvement and maintenance of environmental quality, with onward effects on recreational activities and tourism. Environment-friendly policies to encourage stronger crayfish stocks should thus also increase economic investment at a human scale.

Participation in a cluster of biodiversity-related projects:

CRAYNET participates in a cluster of 23 projects on biodiversity research, known as BIOTA. The aim of the cluster is to determine and promote strategic approaches to biodiversity assessment and management in Europe. Cluster projects deal with a variety of plant and animal groups as models, and BIOTA may later be extended to include further projects arising from the third call for proposals in FP5 and from future calls for proposals related to biodiversity. The cluster will help to co-ordinate a collective European effort to develop biodiversity research; provide an opportunity to enrich each project by an exchange of ideas; and, where appropriate, increase the effectiveness of each proposal through joint field work or other activities. Occasionally, where the Commission may require an answer to a policy-relevant question related to biodiversity, the cluster will provide a reasoned, rapid response to such questions, provided that such questions fall within the competence of the cluster and do not require additional research.

CONCLUDING REMARKS

The authors hope that CRAYNET will be a successful force for integrating knowledge on crayfish in freshwater ecosystems at an European level   The four thematic meetings should allow widespread participation of all crayfish workers, both scientists and managers; the website will allow wider and sometimes more informal communication, and the atlas will provide a basis for all furture research.

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CRAYFISH IN EUROPE – AN OVERVIEW OF TAXONOMY, LEGISLATION, DISTRIBUTION, AND CRAYFISH PLAGUE OUTBREAKS

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ABSTRACT

With the recent splitting of *Austropotamobius pallipes* into two species there are now six indigenous crayfish species (ICS) (*Astacus astacus, A. leptodactylus, A. pachypus*, and *Austropotamobius italicus*, *A. pallipes*, *A. torrentium*) and at least five non-indigenous crayfish species (NICS) (*Cherax destructor*, *Orconectes limosus*, *O. immunis*, *Pacifastacus leniusculus*, *Procambarus clarkii*) recognised in Europe. The taxonomy of the ICS is in a state of flux, but the use of various molecular genetic techniques is being used to clarify the species, most notably those belonging to the *Austropotamobius* species complex. The generalised distribution of these species is outlined, partly to emphasise the current overlap between indigenous and non-indigenous species, and also to highlight the fact that detailed maps are needed for conservation and management purposes. Crayfish plague has affected most countries in Europe since the 1860s, and many continue to be affected up to the present day. Many European countries have legislation in place to protect their ICS, and also to combat the inroads being made by NICS and crayfish plague.

A number of West European countries have schemes for mapping the detailed distribution of their crayfish. However, currently there is no pan-European scheme. As part of the CRAYNET programme it is planned to try and get countries to put their data into a central database to be held at the Natural History Museum in Paris so that an atlas of crayfish and crayfish plague distribution can be produced that will be of use to environmental managers.

Keywords: crayfish, Europe, taxonomy, legislation, distribution, crayfish plague, threats

INTRODUCTION

The distribution of the indigenous crayfish species (ICS) and non-indigenous crayfish species (NICS) occurring in the wild in Europe has recently been extensively reviewed by Holdich (2002a) as a forerunner to setting up a database and atlas as part of the CRAYNET programme (Reynolds, this volume). This paper summarises and updates what is known of the taxonomy, legislation and current distribution of crayfish in Europe; as well as giving an overview of the spread of crayfish plague, with particular reference to the British Isles.

The distribution of ICS in Europe has been highly influenced by the last ice-age and subsequently by climate and man-made factors (e.g. habitat destruction, pollution, canal building), including the introduction and establishment of NICS. Those from North America are now wide-spread and are causing problems due to the fact that they act as vectors for crayfish plague caused by the fungus, *Aphanomyces astaci* Schikora 1903. They are also often superior competitors to ICS, and can have a negative impact on the environment through their trophic and burrowing activities (Holdich, 1999; Westman, 2002). The elimination of nuisance populations is almost impossible without resorting to the use of chemicals (Holdich *et al*., 1999; Sibley *et al*., 2002b; Hiley, b, this volume; Kozak, this volume). However, on the positive side, there have been commercial, socio-economic and recreational benefits to the establishment of NICS in some countries, e.g. Finland, Spain and Sweden (Ackefors, 1999; Westman, 2002).

TAXONOMY

According to the simplest taxonomic scheme (Albrecht, 1982) there is one genus and five species of indigenous crayfish in Europe, whilst the most complex lists five genera and 19 species (Starobogatov, 1995). Until recently (see below), the most widely accepted scheme, in Western Europe at least (Holdich, 1992), is of two genera, *Astacus* and *Austropotamobius*, with *Astacus* having three species, i.e. *astacus* (Linnaeus 1758) (noble), *leptodactylus* Eschscholtz 1823 (narrow-clawed) and *pachypus* Rathke 1837 (thick-clawed), and *Austropotamobius* two, i.e. *pallipes* (Lereboullet 1858) (white-clawed) and *torrentium* (Shrank 1803) (stone). In some East European literature *Astacus leptodactylus* is known as *Pontastacus leptodactylus*, *Astacus pachypus* as *Caspiastacus pachypus*, and *Austropotamobius pallipes* as *Atlantoastacus pallipes*.

The taxonomy of indigenous crayfish in Europe is in a state of flux at present. Molecular genetic techniques are being used to try and sort some of the problems out, most notably for the *Austropotamobius* species complex (Grandjean & Souty-Grosset, 2000; Grandjean *et al*., 2002). Current thinking is that *A. pallipes* consists of two species, *A. pallipes* and *A. italius*. *A. pallipes* appears to be a unique species, whilst *A. italicus* can be divided into three subspecies, *A. i. carinthiacus*, *A. i. carsicus* and *A. i. italicus* (Grandjean *et al*., 2002). Molecular genetic technique can also be used to study variation within one species, and indications are that *A. pallipes* in Britain and Ireland are very similar to those in parts of France and may have been introduced from there in relatively recent times (Grandjean *et al*., 1997a, b; Souty-Grosset *et al*., 2000).

Whilst more detailed morphological and molecular genetic studies may reveal a greater number of 'true' species in Europe, from a monitoring point the fewer the species the better, as a plethora of species that can only be separated by detailed analysis will make any mapping scheme impossible! The subdivision of *Austropotamobius pallipes* into *A. pallipes* and *A. italicus* (Grandjean *et al*., 2002) will involve a rethink of their distribution.

In addition to the indigenous crayfish in Europe there are also at least five non-indigenous species in the wild, i.e. from North America – *Orconectes limosus* (Rafinesque 1817) (spiny-cheek), *O. immunis* (Hagen 1870) (calico), *Procambarus clarkii* (Girard 1852) (red swamp) and *Pacifastacus leniusculus* (Dana 1852) (signal), and from Australia, *Cherax destructor* Clark 1936 (yabby). In addition, many other Australian and North American species are on sale in aquarist centres, such as the Australian redclaw crayfish, *Cherax quadricarinatus* (von Martens 1868), and the North American white river crayfish, *Procambarus zonangulus* Hobbs & Hobbs 1990, which may eventually end up in the environment.

LEGISLATION AND DISTRIBUTION OF ICS IN EUROPE, WITH PARTICULAR REFERENCE TO GREAT BRITAIN

Legislation

Taylor (2002) and Vigneux *et al*. (2002) has reviewed the legislation covering ICS in Europe. Only three species, i.e. *A. astacus, A. pallipes and A. torrentium* are listed as protected in Appendix III of the Bern Convention. The EU Habitats Directive lists *A. pallipes* under Appendix II, and *A. astacus*, *A. pallipes* and *A. torrentium* under Appendix V. Species listed under Appendix III of the Bern Convention and Appendix V of the Habitats Directive are those whose exploitation or harvesting should be subject to appropriate control in member states. Species listed under Appendix II of the Habitats Directive are those that require the designation of protective sites or special areas of conservation (SACs). SACs are to be identified and put in place by 2004 by those countries that signed the Convention on Biological Diversity at the 1992 Earth Summit in Rio de Janeiro. Baille & Groombridge (1996) list *A. astacus*, *A. pallipes* and *A. torrentium* as vulnerable due to range reductions and population declines. No ICS are listed by CITES (www.cites.org/CITES/eng/append/index.shtml).

Details of the legislation covering individual countries in Europe is provided in Gherardi & Holdich (1999) and Souty-Grosset & Grandjean (2002).

Distribution

The distribution of ICS by country is given in Table 1 and their generalised distribution is shown in Figs 1-4. Where there are only one or two records for a country these are shown separately, but where a species is wide-spread then the whole country is shaded in. For further details see Holdich (2002a).

Astacus astacus (Fig. 1)

Despite the ravages of crayfish plague the noble crayfish still has a wide distribution in both Western and Eastern Europe, although the number of populations has been severely reduced (Westman, 2002). It is widely harvested in Scandinavia and Eastern Europe, and is farmed extensively in Western Europe (Ackefors, 2000). Some countries apply strict seasonal and size catch quotas in order to conserve stocks (see papers in Gherardi & Holdich, 1999). The pre-plague harvest in Nordic and Baltic countries exceeded 2000 tonnes annually, whereas now it is less than 200 (Skurdal *et al*., 1999). It is likely that its original occurrence in some northern and central European countries, e.g. Scandinavia, is due to stocking from more southerly populations. It may also occur in some bordering countries such as Turkey, and has been introduced successfully into Morocco.

The noble crayfish was introduced into S. W. England in 1984 whence it escaped into a local watercourse (Holdich *et al*., 1995). It was subsequently placed on Schedule 9 of the Wildlife & Countryside Act (1981) in 1992 as a potential threat, i.e. as a superior competitor for resources (it does not carry crayfish plague), to the indigenous white-clawed crayfish (Scott, 2000).

Astacus leptodactylus (Fig. 2)

The narrow-clawed crayfish, also known as the swamp or Turkish crayfish, has a wide distribution in Western and Eastern Europe, but its presence in Western Europe is probably mainly due to stocking from Eastern Europe. It does not occur in Norway or Sweden, but has recently been found in Finland. It is an invasive species and has been responsible for displacing other indigenous crayfish species. It could be considered as a NICS to Western Europe (Holdich, 1999; Westman, 2002). Starobogatov (1995) lists many species and subspecies for *Pontastacus* (= *Astacus*), but Przemyslaw (2002), at least, found that many of the morphological characters used to separate them proved of little use in a taxonomic study of populations in Poland.

It is widely harvested in Eastern Europe and is farmed to a limited extent in Western Europe. In the recent past Turkey was the main supplier to West European markets, but outbreaks of crayfish plague and overfishing decimated the industry in the 1980s (Holdich, 1993).
It was originally introduced into Britain in the 1970s for the restaurant trade and has subsequently become widespread in the wild due to escapes and stockings. It is common in the south of England, where it is extensively harvested (Rogers & Holdich, 1995). A few attempts have also been made to farm it in England. It was placed on Schedule 9 of the Wildlife & Countryside Act (1981) in 1992 as a potential threat, i.e. as a superior competitor for resources (it does not carry crayfish plague), to the indigenous white-clawed crayfish (Scott, 2000).

Astacus pachypus

The thick-clawed crayfish is restricted in its range to S. E. Europe, although too little has been published on its distribution to map it here. It is extensively harvested from the rivers running into the Black Sea and Caspian Sea as well as their coastal waters (Holdich, 2002a). No attempts appear to have been made to introduce it outside its natural range.

Austropotamobius pallipes/italicus (Fig. 3)

As *A. pallipes* and *A. italicus* have only recently been clearly separated (see below) their distribution has been combined until their separate distributions are better defined – see Grandjean *et al*. (2002) for the generalised distribution of these two species (although it should be pointed out that for the subspecies of *A. italicus* their map is inaccurate and gives a misleading picture, e.g. for Germany and Hungary).

The white-clawed crayfish has a widespread distribution stretching from Ireland in the west to some countries bordering the Adriatic in the east. It is not known from Scandinavia or from much of Eastern Europe. It has become virtually extinct in Portugal in recent years, and is under threat in Spain from crayfish plague and NICS. Three sub-species of *pallipes* have been recognised in the past by some authorities, i.e. *italicus*, *lusitanicus* and *pallipes*, but others consider that *italicus* and *lusitanicus* should be given species status as well as *pallipes*. Grandjean *et al*. (2000, 2002) suggest that just two species, *pallipes* and *italicus* (with three subspecies), should be recognised. *A. pallipes* is the commonest indigenous crayfish species in the British Isles and France, but in some countries it has a restricted distribution, e.g. Germany. *A. italicus italicus* occurs in Italy and Spain (where it has been introduced from Italy and was previously identified as *lusitanicus*); *A. italicus carinthiacus* occurs mainly in Austria and Switzerland; and *A. i. carsicus* in the Balkans (Grandjean *et al*., 2002). These species were probably more common before the onset of crayfish plague. Unlike *A. astacus* and *A. leptodactylus* species belonging to *Austropotamobius* are not now harvested or farmed to any great extent.

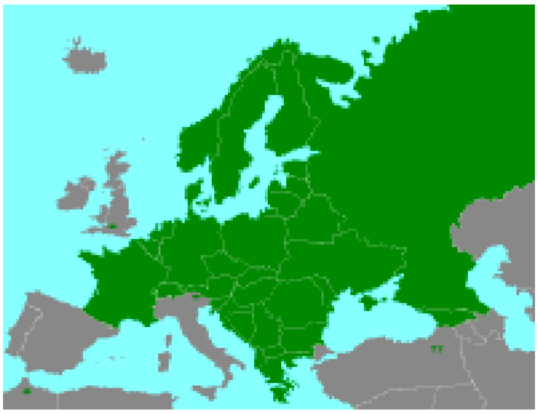

Figure 1. Generalised distribution of *Astacus astacus* in Europe.

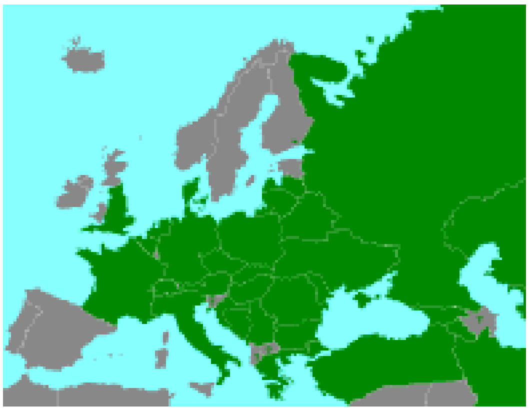

Figure 2. Generalised distribution of *Astacus leptodactylus* in Europe.

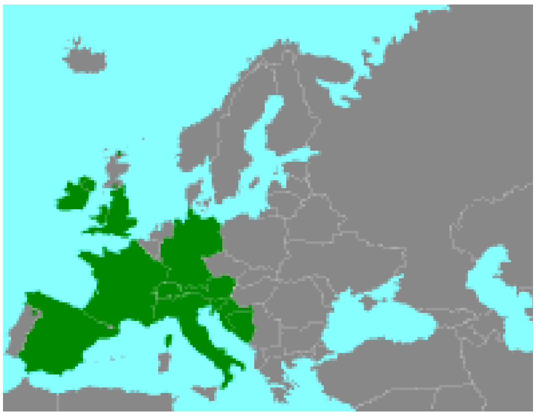

Figure 3. Generalised distribution of *Austropotamobius pallipes/italicus* in Europe.

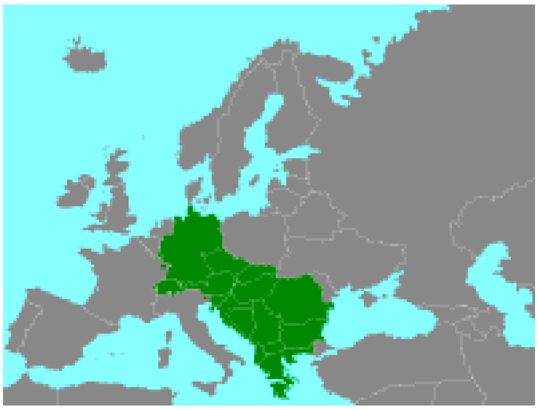

Figure 4. Generalised distribution of *Austropotamobius torrentium* in Europe.

There is some debate as to how the white-clawed crayfish reached the British Isles, i.e. naturally after the last ice-age, with tribes as they moved north-westwards after the last ice-age, or relatively recently due to the actions of man (Holdich, 2002a). One of the earliest literature records for *A. pallipes* in England is of their introduction (from where or whether they were already present in the area is not mentioned) into the R. Ure in Yorkshire by a C. Metcalf who lived from 1513-1574 (Fryer, 1993). Whatever its origins it is now wide-spread in England and Wales, and despite the inroads being made by crayfish plague and NICS, many large, healthy populations still exist (Holdich & Rogers, 1997; Holdich *et al*., 1999; Sibley *et al*., 2002a; Sibley, this volume). It has been introduced into Scotland in the last 75 years, but only two populations are known (Maitland *et al*., 2001). Good populations exist in Ireland (Reynolds *et al*., 2002a, b; Reynolds & Demers, this volume), despite the impact of crayfish plague in central regions in the 1980s (see below).

***Austropotamobius torrentium* (Fig. 4)**

The stone crayfish mainly occurs in central and south-eastern Europe, as far as the countries bordering the western Black Sea. Its distributional range is thought to be much more restricted now than it was before the advent of crayfish plague, although it still can be the commonest indigenous species in some countries. In pre-plague times it was common in France and had been thought to be extinct until its rediscovery recently. It is not harvested or farmed to any great extent.

LEGISLATION AND DISTRIBUTION OF NICS IN EUROPE, WITH PARTICULAR REFERENCE TO GREAT BRITAIN

Legislation

At the Earth Summit in 1992, 165 nations signed the United Nations Convention on Biodiversity, which requires its signatories "to prevent the introduction of, control and eradicate those alien species which threaten ecosystems, habitats or species" (Article 8h). Member States in Europe were also encouraged to ensure "that the deliberate introduction into the wild of any species which is not native to their territory is regulated so as not to prejudice natural habitats within their natural range or the wild native fauna and flora and, if they consider it necessary, prohibit such introduction" (Council Directive 92/43/ECC). However, as pointed out by Tibbetts (1997) little has been done to implement such measures. Crayfish are unusual amongst animals in that they break the Three Tens Rule, which states that approximately 10% of imported species become introduced, 10% of introduced species become established, and 10% of those established become pests. (Williamson, 1996). Most of the NICS introduced into Europe have done very well in their new environment and in Britain, at least, all those introduced have become pests, with the exception of *Cherax quadricarinatus*.

Details of the legislation covering individual countries in Europe is provided in Gherardi & Holdich (1999) and Vigneux *et al*. (2002). Britain and Ireland probably have the most stringent laws in Europe covering NICS (Holdich & Rogers, 1997; Holdich *et al*., 1999; Scott, 2000). Indeed Ireland, because of its ban on such imports, currently has no NICS, although it has suffered from an outbreak of crayfish plague (Reynolds *et al*., 2002). Estonia and Norway, and most East European countries do not currently have any NICS.

Distribution

The distribution of NICS by country is given in Table 1 and their generalised distribution is shown in Figs 5-7. Where there are only one or two records for a country these are shown separately, but where a species is wide-spread then the whole country is coloured in. For further details see Holdich (2002a).

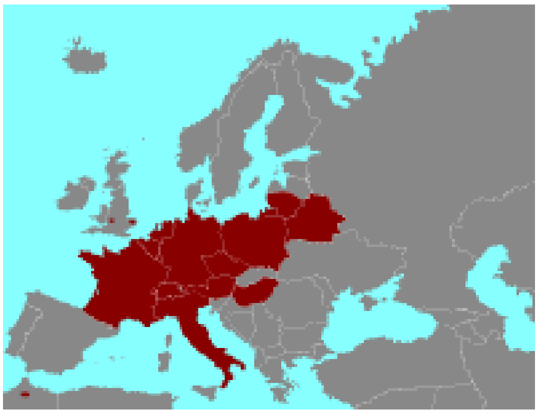

Figure 5. Generalised distribution of *Orconectes limosus* in Europe.

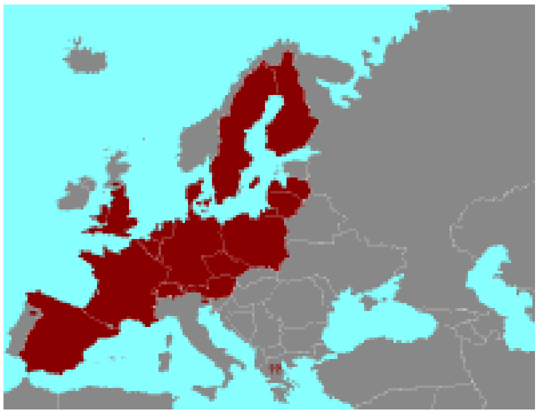

Figure 6. Generalised distribution of *Pacifastacus leniusculus* in Europe.

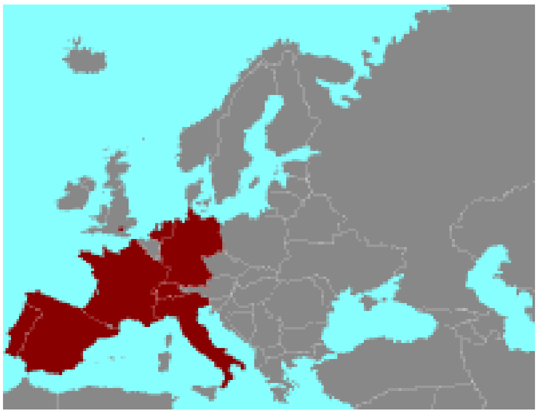

Figure 7. Generalised distribution of *Procambarus clarkii* in Europe.

Figure 8. Weir on the River Bain (Lincs). (Photo. P. Smith, Env. Agency).

Figure 9. Two signal crayfish bypassing a weir (Photo. P. Smith).

***Orconectes limosus* (Fig. 5)**

The spiny-cheek crayfish, also known as the American or striped crayfish, was originally introduced from the Delaware River (USA) into a pond on the German-Polish border in 1890. It is one of many *Orconectes* species, but the only one to be successfully introduced into Europe (Hamr, 2002). Since then it has become one of the commonest species in some of the 15 European countries it has spread to. It has also been successfully introduced into Morocco.

It is an invasive species and acts as a vector of crayfish plague, consequently it has been responsible for displacing ICS in many countries.

It has been introduced into Britain and is breeding at one site in the West Midlands at least. Its distribution in Britain is uncertain. It has yet to be put on Schedule 9 of the Wildlife & Countryside Act (1981).

Orconectes immunis

The North American calico crayfish is relatively new to the European crayfish fauna. It was probably released or escaped from an aquarium in the Rhine Valley in Germany and there are now a number of small breeding populations east of the R. Rhine (Dehus *et al*., 1999). A specimen was found in the R. Rhine in 2000 some 20 km away from the introduction site (P. Dehus, pers. comm.).

Pacifastacus leniusculus (Fig. 6)

The origins and spread of the signal crayfish in Europe have been well documented (Lowery & Holdich, 1988; Gherardi & Holdich, 1999; Lewis, 2002). It was originally introduced into Sweden from California in 1959, as it was considered to be an ecological homologue of *A. astacus*, which had been badly affected by crayfish plague. After successful trials it was released into thousands of lakes and ponds in 1960 and subsequently. It was subsequently introduced to many other European countries and is now established in 21 of them. It is a highly invasive, burrowing species, which acts as a vector of crayfish plague. It is very difficult to keep contained and once in a river it will move downstream and upstream, often circumventing weirs by climbing out of the water (Figs 8, 9). A good example of how it has invaded a water course, and attempts to remove it, is given by Sibley (2000). There are both positive (Ackefors, 1999) and negative (Holdich, 1999) aspects to its introduction to Europe.

The signal crayfish was introduced into England for aquacultural trials in the 1970s and based on the success of these it was supplied to many potential crayfish farmers and research institutions. Due to escapes and stockings it subsequently became widespread in England and Wales (Holdich & Rogers, 1997; Holdich *et al*., 1999; Sibley et al., 2002a; Sibley this volume), and has recently been found in large numbers in some Scottish rivers (Maitland *et al*., 2001). It was placed on Schedule 9 of the Wildlife & Countryside Act (1981) in 1992 as a potential threat, i.e. as a superior competitor for resources to the indigenous white-clawed crayfish, and as a vector of crayfish plague (Scott, 2000). As well as displacing the indigenous crayfish it also has an adverse impact on the other freshwater biota due to its trophic activities, and on the environment due to its burrowing activities.

Procambarus clarkii (Fig. 7)

The red swamp crayfish is the dominant commercial species in the world, with over 85 000 tonnes being harvested annually from the wild and farms in the USA, and from the wild in China, Kenya and Spain where it has been introduced (Huner, 2002). It was originally introduced into southern Spain from Louisiana in 1973 and rapidly spread out from there to other parts of Spain.

Table 1. Occurrence of wild populations of ICS and NICS in Europe.

	Indigenous*					Non-indigenous				
	Aa	Al	Ap	Aup/I[+]	Aut	Cd	Ol	Oi	Pl	Pc
Albania	x	?			x					
Andorra	x									
Armenia		x								
Austria	x	x		x	x		x		x	
Azerbaijan			x							
Azores (Portugal)										x
Balearic Is (Spain)										x
Belarus	x	x					x			
Belgium	x	x					x		x	
Bosnia-Herz.	x	x		x	x					
Bulgaria	x	x	?		x					
Canary Is (Spain)										x
Corsica (France)				x						
Croatia	x	x		x	x					
Cyprus	??								??	??
Czech Rep.	x	x			x		x		x	
Denmark	x	x							x	
England	x	x		x			x		x	x
Estonia	x									
Finland	x	R							x	
France	x	x		x	R		x		x	x
Georgia	x	x								
Germany	x	x		x	x		x	x	x	x
Greece	x	x			x				??	
Hungary	x	x			x		x			
Ireland North.				x						
Ireland Rep.				x						
Italy	R	x		x	R		x		R	x
Kaliningrad (Russia)	x	x					x		x	
Kazakhstan		x	x							
Latvia	x	x							x	
Liechtenstein	R			R						
Lithuania	x	x					x		x	
Luxembourg	R				R		x		x	
Macedonia	x	?			x					
Moldova	x	x								
Netherlands	x	x					x		x	x
Norway	x									
Poland	x	x					x		x	
Portugal				R					x	x
Romania	x	x			x					
Russia	x	x	x						??	
Scotland				R					R	
Slovakia	x	x			x					
Slovenia	x			x	x					
Spain				x		x			x	x
Sweden	x								x	
Switzerland	x	x		x	x		x		x	x
Turkey	??	x								
Turkmenistan		x	x							
Ukraine	x	x	x							
Uzbekistan		x								
Wales				x					x	
Yugoslavia	x	x			x					

Aa, *Astacus astacus*; Al, *Astacus leptodactylus*; Ap, *Astacus pachypus*; Aup, *Austropotamobius pallipes/italicus*; Aut, *Austropotamobius torrentium*; Cd, *Cherax destructor*; Ol, *Orconectes limosus*; Oi, *Orconectes immunis*; Pl, *Pacifastacus leniusculus*; Pc, *Procambarus clarkii*.

* Crayfish indigenous to Europe as a whole, but not necessarily indigenous to a country where they now occur, having being introduced in recent times. However, in many cases they are now considered to be indigenous by that country.

+ the distribution of *Austropotamobius pallipes* and *italicus* has been combined until their separate distributions are better defined.

? Present in adjoining countries and may be recorded with more intensive surveying.

?? Indicates that an introduction has been made but its outcome is not known or is yet to be reported officially.

R Restricted distribution, i.e. one or few populations, but may be locally abundant, e.g. *A. pallipes* and *P. leniusculus* in Scotland.

Procambarus clarkii is an ecologically plastic, burrowing, invasive species that acts as a vector of crayfish plague. Although considered to be a pest in Spain it is also a valuable commodity, and this has contributed to its expansion into natural waters of seven other European countries, as well as some islands, i.e. Azores, Majorca, and Tenerife, and the R. Nile in Egypt. There are both positive (Ackefors, 1999) and negative (Holdich, 1999) aspects to its introduction to Europe.

It occasionally crops up in the wild in Britain as a result of escapes from aquaria or deliberate releases, but the only known breeding populations occur in ponds on Hampstead Heath in London. This species has yet to be put on Schedule of the Wildlife & Countryside Act (1981).

Procambarus zonangulus

The white river crayfish was originally introduced into southern Spain at the same time as *P. clarkii* but it did not become established. Dehus *et al*. (1999) and Westman (2002) report its occurrence in the wild in Germany. However, Dehus (pers. comm., 2001) has said that although it has been abundant in the aquarium trade in Germany it has yet to be recorded from the wild.

Cherax destructor

A number of species of *Cherax* are imported into Western Europe from Australia for the restaurant trade, and also for aquacultural trials (e.g. Italy), but only the yabby, *C. destructor*, has so far become established in the wild, i.e. in the Zaragoza region of Spain.

Cherax quadricarinatus

The redclaw crayfish from Queensland, Australia is one of many crayfish imported for the aquarium trade in Europe, often through Asian countries, e.g. Hong Kong. It is a tropical species and has yet to be recorded from the wild, but could possibly survive where there are heated effluents.

This is the only crayfish species from outside Europe that can legally be imported into Britain and kept in covered, heated aquaria (Scott, 2000).

CRAYFISH PLAGUE IN EUROPE

Alderman & Polglase (1988) and Evans & Edgerton (2002) give accounts of the biology of the crayfish plague fungus, *Aphanomyces astaci*, whilst Alderman (1996) describes the origins and spread of crayfish plague in Europe, including Britain. (See also www.defra.gov.uk). The disease is carried by North American crayfish, which are largely immune to its effects, but is lethal to Asiatic, Australasian and European crayfish species. The disease probably first appeared in Europe in Lombardy (Italy) in 1859 and subsequently affected many watercourses on the north side of the R. Po. It is not known what its origin was but it might have been via infected American crayfish in the ballast water of a trans-Atlantic steamship. Interestingly, no further outbreaks of crayfish plague have been reported from Italy from 1900 to this day.

The second area affected was the Plateau de Langres in France, with the Meuse, Seine and Rhine being affected from 1874-1877, subsequently the disease spread to many departments in France up until 1890. Germany (Strasbourg and Alsace) and Austria were also affected from 1879, as were Belgium, Luxembourg, and what is now the Austrian-Slovenian border area from 1880. The disease reached Switzerland and new areas of Germany and upper Austria in 1881. Many outbreaks occurred in subsequent years in Germany, Slovenia and Austria from 1881 onwards. By 1886 north-eastern Latvia was affected. In the early 1890s major outbreaks were recorded in Russia, with the disease reaching the Black Sea and Caspian Sea. France, the Balkans, Latvia, Germany and Russia continued to be affected in the 1890s, and in 1894 Estonia was affected. Germany, Russia and parts of what is now Poland, continued to be affected in the early 1900s. Finland was affected in 1900, and the disease reached Sweden in 1907. Large-scale mortalities occurred in Germany from 1912-1914 and from 1923-1925. New outbreaks occurred in Latvia and Lithuania in 1920, and the disease continued to spread in Sweden. Outbreaks were recorded for Latvia in 1943, and the Baltic States continued to be affected into the 1960s.

Crayfish plague is thought to have affected the Iberian Peninsula for the first time in 1955 and then again in 1965, although it was not positively identified until 1978, when further mortalities occurred. Norway was affected in 1971, and again in 1990 in rivers flowing into Sweden, the disease moving upstream. The first suspected case of crayfish plague in England occurred in 1981. Greece was affected in 1982, Turkey in 1984, and Ireland in 1987.

Alderman (1996) dismisses claims that crayfish plague entered Britain from Europe in the late 1800s and caused mass mortalities in the R. Thames basin, mainly because the populations quickly re-established themselves – usually an unknown event after a crayfish plague outbreak. However, Alderman admits that we can never be sure if crayfish plague did reach our waterways earlier than the 1980s. Further mortalities occurred in the Thames basin in the 1930s and were attributed to porcelain disease, caused by the microsporidian, *Thelohania contejeani* Henneguy & Thélohan 1892, although as Alderman points out, this disease does not usually cause mass mortalities. However, in recent studies by this author on the R. Witham in Lincolnshire many living and dead individuals affected by the disease were found after two mortalities in 2001 (Tero *et al*. this volume). This disease may have more of an effect on populations than previously thought and needs to be monitored during surveys.

The spread of crayfish plague in Britain has been well documented from the early 1980s onwards (Holdich *et al*., 1995; Alderman, 1996). The North American signal crayfish, *P. leniusculus,* was introduced into Britain from 1976 onwards and was widely distributed to potential crayfish farmers. Many subsequently escaped into the wild. Crayfish plague outbreaks started soon after and rapidly spread to many catchments (Alderman & Polglase, 1988; Alderman, 1996), many outbreaks being reported from 1981-1987 (Table 2). Although none were reported in 1988 or 1989 a number of outbreaks occurred in 1990 resulting in all the major crayfish-bearing river systems south of the R. Trent having being affected by crayfish plague (Alderman, 1996). The disease moved into Welsh rivers in 1990 and 1991. The disease was also suspected of affecting populations in the Derbyshire Peak District in 1991, and further outbreaks occurred in the R. Thames catchment in 1992 (Alderman, 1996). There have also been many unexplained mortalities, including one in the north of England 1993, which may have been due to crayfish plague. Further mortalities occurred in the Derbyshire Peak District and the Thames catchment in 1993. There was then a lull in outbreaks until 1999, when one occurred in the R. Shep in Cambridgeshire (Rogers, 1999; Aldridge, 2000; Slater *et al*., 2000), and another in the R. Ribble (Lake District) (P. Bradley, pers. comm.). There has only been one reported case where there has been apparent natural recovery of a population affected by crayfish plague (Gerrard *et al*., this volume). Table 2 shows those catchments in the British Isles affected from 1981 to 1999. Crayfish plague has also affected populations of *A. pallipes* in the Irish Republic even though no NICS have been reported in that country (Reynolds, 1988).

Although it is not known for sure that *P. leniusculus* was responsible for the initial outbreaks of crayfish plague in Britain it was found to be a vector of the disease in Britain in 1988 (Alderman *et al*., 1990). Lilley *et al*. (1997) subsequently showed by random amplified polymorphic DNA (RAPD) analysis of the crayfish plague fungus that at least some of the outbreaks in England are the result of imports of *P. leniusculus* from northern Europe or North America after 1970. RAPD analysis has shown that four strains of the fungus appear to be present in Europe, i.e. A - from the original introduction in the 1860s, B – from signal crayfish introduced into Sweden in the 1960s, C – from signal crayfish imported from Canada, and D from red swamp crayfish introduced into Spain in the 1970s (Diéguez-Uribeondo & Söderhäll, 1999). Alderman (1996) points out that in the majority of outbreaks in Britain signal crayfish had been noted to be in close proximity to the infection site. However, mixed populations of white-clawed crayfish and signals may indicate that not all signals carry plague, although as shown by Holdich & Domaniewski (1995), the indigenous species may still be eliminated by the superior competitive abilities of the signals. Mixed populations of noble and signal crayfish are also known, e.g. Finland. In one case despite a long period (30 years) of living together the noble crayfish has eventually been eliminated, possibly by reproductive interference (Westman & Savolainen, 2001; Westman *et al*., 2002).

The spread of crayfish plague in Europe has largely been blamed on commercial trappers and wholesalers, infected equipment, and the stocking of waters with infected crayfish, and on restocking with and farming North American crayfish (Alderman, 1996). The movement of fish and water for farming purposes may also have helped spread the disease (Alderman *et al*., 1987). In the late 19^{th} C and early 20^{th} C crayfish plague had affected ICS in Austria, Belgium, Bulgaria, Denmark, Estonia, Finland, France, Germany, Hungary, Italy, Latvia, Lithuania, Netherlands, Poland, Romania, Russia, Sweden, Yugoslavia, and, more recently, England, Ireland, Norway, Spain Turkey and Wales. It is likely, although not confirmed, that Greece and Portugal have also been affected.

Table 2. Confirmed and suspected outbreaks of crayfish plague in the British Isles (mainly taken from Holdich *et al*., 1995).

River/lake	Catchment	Date	Confirmed
Lee	Thames	1981-82	MAFF
Sherston	Bristol Avon	1981-82	MAFF
Blackwater	Thames	1982	Unconfirmed
Wey	Thames	1983	MAFF
Avon	Hampshire Avon	1984	MAFF
Kennet	Thames	1984	Unconfirmed
Frome	Dorset Frome	1984	Unconfirmed
Stour	Dorset Stour	1984	Unconfirmed
Colne/Misbourne	Thames	1985	(MAFF
Darent	Thames	1986	Lowery, R. S. (pers. comm.)
Dowles Brook	Severn	1987	MAFF
Lough Lene	Shannon/Boyne	1987	Matthews & Reynolds (1990)
By Brook	Bristol Avon	1990	MAFF
Somerset Frome / Mells River	Bristol Avon	1990	MAFF
Ise (Kettering)	Nene	1990	MAFF
Camlad (Newtown)	Severn	1990	MAFF
Tributaries (Herts)	Welsh Wye	1990	Unconfirmed
Arrow (trib. R. Lugg), Eardisland	Welsh Wye	1990	MAFF
Wye (Buxton)	Derbys. Wye	1990-91	Unconfirmed
Clun (Welsh border)	Teme/Severn	1991	MAFF
Blyth (Northumbria)	Blyth	1992	Unconfirmed
Wycombe Dyke	Thames	1992	MAFF
Avening Brook	Glos. Frome	1993	Unconfirmed
Bradford/Lathkill (Derbys)	Derwent/Wye	1993	Unconfirmed
Tillingbourne (nr Dorking)	Thames	1993	Unconfirmed
Shep (Cambs)	Rhee	1999	Rogers (1999)
Ribble catchment	Ribble	2000-02	CEFAS / Bradley (in prep)

Therefore, virtually the whole of continental Europe had been affected by the late 1980s, and many countries have continued to be affected for over 100 years, with outbreaks still occurring on a regular basis. The once uniform distribution of indigenous crayfish populations has been fragmented and the production of indigenous species is only a fraction of what it was in pre-plague years (Westman, 2002). Edsman (2002) reported that as many as 160 outbreaks occurred in Sweden between 1994 and 1997. Other recent occurrences of the crayfish plague fungus have been reported for Finland, Spain and Germany (Vennerström *et al*., 1998; Diéguez-Uribeondo & Söderhäll, 1999; Oidtmann *et al*., 1999; Nylund & Westman, 2000), as well as for England (see above). Interestingly, France had not reported any new outbreaks since the late 19th C until recently (Machino & Diéguez-Uribeondo, 1998; Neveu, 1998a, b, 2000; C. Souty-Grosset, pers. comm., 2002).

Although there have not been many reported outbreaks of crayfish plague in Britain over the last decade, the three North American species occurring in the wild (*Orconectes limosus*, *Pacifastacus leniusculus* and *Procambarus clarkii*) are all known to be carriers of the disease (Vey *et al*., 1983; Alderman *et al*., 1990; Diéguez-Uribeondo & Söderhäll, 1993), so their spread should be curtailed whenever possible. Although the zoospores of the fungus can remain motile for up to three days they are capable of encysting and re-emerging up to three times over a number of weeks, so equipment needs to be thoroughly dried or disinfected when moving between sites if NICS are present. Oidtmann *et al*. (2002) found that it is unlikely that the plague fungus could survive passage through the gut of mammals or birds. However, they did find that infected abdominal cuticle was still viable after passing through the gut of fish, and they warn that one means of transferring the plague fungus may be via fish faeces. Oidtmann *et al*. (2002) found that the best way of disposing of cadavers of crayfish killed by plague was to boil them, as viable stages of the fungus were still found two days after freezing cadavers.

As pointed out by Cerenius *et al*. (2002), the key to crayfish plague control is to get rid of the vector, as once the fungus has no host it cannot survive. However, eradication of nuisance crayfish is a very difficult task without resorting to chemicals (Sibley *et al*., 2002b; Hiley, a, this volume; Kozak, this volume).

MAPPING &MONITORING

The generalised distribution of ICS and NICS in Europe is shown in Figs 1-7. Comparison of Figs 1-3 with Figs 4-7 shows that there is considerable overlap between the distribution of indigenous and non-indigenous species. Whilst such maps are useful for discussion purposes they are of little use to environmental managers, who need to know the more detailed distribution, not only of the crayfish, but also of crayfish plague. Such information is particularly important when stocking or restocking ICS, and setting up protective areas such as SACs (Holdich *et al*., 2002b; Schultz *et al*., 2002).

A number of West European countries have schemes for mapping the detailed, i.e. on a catchment basis, distribution of their crayfish (e.g. Austria, England and Wales, Spain, Sweden) (Holdich, 2002a). However, currently there is no pan-European scheme and each country produces maps in a different format. As part of the CRAYNET programme (Reynolds & Souty-Grosset, this volume) it is planned to try and get countries to put their data into a central database to be held at the Natural History Museum in Paris. In addition, areas that have been affected by crayfish plague will be mapped. The database will be updated on a regular basis. It will allow environmental managers not only to see the distribution of crayfish and crayfish plague in individual water bodies in their own countries, but also in neighbouring countries, an important fact to be aware of when rivers and lakes cross international boundaries. However, there may be some resistance to allowing detailed access to the data as some countries may wish to protect their stocks from commercial trappers.

Monitoring of crayfish populations in England and Wales has been carried out since the 1980s, but was mainly dependent on government financing, through its various agencies, to the University of Nottingham (see Harding & Cooper, this volume). The data up to 1996 (Holdich *et al*., 1995) was placed in a database at the Biological Records Centre at Monks Wood and is available for consultation through the National Biodiversity Network scheme (Harding & Cooper, this volume). Since 1996 the Environment Agency has gathered records as part of its routine biological monitoring programme, and individuals have also sent in records. A database has been compiled of the Agency's records and the results of this are shown in Sibley *et al*. (2002a) and Sibley (this volume). Many records exist, however, that are not in the database. What is needed is for all parties to get together to compile an up to date database. Not only would this be of use to environmental managers in England and Wales, but it could also give a great impetus to the CRAYNET scheme.

Monitoring of crayfish populations in Europe can only occur if surveyors can recognise individual species and the symptoms of crayfish plague. It is important therefore that such people are trained at on site courses and/or by educational leaflets (Puky *et al*., 2002).

CONCLUSIONS

There is much speculation about the future of ICS in Europe due to the random spread of crayfish plague and the invasive capabilities of NICS. Taugbøl & Skurdal (1999) have suggested two scenarios. First is that in 100 years all suitable watersheds will be occupied by NICS, with only a few populations surviving in protected localities. Second is that some countries currently without NICS, e.g. Estonia, Ireland and Norway, will continue to be free of them; and most countries will have numerous, viable populations of ICS that are valued by the public and protected by the authorities.

One would like to think that the second view will prevail, but commercial pressures may be such that governments relax their laws and allow the first scenario to happen. It is up to ecologists to show governments that ICS are a keystone and valuable part of the freshwater fauna (see Reynolds & Souty-Grosset, this volume), and that NICS may have adverse effects on this relationship. By having effective monitoring systems evidence can be presented to the authorities on where ICS are and what the threats are to them (see Souty-Grosset & Grandjean, 2002). This is what has happened in England and Wales over the last 20 years and it has resulted in very stringent legislation (Scott, 2000) that has helped protect the white-clawed crayfish so that we still have many hundreds of very large populations today, although as shown by Hiley (a, b, this volume) and Sibley (this volume) the threat of competition from NICS (particularly the signal crayfish) is very real and may result in the indigenous crayfish being confined to isolated refuges in the future.

Future threats to ICS in Europe include the introduction of further invasive crayfish species from North America, e.g. *Orconectes rusticus*, the spread of *Cherax destructor*, and in Britain, the further spread of *Orconectes limosus*. The recent discovery of a parthenogenetic crayfish of unknown species and origin (known as Marmorkrebs, the marble crayfish due to its pattering) in the aquarium trade in Germany raised fears of what might happen if it escapes and becomes established in the wild (Scholtz *et al*., 2003).

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CRAYFISH ON THE NET IN THE UK

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ABSTRACT

Data on the distribution of native and introduced species of freshwater crayfish in the UK are now accessible via the Internet. The National Biodiversity Network's Gateway (www.searchnbn.net) enables data owners and custodians to provide controlled access to their data for other users. Among many other datasets, access to data covering crayfish in the UK has been provided by the Biological Records Centre and the Environment and Heritage Service. The level of access to detailed data is controlled by the data owner/custodian, but a summary of the data is available publicly. The NBN Gateway enables users to examine species data in relation to other spatially referenced datasets, such as the boundaries of designated and protected sites.

Keywords: crayfish, native, introduced, linking datasets, internet, National Biodiversity Network, United Kingdom

INTRODUCTION

The National Biodiversity Network (NBN) has been established to facilitate the mobilization, sharing and use of data and information about the biodiversity of the UK. Our demonstration at the Nottingham conference showed examples of data and information relating to freshwater crayfish in the UK that are now being made accessible on the internet via the NBN Gateway. The demonstration was based on two spatially referenced datasets of the distribution of native and introduced freshwater crayfish in the UK. Despite their differing origins and contents, these two datasets have common temporal, spatial and taxonomic information. This allows their direct comparison and the ability to show the spatial distribution of a single species.

DATASETS

Nottingham University dataset

The dataset was compiled by David Holdich and his colleagues, particularly Ian Reeve and David Rogers, at Nottingham University under various contracts to the Environment Agency and English Nature (formerly the National Rivers Authority and Nature Conservancy Council), and the Natural Environment Research Council.) The dataset, covering Great Britain only, was compiled from many sources (Holdich, *et al*., 1995) with records covering the period 1900 to 1996. The data were computerized and are managed by the Biological Records Centre (BRC) (www.brc.ac.uk) on behalf of English Nature and the Joint Nature Conservation Committee (JNCC).

Environment and Heritage Service (EHS) dataset

The EHS in Northern Ireland commissioned surveys of crayfish in the Lough Erne and River Blackwater catchments in 1996 (www.answer-online.org/project_more details.asp?proj_id=1411), the computerized results of which are managed by the Centre for Environmental Data and Recording (CEDaR) (www.ulstermuseum.org.uk/cedar/) at the Ulster Museum in Belfast.

Metadata for the datasets

Metadata (descriptive data about each dataset) are available on the NBN Gateway.

NBN AND THE GATEWAY

Work leading to development of the National Biodiversity Network (www.nbn.org.uk) began in 1996 and NBN was formalised as a charitable Trust in April 2000. NBN has been formed by a consortium of statutory, non-governmental and voluntary organizations with an interest in mobilizing, sharing and using data on UK biodiversity for conservation, research, planning and public outreach. Such a national system was proposed in the UK Biodiversity Action Plan (Cm 2428), based on the findings for the Co-ordinating Commission for Biological Recording (Burnett *et al*., 1995).

The NBN Gateway (www.searchnbn.net), which uses the internet to provide controlled access to data and information, is central to the identity and success of NBN. The suppliers of data, normally at the level of a data custodian such as English Nature, BRC, a national voluntary society or a local records centre, define and control the levels of access for each dataset they give access to via the NBN Gateway. The Gateway is still being developed and populated with datasets. The Nottingham University dataset for crayfish, as managed by BRC, was one of the first to be made accessible when the Gateway was launched in pilot form in September 2000.

HOW THE NBN GATEWAY WORKS

Logging into the NBN Gateway Homepage and using the initial search facilities for crayfish reveals metadata for the crayfish dataset managed by BRC, including basic temporal and geographical metadata.

If a ‘Google’ type search is undertaken via the NBN Gateway, using the words ‘white-clawed crayfish’, then 30 results appear, including live links to other websites. The BRC dataset can then be interrogated further using the standard facilities of the Gateway. Summary distribution maps of both native and alien crayfish can be called up for various time periods. In addition, interactive maps allow access for registered users to detailed data and associated metadata for individual records. Links to other websites/datasets can be used for example to get a list of Sites of Special Scientific Interest at which *Austropotamobius pallipes* is recorded (English Nature website), or of Special Areas of Conservation where it occurs (JNCC website).

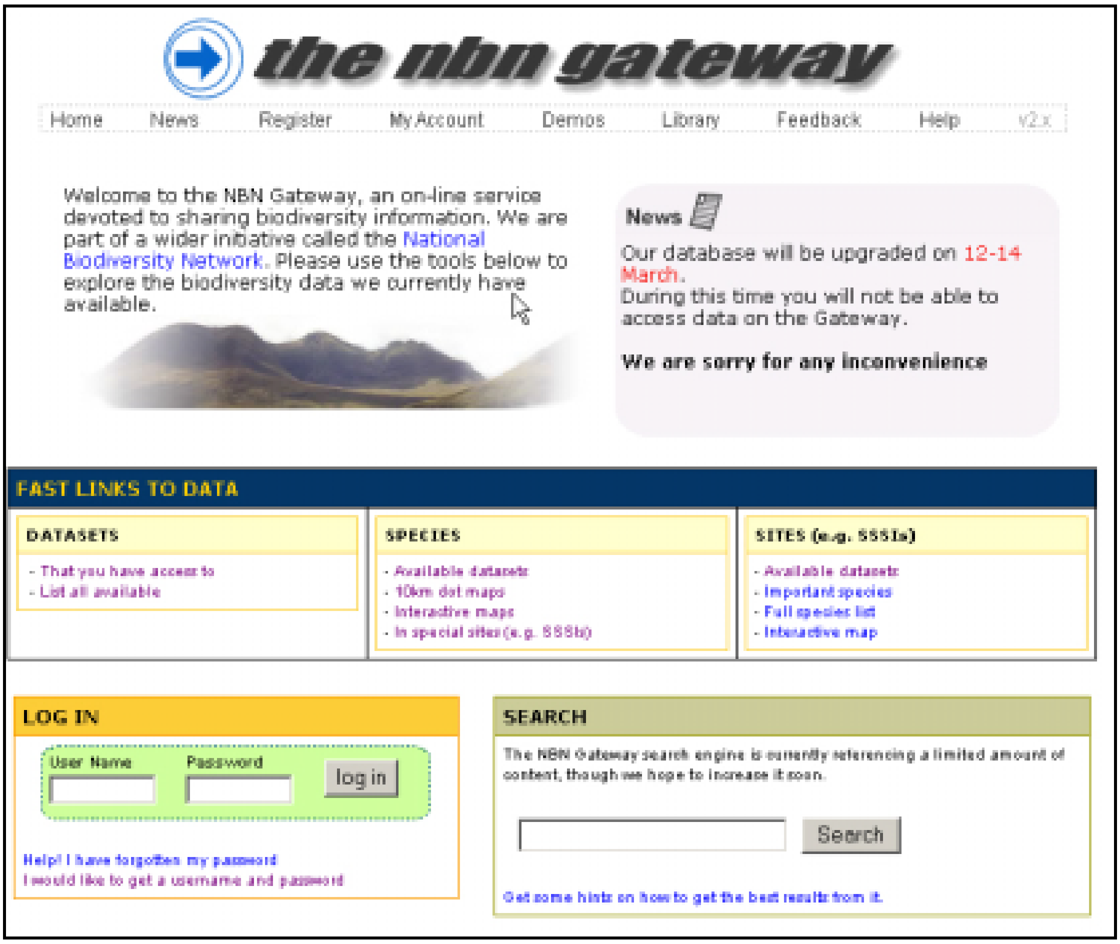

Figure 1. An example page from the NBN Gateway website.

THOUGHTS FOR THE FUTURE

We hope to open up a debate on the mobilization of data on freshwater crayfish in the UK, and in Europe (see also Reynolds & Souty-Grosset, this volume), by providing a few, simple 'take-home messages'.

1. **Up-to-date, reliable, interpreted information** is required to enable informed and accountable decisions to be made about UK biodiversity. The issue has, in the past, been that decisions could be made and actions taken without such information. It is now increasingly accepted that accountability for decisions and actions is almost as important as the decisions and actions themselves.
2. **'Historical' information provides a context for recent data**. Although users of data normally claim they want the most recent, up-to-date and comprehensive data, few users are prepared to invest in the collection, collation and management of such data. For this reason 'historical' information (which for some particularly demanding users may mean from the previous year or even more recent!) may be as good as there is. Also, historical data, spanning several decades, provide an unique resource to measure changes in range and to indicate where populations occurred in the past, for example to inform remedial actions and re-introductions (Sibley *et al*., 2002).
3. **Sharing data makes sense**. Much of the collation and management of biodiversity data in the UK depends, ultimately, on governmental funding although this is often through

tortuous routes of agencies or quangos and contracts or grants. The collation and management that is not government funded, and much of the data collection, is done by volunteers who support the conservation of biodiversity. Former practices, where governmentally funded organizations were reluctant to release data and information, even to well intentioned NGOs, are now largely a thing of the past. In the context of biodiversity data, the NBN offers a unique opportunity for sharing data to the greater benefit of species and their habitats. It is probably not apocryphal to suggest that, in the past, more sites and species have been lost or threatened as a result of data not being shared than have been lost or threatened by data being 'misused' as a result of wide access to them.

4. **Collecting, collating, managing and disseminating data is expensive**. This is an undeniable fact, and information technology has not significantly decreased the cost, but it has made the overall process more efficient and accessible. **But**…
5. **Sharing effort reduces the overall costs**. A more integrated approach to the collection, collation, management and dissemination of data could bring savings and other benefits for all. Several organisations, and individuals, sharing the effort by contributing financial resources, skills or facilities as appropriate, could achieve a greater whole than would be possible by separate initiatives, and they would avoid costly overlap and duplication of effort.

CONCLUSIONS

This paper has been intended to open up a debate on the future supply and management of information on freshwater crayfish in the UK. The possibly idealistic Thoughts for the Future (above) are broadly in line with the principles of the National Biodiversity Network.

- For those who have data, the question is: "Are you willing to share your data (on terms defined by you)?"
- For those who do not have data, but need them, the question is: "Why haven't you got the data you need, and what are you prepared to do about it?"

These two questions form the basis for a potentially rewarding dialogue between users and suppliers. The National Biodiversity Network would be interested in contributing to this debate.

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A MONITORING PROTOCOL FOR WHITE-CLAWED CRAYFISH

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ABSTRACT

A standardised survey and monitoring protocol for white-clawed crayfish has been developed as part of the LIFE in UK Rivers Project. The purpose was to provide a method for assessing whether populations of the white-clawed crayfish in the UK SAC rivers are in favourable condition. This necessitates a survey strategy capable of monitoring at all scales from catchment wide to individual sites. All methods of crayfish survey have limitations, but for this project a new and more rigorous method of selective manual survey has been developed. It forms the basis for the monitoring strategy at river and catchment level. It is based on sampling of the most favourable individual refuges for crayfish in five selected habitat patches within a sampling site. This provides a measure of relative abundance, expressed as an average no. crayfish/10 refuges.

The method offers a more consistent basis for comparison of sites and monitoring units over time and is suitable for a wide range of applications, although occasionally other methods may be needed.

Survey forms have been developed for the new standard method, but are recommended for all crayfish surveys. They record details of the survey, site, environmental conditions at the time of survey and the habitat characteristics most relevant to crayfish. This standardisation of recording will make it easier in future for compilation and analysis of data on crayfish populations both locally and nationally.

The monitoring strategy also addresses the monitoring targets for condition monitoring of populations. It includes new recommendations on grading of population abundance and action required in response to recorded change.

Keywords: *Austropotamobius pallipes*, crayfish, survey, method, monitoring

INTRODUCTION AND RATIONALE

Status of the white-clawed crayfish

The white-clawed crayfish *Austropotamobius pallipes* is under threat throughout its European range. (see Holdich, this volume). The major threats are alien crayfish, the crayfish plague fungus *Aphanomyces astaci* carried by American species, and the impacts on water quality and in-channel habitat due to urban development and agriculture. Sibley *et al.* (2002) and Sibley (this volume) have compiled the latest known distribution of native and alien species in Britain. There has been increasing interest in white-clawed crayfish and a major increase in the number of crayfish surveyors working in the UK, which has contributed to the improvement in the record of crayfish nationally. Nonetheless, although populations are still widespread in England and Wales, the distribution of white-clawed crayfish continued to decline in the 1990s, with many catchments now lacking any recent records of native crayfish. Furthermore, the number of catchments entirely free from alien crayfish is now very low and almost all of these are in Northern England. Holdich & Domaniewski (1995), Holdich *et al.* (1995) showed how signal crayfish *Pacifastacus leniusculus* could outcompete European species. Peay & Rogers, (1999), showed the progressive spread of an apparently plague-free population of signal crayfish in a river, at the expense of a native population. They concluded that the competitive spread of alien crayfish is a severe threat to native populations in all catchments where the two species are recorded.

The white-clawed crayfish is one of the species listed in the Species and Habitats Directive of the European Union. The Directive requires member states to designate Special Areas of Conservation (SAC) for the selected species and habitats and to report at regular intervals (every 6 years) on whether the particular species and habitats are in favourable condition. There are two main aspects to favourable condition, the abundance and health of populations and whether there are current or future external threats to them, individually and overall. Determining condition requires a monitoring strategy, in accordance with JNCC (1998).

Rationale for the project

The LIFE in UK Rivers Project commissioned this study to develop a standardised survey and monitoring protocol for white-clawed crayfish. It was primarily for the SAC rivers designated for white-clawed crayfish, but the intention was that the methods should be more widely applicable, to encourage monitoring to determine the distribution of crayfish in rivers nationally and for use in surveys for other applications. A monitoring strategy requires one or more appropriate survey methods and a protocol for using them. There has been no generally accepted survey method for white-clawed crayfish and no single method is applicable in all conditions.

White-clawed crayfish of all ages use refuges for shelter. Crayfish are vulnerable to predation by fish, water birds, otter and mink and various predatory invertebrates, including adult crayfish (as described in Hogger, 1988; Hill & Lodge, 1994; Nyström, 2002). Birds and fish tend to be active by day, so the crayfish tend to stay in refuges by day and are active at night. Refuges also provide shelter from high flows. Whilst floods are not an issue in still waters and canals, they are important in the highly variable flow regimes of the northern rivers, which are now the stronghold of white-clawed crayfish in England.

These behavioural factors mean that survey methods either rely on finding crayfish in their refuges by day, or catching individuals that are active at night. The advantages and limitations of different methods are summarised in Table 1. Most studies have either used trapping, or some kind of manual search.

Trapping has very low efficiency, plus various biases according to the size (larger animals) and sex of crayfish (more males) (Fenouil & Legier; 1977; Brown & Brewis; 1978; Abrahamsson, 1981). In addition, environmental conditions have a major influence on trapping efficiency. Night-viewing studies and radio-tracking have improved understanding of the behaviour and activity of crayfish and shown the responses to season, temperature and flow (Peay & Hiley, unpublished data; Gherardi *et al*, 1998; Armitage, 2000; Barbaresi &

Gherardi, 2000; Robinson *et al*, 2000). Crayfish do sometimes forage during the winter period, but activity is much less at temperatures below about 8°C. Abrahamsson (1981) and Wright & Williams (2000) have also shown the reduction in activity in signal crayfish populations at lower temperatures. The results of any trapping surveys under these conditions are unreliable.

Although it involves less manual effort, a further disadvantage of trapping is that it requires a minimum of two visits to each site surveyed, which increases the cost. In developing a monitoring strategy, there is always a balance to be struck between the level of accuracy required and the cost of obtaining the necessary data. This is a key factor for the statutory agencies responsible for monitoring species. The advantage of trapping is that it can be used in conditions that are too deep or turbid for any other method. In rivers that lack any areas that can be surveyed by manual survey, trapping may be the only option. The chance of detecting the presence of crayfish is reduced compared to rivers where other methods can be used.

Many surveys to find the general distribution of crayfish were carried out as short, timed searches of potential refuges used by crayfish, or by kick-sampling. Individual surveyors varied in the detail of their methods, making it difficult to compare results between occasions, between sites or between rivers.

Some workers now use fixed area sampling, using quadrats or transects for searching all potential refuges within a defined area of river bed, (e.g. Guan &Wiles, 1996; Peay 1997; Spink & Frayling, 2002). This has the advantage of providing an estimate of population density, in areas where conditions are sufficiently shallow, clear and slow-flowing for thorough manual searching. The big disadvantage is that fixed area sampling is extremely labour-intensive. It is valuable for detailed studies at a few sites, but the resources required mean it is not practical for monitoring whole watercourses and catchments, like those rivers designated as SACs.

The survey method developed for the protocol (referred to here as the standard method) is a form of selective manual search. It is based on the units of habitat most directly relevant to crayfish, the individual refuges. Essentially it involves the selection of a defined number of potential refuges in the most favourable habitat available at any site. Details of the habitat are thoroughly recorded. Its major advantage over timed searches, is that it is independent of the variable work rate in different conditions. It can only be used in conditions where it is physically safe for surveyors to enter the water and where there is adequate clarity. Nonetheless, it is a simple, semi-quantitative method that provides an estimate of the relative abundance of crayfish at a range of sites. It gives the opportunity to compare results between catchments and over time, both of which are essential to any monitoring strategy.

The survey method and monitoring protocol were developed in draft and were field-tested in Summer 2002 in two tributaries of the River Eden SSSI (Site of Special Scientific Interest) in Cumbria, England; a SAC designated for white-clawed crayfish. The results are presented in Peay (2002a). The results from field-testing were used to refine the protocol to the final form described here. The full protocol (Peay 2002b) and the field-testing report (Peay, 2002a) are available on the LIFE in UK rivers website:
http://www.english-nature.org.uk/LIFEinUKRivers/ecological.

Requirements for survey	Advantages	Limitations
MANUAL SEARCH (STANDARD METHOD)		
Clear water; Up to 60 cm deep; Safe access.	Can search refuges. Can catch juveniles. Selective manual searching is generally the best method for preliminary surveys and whole reach surveys for baseline and monitoring studies. Can use for semi-quantitative surveys to obtain information on relative abundance and population structure, including size distribution and sex ratio.	Ineffective for searching bankside refuges or soft substrate effectively. Requires experience to identify appropriate habitats and for searching. Safety issues re access to water. Disturbs habitat to a degree. Requires manual effort.
MANUAL SEARCH (FIXED AREA SAMPLING)		
As for standard method above, also, must have slow flow if using enclosed quadrats.	Fixed area manual searching in favourable conditions can give population density. More juveniles are recorded and recorded size distribution in population is closer to actual.	Disadvantages as for method above, Very labour-intensive. Requires a lot of samples. Disturbs habitat.
TRAPPING (BAITED TRAPS)		
Moderate to low flow required. Temperature above 8^0 C. Traps must be left overnight.	Can trap in deep or turbid water. Can record active crayfish from inaccessible refuges. Little effort required (apart from carrying traps) and may be able to work from bank only.	Low efficiency, so only suitable for populations at high abundance. Efficiency affected by many variables, so catch per unit effort unreliable. Require two visits for each survey session. Only captures active adults. High cost of traps. Risk of vandalism/loss of traps. Some risk to non-target species with funnel traps (water vole). Need to make vole-friendly traps (England and Wales only).
TRAPPING (UNBAITED REFUGE TRAPS)		
Moderate to low flow required. Temperature above 8^0 C. Traps must be left for two or more nights.	Can leave traps out for extended periods, if stable or anchored. Can record crayfish when there are no accessible refuges for manual survey. Can catch some juveniles as well as adults. No risk to non-target species.	Need to make traps (e.g. groups of tubes). Require two visits for each survey session. Efficiency not known. Efficiency may be affected by availability of natural refuges. Some risk of loss of traps.
NIGHT VIEWING		
Moderate to low flow. Temperature above 8^0 C. Clear water not more than 1m deep (otherwise need SCUBA and associated procedures).	Records crayfish from inaccessible refuges. Gives direct view of active animals, including behaviour. One night per session (after preliminary daytime safety check). More effective than trapping, where survey is possible. Can give abundance estimate (though only of active animals). Least disturbance as crayfish do not need to be caught (if only recording numbers and location). No risk to other species.	May not record where population abundance is low. Like trapping, affected by seasonal factors and crayfish response to environmental conditions, also behavioural response to light. Safety issues due to working at night, when obstacles on banks are less obvious. Not suitable in turbid water conditions. Not suitable for unequivocal identification of species, unless catch crayfish (in water up to 60 cm).

Table 1. Summary of methods for surveying crayfish.

THE SURVEY AND MONITORING PROTOCOL

Outline of the survey method and monitoring protocol

The protocol is summarised in Fig. 1, showing the progressive scales from whole catchment to individual refuge. All of these scales need to be considered in the monitoring strategy. At the highest level, there is the catchment, where a range of factors may affect the suitability of a river for white-clawed crayfish. These include:

- alien crayfish;
- the risk of crayfish plague;
- the risk of pollution;
- land use, erosion and siltation, and nutrient loading.

These factors all require consideration in assessing whether the population of white-clawed crayfish in a river is in favourable condition or not. The protocol gives recommendations on the data required.

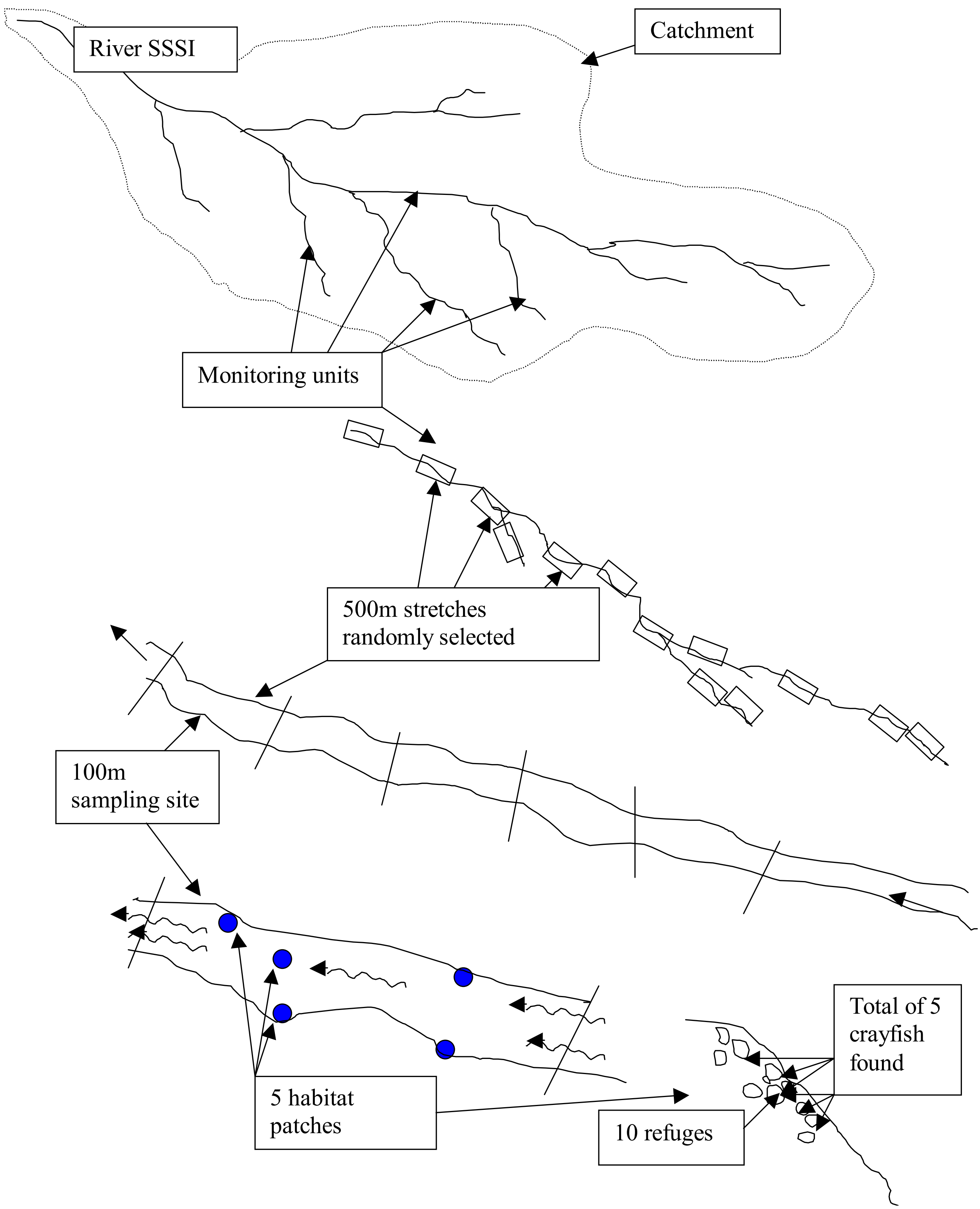
Populations of crayfish may vary considerably in different tributaries. River SSSIs and SACs are sub-divided into SSSI monitoring units. These tend to have a geomorphological basis, reflecting major changes in gradient, geology and flow. A monitoring unit is defined in the protocol as any length of river for which an estimate is required of crayfish presence and relative abundance, although it will usually be at least 10 km in length in a river SAC.

Within the monitoring unit, randomly selected stretches of river 500 m in length are used for selecting sites to survey. The sampling site is a short length of river where the crayfish survey is carried out, usually 100 m, but this may be 200 m in large rivers. The habitat patch is an area within a sampling site that a surveyor decides has a suitable combination of in-channel habitat and flow conditions to support crayfish. The size of the habitat patch varies, but is not less than 1 m^2 and may be up to about 20 m^2 of channel. The individual refuge within a habitat patch is the basic unit of survey. It is usually a boulder (>25 cm) or large cobble (15-25 cm). It may be any other feature that offers relatively stable shelter for one crayfish, or sometimes several; such as a block of rubble, an old tyre, or even a large lump of clay.

Within any 500 m stretch of river, the surveyor starts at the downstream end with a 100 m site. If this has sufficient accessible habitat patches it is surveyed, or is extended to 200 m if necessary (usually only in large rivers). If there are fewer than five suitable habitat patches in the extended site, a further 200 m is assessed and surveyed. If conditions are still not suitable, habitat details are recorded and a different stretch is surveyed. In each relatively homogenous habitat patch selected for survey, ten individual refuges are chosen, those considered by the surveyor to have the best chance of hiding one or more crayfish. The surveyor records the habitat searched and the catch of crayfish in each patch. At each site the relative abundance is defined as the average number of crayfish per ten refuges searched (i.e. average per patch).

Unless the monitoring unit is very short in length, the number of stretches to be sampled in a monitoring programme does not depend on the proportion of the total length sampled, but on the likelihood of finding crayfish.

Figure 1. Schematic diagram of monitoring protocol.



Methods used in the field-testing

Field-testing of the protocol described above was carried out in two tributaries of the River Eden in Cumbria, Scandal Beck and the River Lowther. Both are within a SSSI designated for white-clawed crayfish. Scandal Beck is a limestone stream with abundant boulders and cobbles; about 10 m wide and mainly less than 0.5 m deep. The River Lowther drains Pennine moorland in its headwaters and although it has limestone in part of the catchment, it has varied geology and morphology. In its lower reaches it is more than 20 m wide and there are many slow-flowing areas more than 1 m deep, which restricts access for survey to the shallower margins in some stretches.

The aims of the field-testing were to validate the use of the survey method in the field; to determine the variability between surveyors and occasions, and to determine the variability between sites, both on a watercourse with an abundant population and on one where habitat characteristics are varied and conditions are less favourable for surveys.

The variability between surveyors and occasions was tested by a replicate trial. Six 100 m lengths of Scandal Beck were surveyed by four different surveyors on separate occasions. In addition, ten 500 m stretches were surveyed on Scandal Beck, within which 35 sites were surveyed. On the Lowther, ten stretches were surveyed, with 23 sites. Apart from the replicate sessions, surveyors worked in groups of two or three on every site for safety.

Data from the surveys were classified by stretch, site, habitat patch, order (the first or second group of five refuges selected within a habitat patch), day and surveyor. For the analysis of the survey data, each observation consists of a crayfish count per five refuges. These observations have a Poisson distribution, with the log of the mean being modelled as linear in the characteristics described above.

Results

The replicate survey results are summarised in Table 2.

Table 2. Mean counts of crayfish per five stones in the replicate surveys, Scandal Beck.

	Replicate site					
Day	RA	RB	RC	RD	RE	RG
1	5.8	4.8	3.9	5.7	7.1	5.4
2	3.8	4.6	3.4	4.7	4.9	4.0
3	2.2	7.6	1.9	6.3	3.9	9.4
4	2.8	4.3	3.3	3.0	3.6	5.1

In the replicate trial the differences between surveyors made the largest contribution to the variance (see Table 3 below). This was a deliberately extreme test, involving surveyors who were working alone and whose experience of crayfish survey ranged from novice to many years. The surveyor effect can be reduced by having two people working jointly at a site (selecting two or three patches each). It is advisable for surveyors to have some experience of crayfish survey and prior training in the method. The closest correspondence of results from the replicate trial was between the two surveyors who were carrying out most of the survey work elsewhere on the rivers.

Table 3 shows the analysis of the coefficients of variation. The patch and site effects are similar. There is as much variation between individual habitat patches as there is between sites. This is because all the 100 m sites in this watercourse contain a range of habitats, such as riffles, glides and pools. The existence of a patch effect shows that as many patches as practicable should be surveyed. It is far better to sample five patches than to sample the same number of refuges in one large patch. The order effect is minimal. This means that the amount of survey could be reduced to five refuges in five patches if required (25 refuges total). As the biggest component of time in the survey is getting to the survey site, however, there is only a small saving in reducing the number of refuges searched. Hence ten refuges per habitat patch (50 refuges total) is recommended.

For the main surveys the greatest variability is between stretches of the rivers, rather than between 100 m or 200 m sites within a stretch. To obtain an estimate of the distribution and relative abundance of crayfish in a whole river it is more important to sample sufficient 500 m stretches than to survey several sites within a single stretch.

Table 3. Components of variance in the surveys of two tributaries of the River Eden.

Factor (posterior medians of variance)	Scandal Beck, replicate sites	Scandal Beck, all sites	River Lowther, all sites
Day	0.01	0.05	*
Stretch	n/a	2.15	0.35
Site	0.09	0.14	0.08
Patch	0.11	0.05	0.1
Surveyor	0.17	0.18	

n/a not applicable
* day effect corresponds to stretch

The average abundance of crayfish recorded in Scandal Beck was 4.75/10 refuges $\pm$ 1.1 (95% confidence limits, 41 sites). In the River Lowther it was 2.90 $\pm$1.48 (95% confidence limits, 23 sites). Both rivers had healthy populations with less than 3% incidence of thelohaniansis (porcelain disease), a lethal disease in white-clawed crayfish.

Monitoring strategy

The information on the variability of the crayfish populations enables predictions to be made about the number of monitoring sites required for different levels of precision. The number of sites surveyed in the field-testing was intended to be higher than that which might be required as part of a monitoring programme. The number of sites to survey depends on whether the aim is simply to detect the presence of crayfish, or to provide a basis for determining whether the relative abundance changes from one monitoring cycle to the next.

To obtain an estimate of the abundance of crayfish in a monitoring unit, (based on using the survey method outlined above), the number of sites (n) required for a monitoring survey can be calculated for a chosen precision (*x,* where *x* is confidence interval for the abundance, within *x*% of the mean for the monitoring unit):
$n= ((2 \text{ x cv x } 100)/x)^2$.

The coefficient of variation (cv, the ratio of standard deviation to mean) can be calculated from survey data from the monitoring unit, or from surveys of comparable monitoring units.

In most monitoring units it is more effective to omit any stretches with no habitat suitable for manual survey than to carry out a trapping programme. This is so because a relatively large number of traps is required to provide a semi-quantitative measure of relative abundance (catch per unit effort). If trapping is done well, it takes just as much effort to select patches suitable for setting a trap as finding those suitable for manual survey. Travel to the survey site and access to the river bank often take much longer than the survey work itself. This makes trapping more expensive in time and hence cost, as it requires two visits for each survey.

There may be some rivers, however, where the number of 500 m stretches with any areas accessible for manual survey is so low that trapping is the only option. The ability to detect the presence of crayfish and changes in the population will be much less, but trapping surveys may still be needed, especially if there is a requirement to detect the spread of alien crayfish. A draft protocol for trapping has been developed during the project, but has not been field-tested to date.

Refuges used by crayfish

The key features of potential refuges for crayfish are that they are:

- big enough to amply cover the crayfish;
- relatively stable and resistant to high flows;
- in flow that is not too fast for a crayfish to walk in it;
- not too silted.

Foster (1993) showed that the use of refuges is related to body size. This has been confirmed by other studies. Crayfish prefer large refuges to a much greater extent than could be accounted for simply by avoiding predatory fish. In rivers, the ability of refuges to resist movement during spates is an important factor.

Table 4 summarises the detailed preferences of crayfish for habitat features. This provides a guide to recognising habitat patches and individual refuges and hence improve consistency between surveyors. This is based in part on the work of Foster (1995), Smith *et al.* (1996), Naura & Robinson (1998), Holdich & Rogers (2000) and on the field experience of the author. The subdivision of cobble into large and small categories and the guidance on velocity are based on experience from the field-testing (Peay, 2002a). Additional detail on habitat for white-clawed crayfish is given in the protocol and in guidance on habitat for white-clawed crayfish and its restoration (Peay 2002b, 2003).

White-clawed crayfish burrows

One of the features in Table 4 is the strong preference for crayfish for refuges in steep banks with complex structure – areas that normally cannot be searched by manual methods. It is usually difficult to prove whether crayfish are using the banks as refuges, as they cannot be searched manually. It is sometimes possible to observe crayfish emerging from or retreating into refuges in the banks during night-viewing surveys. Crayfish can be seen emerging from refuges when normally submerged banks are exposed during engineering works. In a short section of stream in Leeds, the estimates of crayfish density from a single drain-down of a stream were 4.8 crayfish m^{-2} from a length of bank and 0.5 crayfish m^{-2} from the rest of the channel (Scott Wilson, 1998). Trapping can detect crayfish in rivers that have little habitat accessible for manual survey, but does not show whether the animals are using the banks, or other inaccessible habitat in the channel.

As part of the field-testing in the Eden tributaries the opportunity was taken to confirm the use of refuges in banks. Where in-channel refuges are somewhat limited, white-clawed crayfish make burrows in banks (see also Gerard *et al*., this volume; Tero *et al*., this volume). It has sometimes been assumed that only signal crayfish excavate burrows. At one of the survey sites on Scandal Beck the use of burrows by white-clawed crayfish was conclusively demonstrated. Surveyors carefully reached in an arm to widen individual burrows sufficiently to remove the occupying white-clawed crayfish. These were usually about 0.3 to 0.5 m into the bank. A characteristic of the burrows is that they are distinctively wider (c. 3-7 cm) than high (c.2-4 cm). Dimensions are approximate as the entrances are affected by water action.

Table 4. Crayfish habitat preferences – a guide to identifying habitat patches and refuges.

Crayfish strongly prefer	**more than**	**much more than (or avoid)**
boulders (>25 cm), stone or other material >	large cobbles (15-25 cm) >>	small cobble (6-15 cm)
slow-flowing glides and pools (provided there are refuges) >	riffles >>	high energy areas such as rapids (avoided)
localised velocity of 0.1 m sec^{-1} or less >	less than 0.2 m sec^{-1} >>	more than 0.2 m sec^{-1} (avoided)
boulders or large cobbles in groups with crevices between them >	isolated large stones on smaller substrate such as pebble and gravel >>	a lot of small stone (small cobble and pebble)
deep crevices in bedrock (can't search usually) >	partly flattened boulders and large cobbles >>	high-sided, rounded cobbles (more easily rolled in spates)
underlying substrate of fine gravel/sand with some pebbles >	pebble and coarse gravel >>	clay
loose boulders	>>	deeply bedded boulders in a compacted bed (not accessible to crayfish)
submerged refuges in stable banks (e.g. natural crevices, stone block reinforcement or stable, slightly undercut banks with overhanging vegetation, large tree roots etc.)>	refuges in the slow-flowing margins >	refuges in mid channel (especially if flow is a run or higher energy)
margins next to favourable bankside habitat >	margins where adjacent banks have no scope for refuges (e.g. shallow slopes) >>	margins where adjacent earth banks are slumped and actively eroding

Recording

Details of each survey are recorded on a double-sided field-recording form. Although designed for use in the standard method, it can be used with any of the other survey methods for crayfish. The recording form is given in Appendix 1. There is guidance on how to complete the habitat record and the crayfish record, which make up the recording form, in Appendices 2 and 3. There are four categories of information recorded (Table 5):

- general information about the site, survey and environmental conditions;
- the characteristics of each habitat patch that are most relevant to crayfish;
- details of each crayfish caught, and
- a qualitative assessment of the potential habitat suitability for crayfish in the mid channel, margins and banks, plus an assessment of the accessibility for survey.

Photographs of the site are also taken.

The information on the crayfish is already routinely collected in most surveys. The details on environmental conditions are important as they indicate how favourable conditions were at the time of survey. This is especially important for survey methods that depend on the activity of crayfish (night-viewing and trapping). The information on habitat patches shows the areas of the channel that the surveyors consider to be the most favourable for crayfish and have searched. This will vary between sites and rivers, but comparisons between patch types and sites can be made when required.

Table 5. Summary of features to be recorded in crayfish surveys.

Survey and environmental	Patch	Crayfish	Evaluation
Surveyors, site location, date, start and finish time, temperature, flow conditions, clarity, survey method, general description of the site.	Location in channel, habitat feature (glide, riffle etc.), extent, depth, types of refuges present, substrate beneath, degree of siltation, potential refuges in the bank, shading, number of crayfish.	Species, sex, size, condition (damage, disease, moult, signs of breeding, i.e. eggs, young, old glair strands).	Amount of crayfish habitat (in mid channel, margins, banks), "surveyability".

Surveyors can provide a qualitative estimate of the amount of habitat potentially available in the mid channel, margins and banks of the river. They also give an indication of how readily the site can be surveyed using manual survey. It shows whether there were there many other habitat patches that could potentially have been selected, or most of those that were accessible were sampled during the survey.

Selectivity of the standard method

The size distribution of the crayfish catch provides information about the selectivity of any survey method. Fig. 2 shows the typical size distribution for the standard method. The source data is a series of survey sites from Scandal Beck, a tributary of the River Eden (Peay, 2002a). Data for the other main tributary investigated is similar. In summer surveys there is no significant difference in the number of males and females caught. Size data have been aggregated here for clarity. There is a clear bimodal distribution, with modes at 10 and 24 mm CL (carapace length) respectively. Juvenile crayfish are well represented (over 40% less than 25 mm CL), although the 1+ year class around 10 mm CL is a smaller proportion than occurs in the natural population. This is partly because small crayfish are harder to spot, but mainly because the "best" refuges selected during the survey are more likely to be occupied by larger animals. The survey was carried out in mid July to mid August, when in this northern river many females still had dependent young, hence the 0+ year class is not represented.

Figure 3 shows the size distribution of crayfish sampled in 1x1m quadrats in the same stream in mid August. The sample size is much smaller and hence more variable, but the 1+ crayfish have a slightly higher mode and this is characteristic of fixed area sampling. By contrast, if the same population had been sampled by trapping, the size distribution would be expected to have a single mode between 30 and 40 mm CL. The distribution would tail off sharply, with few animals recorded below 30 mm CL. Trapping provides a small and highly skewed sample of the population.

Limits of detection

The field-testing has shown that surveyors can have a high degree of consistency in identifying suitable habitat, even when it is sparse. Where there is a relatively sparsely distributed population of crayfish, it is most likely to be detected by selecting the areas where conditions are most suitable and refuges for crayfish are abundant. If there is a high density of crayfish and abundant suitable habitat, the proportion of selected refuges occupied by crayfish tends to be higher than at sites where crayfish are present, but the population is small and very patchily distributed.

The lowest recordable level of abundance using the standard method is 0.02, i.e. 1 crayfish from 50 refuges searched, although the probability of finding at least one crayfish if this is the actual abundance is 0.63. The true abundance has to be below 0.014 (1 in 71 refuges) before there is less than 50% chance of finding a crayfish. The lowest actual abundance with a high (90%) chance of recording a crayfish is 0.046 (1 crayfish from 22 refuges). There is only limited information at present about the limits of detection in terms of population density in fixed areas. Nonetheless, initial indications are that it is probably around 0.2 crayfish m^{-2}, based on a bed clearance operation during a crayfish rescue for engineering works (Peay, 2002b).

MONITORING TARGETS

The monitoring protocol is designed for use in assessing whether populations of white-clawed crayfish are in favourable condition. Holdich & Rogers (2000) set out a range of attributes that should be present for a white-clawed crayfish population, including suitable habitat and all of the following characteristics:

- Water quality at GQA Biological class A or B;
- Absence of crayfish plague;
- Absence of alien crayfish;
- Incidence of thelohaniansis (porcelain disease) in not more than 10% of the population.

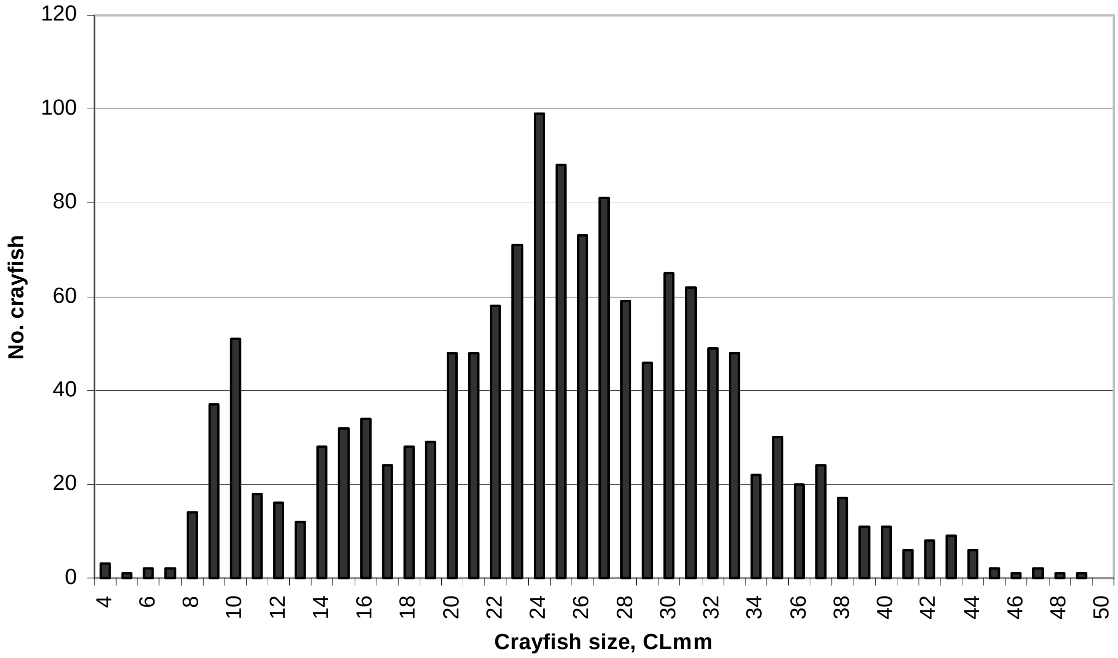
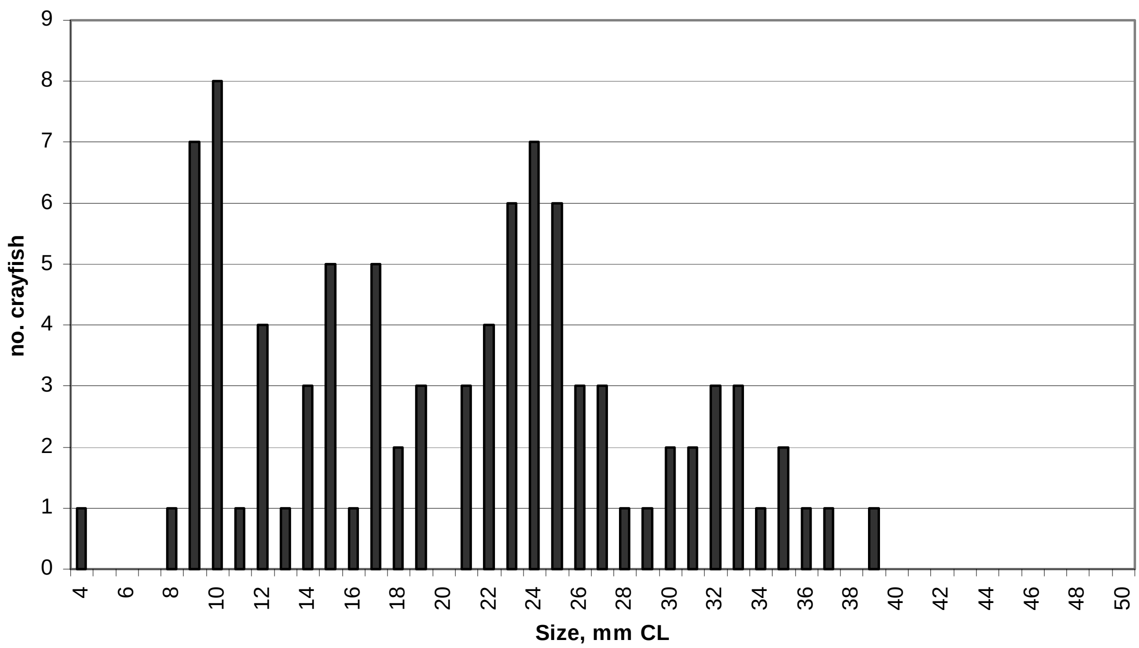


Figure 2. Size distribution of white-clawed crayfish using the standard survey.

Figure 3. Examples of a size distribution of white-clawed crayfish from quadrats.



The impact of thelohaniansis on crayfish populations is not known in detail, but at high rates of occurrence the increased mortality in populations may be sufficient to reduce their viability. Pixell Goodrich (1956) reported on very marked fluctuations in the abundance of crayfish in various English rivers and also recorded differing incidence of infection in streams, up to 19%. She considered the infection to be a possible factor in the almost complete disappearance of crayfish from some areas around Oxford. This was long before the first occurrence of alien crayfish and crayfish plague in the UK.

Preliminary guidance is given below on what may constitute favourable condition based on abundance, from present knowledge in 2002. This should be reviewed and where necessary amended after a full monitoring cycle has been completed on a series of rivers.

- Juvenile crayfish <25 mm CL should be present at all sites in the monitoring unit or reach where crayfish are recorded.
- Using the standard method, the proportion of juveniles (<25 mmCL) from a healthy population is likely to be about 40%. If less than 20% of the population is juvenile this may be due to lower efficiency of survey, or may indicate a problem with recruitment.

As yet, there is not enough information to be able to state what the relative abundance of crayfish is likely to be in rivers of different types. Table 6 sets out a grading scale, based on what is currently known.

Table 6. Preliminary grading of the abundance of crayfish

Ave. no./ 10 refuges (at individual sites and average per monitoring unit)	*Population abundance*
>5	***A: Very high***
>=3, <=5	***B: High***
>=1, <3	***C: Moderate***
>0, <1	***D: Low***
0	***E: Absent or undetected***

Table 6 can be used to grade sites and monitoring units on the basis of relative abundance of crayfish determined from standard surveys.

Not all sampled sites in a monitoring unit will have the same abundance, as this depends on the extent of favourable habitat for crayfish in individual stretches. Clearly, there will always be some sites that have abundance higher or lower than the average for the monitoring unit as a whole. Monitoring units of SSSIs and SACs designated for white-clawed crayfish are likely to have populations with an average of moderate abundance or better, at least within the geographic range of the population in the monitoring unit.

There may be some rivers where the natural limitations of available habitat mean that crayfish never reach the relative abundances found in some of the Cumbrian rivers. Even populations with low abundance may be able to continue indefinitely, in the absence of major threats.

Until at least one monitoring cycle has been completed on a series of rivers, it is difficult to set any definitive levels of change in population abundance that should prompt action. Any threats to the crayfish population will require management action (where feasible). Nonetheless, it is suggested that action may be needed if standard surveys show:

- Crayfish abundance at any sampling site falls by two grades.
- Average crayfish abundance in a monitoring unit falls by one grade.
- There is a significant reduction in crayfish abundance over three or more years in succession at any annually monitored sites.
- The proportion of sampled sites occupied by crayfish in a monitoring unit or reach decreases by 10% or more.

If a reduction in abundance of a population is recorded, there should be an investigation as to why this has occurred. Interpretation of the results will be aided by use of information on chemical and biological water quality, pollution risk, siltation and land use, and risk of transmission of crayfish plague. Increases in relative abundance of crayfish will tend to be due to favourable environmental conditions in a particular year, or underlying natural population cycles (currently unknown). It would be preferable to investigate significant increases in abundance as well as reductions, to improve understanding of factors regulating populations.

CONCLUSIONS

The project has led to the development of a strategic approach to monitoring, which can be used for condition assessment for white-clawed crayfish in river SSSIs and SACs. As part of this, a new survey method has been developed. It is a semi-quantitative, easy for crayfish surveyors to learn and records what is actually surveyed in a rigorous way. This should lead to more consistency between surveys. Additional applications of the survey method include:

- determining the presence and distribution of white-clawed crayfish in unsurveyed watercourses;
- crayfish surveys for ecological assessments of new developments;
- baseline and monitoring surveys before and after engineering works that affect banks or channel;
- monitoring (re-)introductions of white-clawed crayfish;
- detecting the presence and spread of alien crayfish.

Other survey methods will still be required for some conditions, or for intensive studies at individual sites. Every method has its limitations and the survey method presented here is no exception. It aims for a reasonable balance between the need to detect populations effectively and provide semi-quanititative estimates of abundance as consistent as possible, whilst keeping costs as low as practicable.

It is recommended that the standard recording form should be used for all survey methods, even if not completed in every detail (see Appendix 1-3). There is a need for an active and accessible national database of crayfish populations, both native and alien (see Holdich, 2002, this volume). Irrespective of method or survey purpose, consistent recording in a standard spreadsheet format will facilitate data compilation and analysis in future, both locally and nationally.

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Appendix 1. Crayfish Survey Form.

Catchment		River				Site (no., name)			
Date (dd/mm/yy)		Surveyors				Grid ref. (d/s end)			
Weather, good 1, mod 2, poor 3		Flow norm 1, low 2, fall 3, rise 4		Water temp. oC		Clarity, good 1, mod 2, poor 3		Start and finish time	
Photo ref. & Location									
Site length (m)		Descript. (channel features, landuse)							
Width channel (m)									

	sample patch 1	sample patch 2	sample patch 3	sample patch 4	sample patch 5
Survey method, std 1, quad 2, net/kick 3, trap 4, view 5					
Details (if not standard)					
Extent (l x w patch)					
Channel (1 margins, 2 mid, 3 both, other specify)					
Depth (metres)					
Feature (1 marg. d'water, 2 pool, 3 glide, 4 run, 5 riffle)					
Refuges in channel	tick all present in patch, ring main type(s) searched				
cobble (6.5-15cm)					
cobble (15-25.6cm)					
boulder (25.6-40cm)					
boulder (>40cm)					
rubble (give size)					
woody debris					
other urban debris					
tree roots, fine					
moss					
filamentous algae					
other submerged veg.					
emergents					
Main substrate beneath					
bedrock					
cobble (6.5-15cm)					
pebble (<6.5cm)					
gravel (<1.6cm)					
sand (<2mm)					
clay					
silt					
Siltation none					
low					
moderate					
high					
Refuges in bank none					
cobble/boulder					
tree roots, large					
vertical or undercut bank					
dry stone wall					
other reinforced					
crayfish burrows					
Shading above					
Crayfish/10 refuges, or per unit (depending on method)					
Search time					
Bullhead present?					

Evaluation crayfish habitat for whole site (0 none, 1 pres., 2 freq., 3 abund.)	Score
in margins	
in mid channel	
in banks	
surveyability	

Notes (survey conditions, patches etc.):

Catchment			River				Site reference		
Date			Surveyors				Sheet no.		
Record no.	Species	Sex	Carapace length, mm	Damage	Disease	Breeding	Moult	Sub-site location ref.	Catch method
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
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45									

Additional comments:

Appendix 2. Crayfish Survey Form – Instructions for the Habitat Record sheet.

Catchment	name	As defined by Environment Agency or other relevant statutory agency
River	name	As on maps or as defined by statutory agency
Site	reference	Can include number/code, plus a name/description
Date	dd/mm/yy	day, month, year
Surveyors	name(s)	**two or more surveyors recommended for safety**
Grid ref.	OS grid ref	at downstream end, unless otherwise noted; 10 figure, to c. 10m (e.g. NY 7274 0715)
Weather	1 good	dry, fairly bright, not windy
	2 mod.	dry, overcast, may have some drizzle or wind
	3 poor	rain and/or wind, **should avoid survey in these conditions**
Flow	1 normal	no obviously high or low flow conditions
	2 low	parts of banks and bed exposed, reduced width of wetted channel in many areas, may be shallow pools left.
	3 falling	flow conditions are adequate for survey, but flow is reducing after high flow, may have had some rain in past 2 days.
	4 rising	**Do not survey in high or increasing flow.** Record this if conditions were suitable initially, but have any increase in velocity, onset of foam flecks or any rise in level during survey - **recommend end survey now** - safety riskand deteriorating conditions for survey.
Water temperature	degrees C	Affects catch efficiency. Cold conditions, crayfish are deeper in bed, but sluggish so juveniles easier to catch. High temperature, more crayfish active on bed, escape swims very fast - net only. **Always record this for trapping or night-viewing.**
Clarity	good	water clear, visibility to bed good to 50cm depth
	moderate	water largely clear, though may be some suspended solids. Visibility reasonably good to 30cm, but may be more difficult to see clearly at 30-60cm. Or may have to wait longer than usual for bed to clear. Or water is clear, but coloured (e.g. peat-staining) - note this.
	poor	High degree of turbidity/suspended solids, sufficient to make manual searching difficult. Will affect survey efficiency and may need to use other methods, netting, set traps.
Start finish	hh:mm	arrival time at site, at start of session and departure time; option to record time to walk to site in Notes.
Photo ref.	no./ code	No. or other reference, normally at least 1 general photo, optional extras for features. Can detail up to 10 on form. Location: OS grid ref., or brief description (e.g. view u/s from d/s end; refuges in P3).
Site length		Total site length, normally 100m; may be 200m for large rivers. May be less than 100m for intensive fixed area surveys.
Width		approximate width in metres, or can give range
Description		Overall features of the channel, (e.g. proportion/location of glides, riffles); type of banks (e.g. if banks steep, undercut, left bank gently sloping, fringe of emergent vegetation, etc.), land use (e.g. woodland, adjacent pasture, fenced or not)
Survey method		Standard method (1). If other methods used, show in which patches. **Never aggregate number of crayfish caught by different methods.**
	1 standard	selective search of refuges, 10 in each of 5 patches generally. If do more patches continue on a 2nd sheet.
	2 quadrat	complete search of all possible refuges in a small, defined area, may be fully enclosed or open (state which).
	3 net/kick	selective sweep-netting or kick-sampling
	4 trap	crayfish trap, 4A baited trap, 4B unbaited trap, including refuge trap
	5 view	night view, in clear water at night with a torch.
	6 other	electro-fishing, scuba etc., give details

Details	describe	if trap, state type used; (e.g. pyramid trap, 2mm mesh, straight-sided top entry; Swedish trappy, extra 1mm mesh wrapping; refuge trap, 8 no. 30mm tubes). If quadrat give dimensions and whether enclosed or not. Use space in notes section if required.
Extent	metres	give approximate dimensions of each sample patch, may be as little as 1m^2, or up to 10 m length of channel. (l is distance u/s, w is distance at right angles to bank), typically 1-10m^2 in stony streams.
Channel	1 margin, 2 mid, 3 both	Margin, not more than a quarter of channel from left or right bank, or as distinguished by a change in flow type (e.g. mid channel riffle or run may have glide or marginal deadwater in shallow margins); usually within 1-2m of bank.
Depth	metres	average in habitat patch surveyed, or can give range
Feature		Terms as in RHS. Can also record if canal, A; pond <0.1ha, B; pond/lake >0.1 ha, C. Can add E to 1 or 3 to indicate that this margin is next to higher energy flow., e.g. 3E is a glide at the edge of a run or riffle
	1	marginal deadwater; in margin, no discernible flow, or only slight upstream eddy
	2	pool; no obvious flow, deep water, extends across most of width of channel.
	3	glide; visible flow, but no waves or surface disturbance, except possible ripples around exposed rocks.
	4	run; faster than a glide, surface has rippled surface, but little turbulence, may get a few small waves around stones, but minimal. Typically upstream of a riffle, or where channel narrows and speeds flow.
	5	riffle; shallow fast-flowing water with a disturbed surface and mainly unbroken standing waves on the surface, a feature with relatively high energy of flow. (Don't record as riffle if just due to submerged plants).
	6	Rapid, has whitewater broken standing waves, normally over cobble, boulder or bedrock, with a steep gradient; high energy (seldom suitable for crayfish or survey or both). (Traditionally might have been classed as steep riffle).
Refuges		Tick all refuges in the channel present in the habitat patch. Ring main type(s) searched.
	cobble	Large cobble 15-25cm is preferred, especially in high/moderate energy watercourses. Small cobble 6-15cm will be used only by small crayfish, if at all.
	boulder	Do not haul out deeply bedded boulders. **Safety - be careful handling large stones**.
	rubble	any loose construction materials, 15cm and larger, e.g.concrete or brick Give typical size of material.
	woody debris	trees, logs, branches and other flood debris in the channel
	other urban debris	anything manmade offering a potential refuge, (e.g. old tyre, traffic cone, large can, supermarket trolley full of leaf litter, etc.)
	tree roots, fine	underwater tree roots; fine, matted, e.g. alder. (Note: large roots in banks are in Bank features)
	moss	record only if extensive enough to provide a refuge,(e.g. abundant swathes of Fontinalis)
	filamentous algae	record only if extensive, e.g. on trailing from rocks or in patches on bed (ignore minor "fuzz" on rocks, but make comment in notes if this affects visibility or may indicate a problem).
	other submerged	submerged vegetation, any other type, (Ranunculus spp., Callitriche spp., Potamogeton spp.etc.), if sufficiently dense to provide a refuge.
	emergents	rooted emergents, (e.g. Rorippa, Phragmites, Carex, Petasites etc.)
Main substrate beneath	standard types	cobble 6.5-15 cm, pebble<6.5cm, gravel <1.6cm, sand <2mm, clay sticky solid surface, silt "silky" deposited. Search efficiency will be poor if cobble layer present beneath, also lower if bed is silt or clay. **Search everything, down to fine material or solid bed if possible - crayfish may be under small cobble/pebble under a boulder.**
Siltation	none	None. Organic material if present is coarse leaf litter, no accumulation of silt on surfaces
	low	A little silt trapped in moss/algae on stones; refuges clear, e.g. only some leaf litter, or clearing before crayfish can wander off.

	moderate	usually abundant algae on stones or bed, with silt or other fines clouding water when moved, but clearing slowly. May be a little silt below stones. Need to wait longer to view under refuge, but can still see crayfish if present.
	high	Silt cover on all surfaces and some in refuges. May be a soft suspended layer just above bed in deadwater, very slow to clear and may not settle sufficiently for effective survey (crayfish wander off). If lots of suspended silt present, probably unsuitable for crayfish. (If deadwater too silty may need to survey in glides or faster water only)
Refuges in bank		Potential refuges, submerged or usually so at normal flow, with crevices for crayfish - in/adjacent to the sample patch. Omit this if the patch is mid channel only.
	none	none evident, e.g. shallow sloping bank, poached, active erosion, inaccessible reinforcement
	cobble/ boulder	in margins and projecting from bank in water
	tree roots, large	usually associated with undercut banks, projecting roots often forearm thick or more
	vertical or undercut bank	will usually be relatively stable, tend not to have collapsed toe, or if so it is normally submerged. Vertical banks may be bare or have some vegetation. Slightly undercut below water, with overhanging vegetation is favourable.
	dry stone wall	bank reinforced with unmortared stone
	other reinforced	if suitable, providing submerged crevices for crayfish. Less likely to be suitable if there is adjacent fast flow. Describe in notes.
	crayfish burrows	Holes in earth banks, usually submerged, but may be exposed during low flows. White-clawed burrows usually 2-6cm wide, smaller than rat or water vole holes. Characteristically wider than high, though old ones may be eroded more. Burrows often hidden in undercut banks under vegetation. Signal crayfish burrows often larger, also deeper and more extensive. Note if signals causing slumping of banks.
Shading above		any type of canopy cover from trees or shrubs (>33% of this habitat patch with canopy above).
Crayfish		Record no. crayfish caught in 10 refuges, plus escapes if reasonably sure not caught subsequently (or total for equivalent sampling unit, e.g. fixed area, per trap or pair of traps, etc.).
Search time		record time spent searching, excluding survey notes and processing catch
Bullhead present?		**Optional.** May want to record bullhead, which use same habitat at crayfish. Could note presence, or do count per 10 refuges.
Evaluation of crayfish habitat for whole site	abundance code	Score separately for **margins** (area with visibly different flow to mid channel, or up to 1/4 channel width both sides), **mid channel** (consider stream energy and consolidation, mid channel stone may be too bedded to provide refuges)and **banks** (optionally, can score separately for now/summer - N, and normal winter conditions - W)
	0	**not evident, or only minimal potential for refuges**
	1	**present, but localised or sparse, in less than a third of site**
	2	**frequent, covering more than a third of site, or frequent, but small patches**
	3	**abundant. Potential refuge habitat continuous, or semi-continuous, along more than two thirds sample site.**
	?	Can use/include query if not sure of evaluation, (e.g.can't see well or probe)
Surveyability	**0**	**either can't access for manual survey, or fewer than 10 searchable refuges**
	1	**difficult finding sufficient patches, 2 or more considered only moderate or poor potential; or searched more than two thirds accessible refuges.**
	2	**likely 1 to 5 more patches worth surveying, could extend surveyed patches**
	3	**could survey at least 5 more patches similar/equivalent**
Problems		1: signs of pollution, (e.g. septic tank discharge, slurry, etc.) 2: poaching, heavy trampling of banks and stream with bare ground, erosion. Add E if extensive part (>33%) of sample site affected. **If pollution present inform relevant agency.** Give details. Aliens 3. Will record separately, but flag it here too.

Notes		Additional notes on features, or survey. Detail any limitations of the survey (e.g. surveyed from right bank only; too deep in 70m length; peat-staining reduced visibility in water over 0.3m). Include notes on patches or other relevant observations (e.g. abundant moss litter under boulders in P2 and P3; otter spraint on mid channel boulder, eels in patches 1-3; P2 shallow deadwater next to riffle, looked unpromising, but frequent juveniles under exposed mossy boulders, P4 deep cobble/pebble under boulders, reduced efficiency, etc.) Continue on separate sheet if required, ensure have site ref and date.

Appendix 3. Crayfish Survey Form – Instructions for the Crayfish Record Sheet.

References	Catchment, river, site reference, date and surveyor are as on habitat record. **Site ref. and date must always be included** to ensure records are correctly attributed.
Heading	**Sheet no.** - use e.g. 1 of 2 if have more than 45 crayfish recorded at this sampling site
Heading	**Species**
AP	**Austropotamobius pallipes**, white-clawed crayfish
PL	**Pacifastacus leniusculus**, signal crayfish
AL	Astacus leptodactylus, Turkish or narrow-clawed crayfish
AA	Astacus astacus, noble crayfish
PC	Procambarus clarkii, red swamp crayfish
OL	Orconectes limosus, spiny-cheek crayfish
U	**unconfirmed**, can be used temporarily until identification of alien species is checked.
Heading	**Sex**
F	**female**
M	**male**
N	juvenile, 0+ **not** distinguishable
X	**escaped** crayfish, not identified
Heading	**Carapace length**
	Carapace length, to nearest mm, **from tip of rostrum to junction of carapace and tail**. **Do not use total length** (i.e. head to end of tail).
J	**juvenile**, escaped, estimated size <25mmCL (have option to estimate size in more detail e.g. J c.10-15mm)
A	**adult**, escaped, estimated size >25mmCL, (have option to estimate size in more detail)
Heading	**Damage,** record injuries (**optional**, damage need not be recorded)
MR	**missing right** cheliped (large front claw)
ML	**missing left** cheliped
MB	**missing both** chelipeds
RR	**regenerating right** cheliped (noticably smaller than other one)
RL	**regenerating left** cheliped
RB	**regenerating both** (both chelipeds noticably small for the size of crayfish
AR	**antenna** damaged or missing, **right** side
AL	**antenna** damaged or missing, **left** side
OM	one or more **other** limbs **missing** or damaged
OI	**other injury**, e.g. cracked shell (sign of attack by predator, such as heron, or rarely damage during manual survey)
Z	**dead** crayfish, note if porcelain disease or plague in next section, otherwise add note in additional comments on cause of death if known. **NOTE: crayfish may have died outside survey area, keep separate from other results and omit from total catch.**
Heading	**Disease**
PD	**porcelain disease**, Thelohania. Underside of tail is opaque white, instead of translucent. **Always record this**.
BS	**burnspot disease**, discoloured patch(es) on exoskeleton, usually dark brown or black in centre and reddish at rim. Looks like rust. Exoskeleton may be perforated. More likely if crayfish is injured.
CW	**crayfish worms**, Branchiobdellans. Attached to surface of crayfish, usually 1mm to a few mm long, white or off-white colour, not parasitic.
CP	**crayfish plague**, Aphanomyces astaci- see notes. Abnormal behaviour, stiffness in joints, dark patches at junction of legs and tail. **WARNING -take immediate action if suspected and disinfect all gear.**
Heading	**Moult (optional)**
	Intermoult, need not be recorded
BM	Pre-moult (**before moult**), crayfish usually dark and has noticable separation of epidermis from exoskeleton, carapace deforms easily
MM	Moult, (**mid moult**) crayfish feels soft, like gelatin. Only last a few hours.

AM	Post-moult (**after moult**). Light, clean appearance. Post-orbital ridge and cervical groove easily bent. Carapace often feels leathery.
Heading	**<u>Breeding condition (optional)</u>**
B	**berried** female, carrying eggs.
Y	female carrying **young. WARNING! - handle with care**, tail flicking may lead to loss of young. Keep tailed tucked round young and minimise handling.
GS	female has old **glair strands**, former attachments for eggs, look like thick brown threads. If in summer, indicates has bred, if in winter or spring means was infertile or lost eggs.
G	female has new **glair** forming, whitish secretions at the edges of the tail sections, in autumn only, indicates coming in to breeding condition.
S	female has **spermatophore** attached, white mass, only immediately after mating in autumn, rarely seen.
Heading	**<u>subsite location ref.</u>** Optional, can be used to indicate position of crayfish within a sampling site, e.g. in which patch found (P3, P4 etc.). Could also be used in conjunction with habitat codes if required, or other references.
Heading	**<u>Catch Method</u>** **NOTE: catches by different methods should be recorded here and totalled separately, NOT aggregated for the sampling site**
1	Manual, **selective search of refuges** i.e. the standard method, (or a selective timed search if used)
2	Manual, by **quadrat** other fixed area; full systematic search of refuges in a defined area of bed.
3	**Netted** in vegetation or other refuges, by sweep-netting or kick-search
4A	**Trap**, **baited**, any type
4B	**Trap, unbaited**, any type, offers refuge
5	**Night-view**, i.e. survey by torchlight
6	**Electro-fishing**, i.e. usually as incidental records during fisheries survey
Heading	**<u>Additional comments</u>** Can be used to note, e.g. cause of crayfish death if known; evidence for crayfish presence, e.g. " 2 moulted carapaces found" at a site with few or no crayfish recorded; more details on location, e.g. "P4 breeding females all found under large boulders beneath low canopy" observations of behaviour, e.g. "crayfish 7 seen feeding on moss", "nos. 2 and 3 seen in threat display", "7 crayfish under 2 adjacent refuges, may be feeding on dead crayfish" , etc.
Extra	If doing capture mark recapture study, have an option to either replace record no. or location reference with mark details, or add a column to the right

THE DISTRIBUTION OF CRAYFISH IN BRITAIN

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ABSTRACT

This paper describes the distribution of crayfish in mainland Britain for the period 1997 to 2003, presenting available data for England, Wales and Scotland in the form of 10-km square maps. The distribution of the single indigenous crayfish species (ICS) *Austropotamobius pallipes* is compared with that of the five non-indigenous crayfish species (NICS) known to frequent British waters (*Astacus astacus, Astacus leptodactylus, Orconectes limosus, Pacifastacus leniusculus* and *Procambarus clarkii*). In addition to the above maps, the distribution of ICS and NICS across England and Wales is also shown according to a catchment based classification scheme.

The paper serves to update aspects of the work published by Sibley *et al*. (2002), but includes records for Scotland in addition to England and Wales and examines the combined distribution of all five NICS rather than just *P. leniusculus*. The latter alteration was made since all NICS offer a threat to ICS, whether by direct competition or transfer of disease.

Should the current trend in the decline of *A. pallipes* continue, the species faces possible extinction in Britain within approximately 30 years. The distribution of NICS could be expected to double over the next 15 years. These forward projections are based on certain assumptions, which may in fact be flawed, however, they underline the importance of continuing to practice and develop measures necessary for the management of crayfish in Britain if we are to conserve the native species in this country.

Keywords: distribution, crayfish, Britain, decline, extinction

INTRODUCTION

The importance of reliable distribution information is crucial to the formulation and management of strategies for the conservation of indigenous crayfish species (ICS). This truth applies, no matter what the guiding political or geographical constraints, and is as relevant to pan-European initiatives such as CRAYNET (Holdich, this volume; Reynolds & Souty-Grosset, this volume), as it is to national policy (e.g. DEFRA, 2003) or local initiatives (e.g. Spink & Rowe, this volume).

At a national level, the recently published government working group report (DEFRA, 2003) made a number of key recommendations "…to limit the ecological and economic impact of invasive non-native species in Great Britain". The importance of monitoring the status of non-native species (such as the non-indigenous crayfish species (NICS)) is recognised, as is the recommendation to support the development of national and international monitoring networks.

In line with these recommendations it has been agreed that the records collected during the preparation of this and the previous paper will be forwarded to the Biological Records Centre, where they will be screened and entered onto the National Biodiversity Network (NBN) (Harding & Cooper, this volume; Oldaker, this volume).

This paper serves to highlight the changing status of ICS and NICS at national and regional levels in Britain. It is hoped that the data made available on the NBN will contribute to the conservation and management of specific crayfish populations at the local level.

10-KM SQUARE DISTRIBUTION

Records were mapped according to presence within 10-km squares of the Ordnance Survey National Grid for Britain. The lines on the maps indicate the Scottish/English border and the regional boundaries of the eight Environment Agency regions for England and Wales.

The distribution of the single ICS, *A. pallipes,* in Britain during the period 1990-1996 inclusive is shown in Fig. 1 (see Table 1 for a breakdown of results). *A. pallipes* was reported to be present in 298 10-km squares during this period. The actual distribution was likely to have been somewhat higher than shown since apparently long-established populations have subsequently been discovered during targeted survey work in various parts of the country (e.g. the North and Midlands of England). The English North East and Midlands were most densely populated (68 and 65 squares respectively), together accounting for nearly 45% of occupied 10-km squares in the whole of Britain during this period.

Since 1997 the distribution of *A. pallipes* has declined (Fig. 2), falling to 256 10-km squares during 1997-2003 inclusive, a fall of 14% nationally. This decline is actually less than the fall of 20% reported for the period 1997-2001 by Sibley *et al.* (2002). Extending the reporting period by two years has resulted in the addition of 22 “new” records. In practice it seems likely that these populations were already present but previously undetected, perhaps due to low density or the absence of any targeted survey work. It follows that other currently undetected populations of ICS and NICS are also present in Britain.

The distribution of NICS during 1990-1996 is shown in Fig. 3. These species were recorded in 189 10-km squares across Britain during this period, and were most widely distributed in Thames, Anglian and South West regions (49, 41 and 41 squares respectively). Together these accounted for 69% of all occupied 10-km squares.

Since 1997 the recorded distribution of NICS has increased (Fig. 4), with populations found in 300 10-km squares during the period 1997-2003, a rise of 59% nationally. Thames, Anglian and South West regions were again densely populated (70, 56 and 56 squares respectively) accounting for 61% of the total number of occupied 10-km squares. However, the greatest relative percentage increases in NICS were seen in the North East and Midlands of England and in Scotland (129%, 178% and 150% increases in occupied 10-km squares respectively).

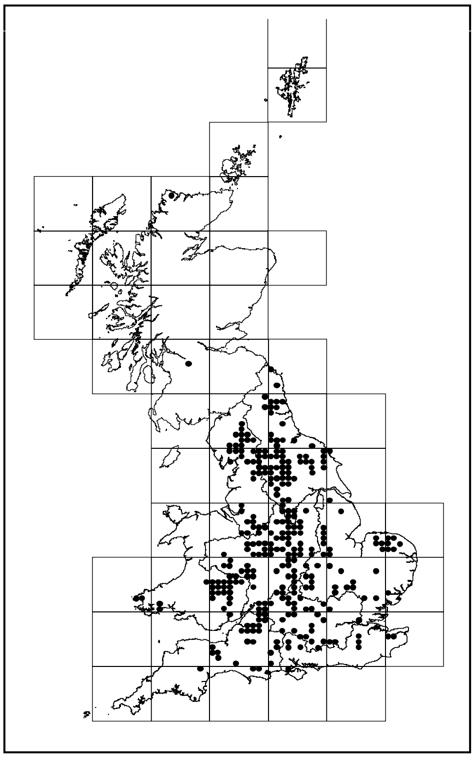

Figure 1. Distribution (by 10-km square) of ICS (*Austropotamobius pallipes*) in Britain based on records for 1990-1996 inclusive.

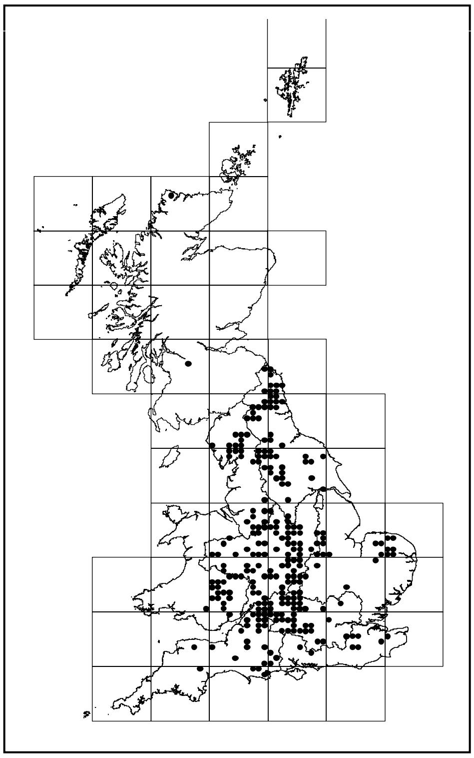

Figure 2. Distribution (by 10-km square) of ICS (*Austropotamobius pallipes*) in Britain based on records for 1997-2003 inclusive.

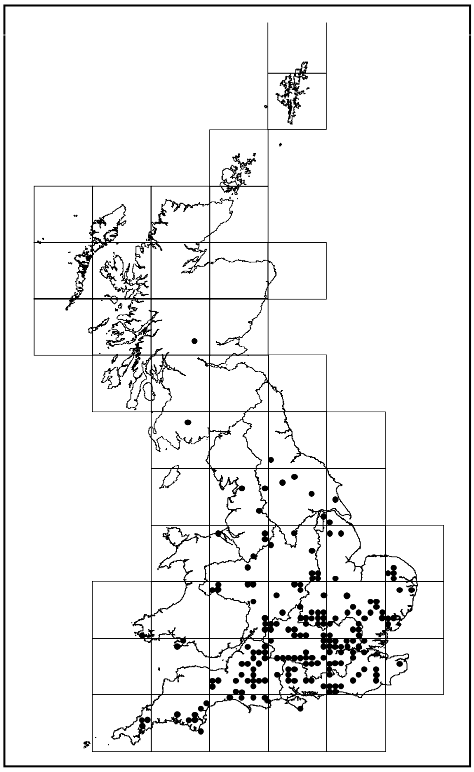

Figure 3. Distribution (by 10-km square) of NICS in Britain based on records for 1990-1996 inclusive.

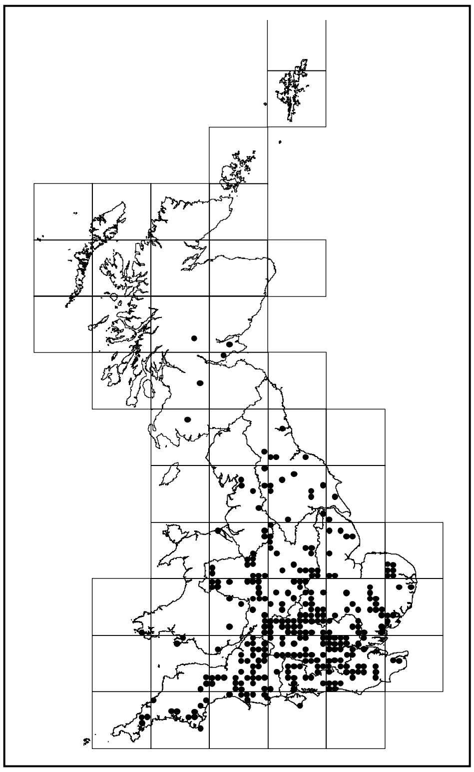

Figure 4. Distribution (by 10-km square) of NICS in Britain based on records for 1997-2003 inclusive.

Table 1. Regional distribution (by 10-km square) of ICS and *NICS (in italics)* in Britain based on the periods 1990-1996 and 1997-2003 inclusive.

	(a)1990-1996		(b)1997-2003		Net change (a to b)	
REGION/COUNTRY	**No. 10-km squares**	**% of total**	**No. 10-km squares**	**% of total**	**No. 10-km squares**	**overall (%)**
ANGLIAN	38 *41*	13 *22*	24 *56*	9 *19*	-14 *+15*	-37 *+37*
MIDLANDS	65 *18*	22 *10*	68 *50*	27 *17*	+3 *+32*	+5 *+178*
NORTH EAST	68 *7*	23 *4*	53 *16*	21 *5*	-15 *+9*	-22 *+129*
NORTH WEST	32 *5*	11 *3*	24 *8*	9 *3*	-8 *+3*	-25 *+60*
SOUTHERN	9 *22*	3 *12*	9 *31*	4 *10*	0 *+9*	0 *+41*
SOUTH WEST	24 *41*	8 *22*	24 *56*	9 *19*	0 *+15*	0 *+37*
THAMES	34 *49*	11 *26*	32 *70*	13 *23*	-2 *+21*	_6 *+43*
WELSH	26 *4*	9 *2*	20 *8*	8 *3*	-6 *+4*	-23 *+100*
SCOTLAND	2 *2*	1 *1*	2 *5*	1 *2*	0 *+3*	0 *+150*
TOTALS	298 *189*	100 *100*	256 *300*	100 *100*	-42 *+111*	-14 *+59*

Sources of data: Holdich & Rogers, 1997; Maitland *et al.*, 2001; Sibley *et a.l*, 2002; P. Collen, pers. comm.; Environment Agency B4W database and numerous Environment Agency contacts.

Figure 5 plots the number of 10-km squares in Britain occupied by ICS and NICS between 1970 and 2003. It is possible to calculate forward projections from this data using lines of best fit, where y = distribution (number of 10-km squares), as follows:

ICS: y = 0 x 10-km squares in +31 years

NICS: y = 600 x 10-km squares (approx. 2 x present distribution) in +15 years

These projections will hopefully stimulate discussion about the level of action required in order to try and safeguard the future of *A. pallipes* in Britain. However, they should be treated with a degree of caution for the following reasons:

The lines of best fit from which the projections are calculated are based on relatively few data points. The projections also assume that current trends will continue forwards without significant deviation from the lines of best fit.

For both ICS and NICS it would seem likely that additional, currently undetected but well-established populations are present in Britain. As any such populations are discovered so these 'new' records would influence the apparent trends in decline/increase illustrated in Fig. 5.

In addition to these points, a number of external factors raise certain questions about the assumption made above – see conclusions below for further comment.

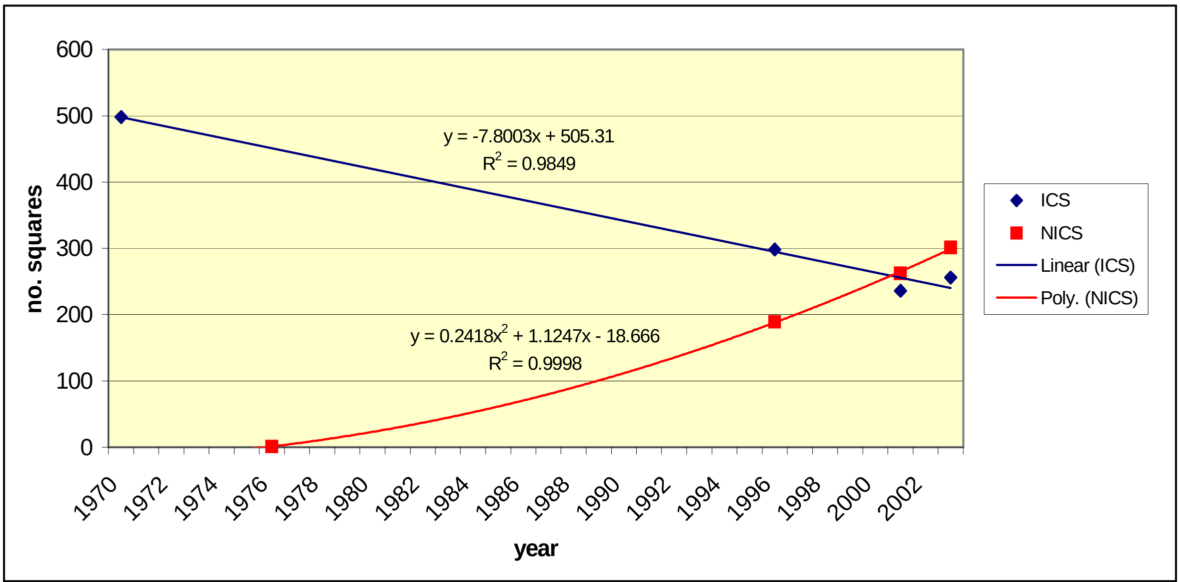

Figure 5. Graph showing number of 10-km squares in Britain occupied by indigenous and non-indigenous crayfish species (ICS and NICS) from 1970 to 2003.

Estimate of number of 10-km squares occupied by ICS in 1970 obtained from Holdich *et al.* (1999).

NICS first introduced to Britain in 1976.

Forward projections were calculated using lines of best fit (linear regression for ICS and polynomial regression for NICS) as follows:

ICS: y = 0 squares in +31 years. NICS: y = 600 squares in + 15 years.

CATCHMENT CLASSIFICATION

One hundred and twenty-nine (129) designated catchment areas across England and Wales were classified according to the relative abundance of ICS and NICS present during the periods 1990-1996 (Fig. 6) and 1997-2003 (Fig. 7) inclusive. There was (and is) great variation in the density of records and crayfish populations present between catchments. Some may therefore be classified as a result of relatively small populations that were, or still are, confined to limited geographical areas (e.g. stillwaters or restricted reaches of rivers or streams). Others may be similarly classified on the basis of a much wider local distribution.

Catchment category descriptions

Each of the catchment areas were allocated one of the following categories:

A (BLUE) Catchments with widespread or locally abundant populations of ICS. NICS absent.

B (PALE ORANGE) Catchments with a limited spread of NICS (including crayfish farms) and widespread or locally abundant populations of ICS.

C (DARK ORANGE) Catchments with widespread or locally abundant populations of NICS (including crayfish farms) and a limited spread of ICS.

D (RED) Catchments with populations of NICS only (including crayfish farms). ICS absent.

E (WHITE) No confirmed crayfish records.

Net changes in catchment category are summarised as follows:

	1990-1996	1997-2003	Net change
Category A (ICS only)	24	12	-12
Category B (ICS & few NICS)	32	25	-7
Category C (NICS & few ICS)	26	30	+4
Category D (NICS only)	16	32	+16
Category E (No crayfish)	31	30	-1

The updated map for 1997-2003 inclusive (Fig. 7) shows an overall decline in the number of catchments containing populations of *A. pallipes* only, with 12 fewer than in the previous period from 1990-1996 (Fig. 6). By contrast, there was an increase in the overall number of catchments where NICS only were present, with 16 more in 1997-2003 than were recorded in 1990-1996.

Explanatory note on the maps

The distribution updates are based on records provided by Environment Agency scientists and on data from the Agency's national freshwater invertebrate database (B4W). The majority of records were collected during field surveys undertaken by Agency workers or licensed contractors using accepted survey techniques (e.g. kick sampling, hand searching, night survey and trapping). Records collected in this way and recorded by a designated Agency scientist were deemed to be genuine and are reported here as confirmed records.

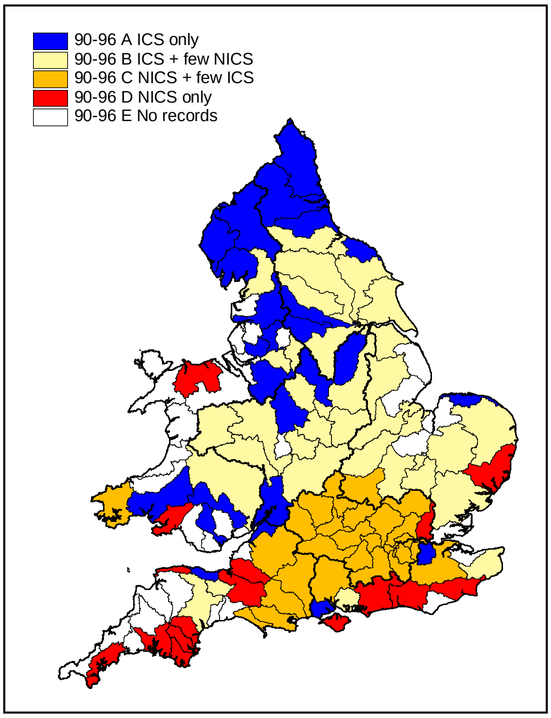

Figure 6. Crayfish distribution in England and Wales by catchment area classification, 1990 -1996 inclusive (modified from Holdich & Rogers, 1997).

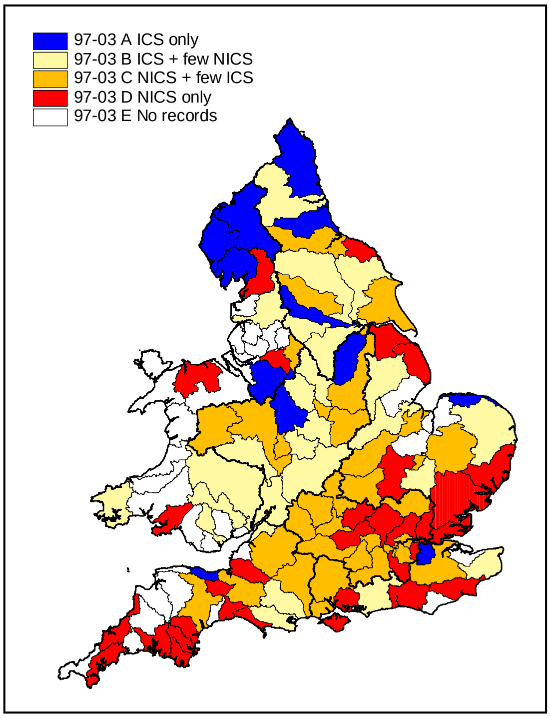

Figure 7. Crayfish distribution in England and Wales by catchment area classification, 1997- 2003 inclusive.

CONCLUSIONS

There has been a decline in the distribution of native crayfish in mainland Britain during the period 1997-2003 compared to the preceding period 1990-1996. Should the current rate of decline, measured according to presence within 10-km squares of the national grid, continue unchecked, the species faces possible extinction in this country within approximately 30 years, and the fears expressed by Hiley (this volume) will become reality.

Non-indigenous crayfish species have increased their distribution during 1997-2003 compared to 1990-1996. The relatively large increases in the distribution of NICS in the North East and Midlands of England are of particular concern given the historical importance of these areas to *A. pallipes.* Similarly, their increased distribution in Scotland, although from just two to five 10-km squares (P. Collen, pers. comm.), is also of concern despite the fact that *A.*

pallipes is only known from two locations in the country (Maitland *et al.*, 2001). The potentially damaging impact of NICS (in this case *P. leniusculus)* on local ecological and economic interests (e.g. salmonid spawning areas) could clearly have serious implications for the future. In terms of Britain as a whole, a sustained rate of increase would see the distribution of NICS double in the next 15 years.

The forward projections were calculated using lines of best fit under the assumption that current trends will continue without significant deviation. This assumption is potentially flawed since a series of unknown factors are likely to come into play and raise the following questions:

ICS: Will the mechanisms causing decline continue to produce the linear regression seen in Fig. 5? For example, how will new encounters between expanding or introduced populations of NICS and resident populations of ICS (which subsequently lead to the local extinction of the latter) increase or decrease in frequency in the future?
As the distribution of NICS increases will the occurrence of crayfish plague outbreaks increase (see Holdich, this volume)?
What impact are changing environmental parameters such as water quality and habitat destruction (or improvement) having on local populations?

NICS: Is there enough as yet unoccupied habitat suitable for populations of NICS to colonise in line with the predicted polynomial regression over the next 15 years?
Will the number of deliberate and accidental introductions and 'natural' range expansion sustain the projected increase in distribution?

Consideration of these questions raises one potential management option for the conservation of *A. pallipes,* which would seem likely to slow its rate of decline. Namely to increase both the protection and distribution of isolated populations of *A. pallipes* which should then be less vulnerable to both direct competition from NICS and to the possible transfer of disease.

The catchment classification system is based on the same data (for England and Wales) as the 10-km square distribution maps. Whilst the presentation of results in this way is somewhat subjective, it does serve to highlight the presence of (even restricted populations of) NICS, particularly those in ecologically sensitive catchments. In general terms NICS are shown to have strengthened their position in the south of England and at the same time have made considerable advances northwards into the remaining strongholds of *A. pallipes*.

Large and seemingly healthy populations of *A. pallipes* still exist in many British waters in 2003, but however the results of this study are presented, it appears that what happens in the next 10-15 years could be crucial to the long-term survival of the species in mainland Britain. The management of selected populations of *A. pallipes*, perhaps including a programme of targeted relocations and re-introductions, represents one potential option for the conservation of the species. At the same time the need for an effective tool for the management of NICS is now as important as ever, and it is to be hoped that further research in this field (e.g. Stebbing *et al.*, this volume) will eventually present a viable method of control.

The fact remains that a co-ordinated programme of monitoring and regular distribution updates are required to best inform the development of local management options and of national and pan-European conservation strategies.

ACKNOWLEDGEMENTS

The catchment classification scheme is based upon work originally presented by Holdich & Rogers (1997) in their strategy for the management of *A. pallipes*. The author is grateful to all those who supplied new records, including Peter Collen for information on the situation in Scotland, and to David Holdich for reviewing the draft text.

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BIBLIOGRAPHY OF BIOLOGICAL AND ECOLOGICAL STUDIES ON CRAYFISH IN THE BRITISH ISLES

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ABSTRACT

A bibliography of scientific papers, selected reports and reviews that are relevant to indigenous and non-indigenous crayfish in the British Isles, as well as diseases such as aphanomycosis and thelohaniasis is presented. MSc and PhD theses are not listed, and papers that are strictly biochemistry and physiology are excluded.

Keywords: crayfish, ecology, diseases, British Isles, bibliography

INTRODUCTION

Bibliographies of studies relating to indigenous and non-indigenous crayfish (ICS and NICS) in the British Isles are given in Holdich & Rogers (1997, 2000). There follows an updated bibliography relating to those studies on biology and ecology, including diseases, but excluding pure biochemistry and physiology.

Although papers on crayfish are scattered throughout the literature Holdich & Lowery (1988), Gherardi & Holdich (1999), Rogers & Brickland (2000), and Holdich (2002) are particularly good sources of information, as are the proceedings of the International Association of Astacology conferences, *Freshwater Crayfish* (Volumes **1-13**), and the French journal, *Bulletin Français de la Pêche et de la Pisciculture*, particularly volumes **281** (Vigneux, 1981), **347**(4) (1997), **356**(1) (2000), **361** (2001), and **367**(4) (2002) (Souty-Grosset & Grandjean, 2002) (the majority of papers are in English). *Freshwater Crayfish* can be difficult to get hold of unless you are a member of the IAA (contact the author of this paper for details about joining). All 13 volumes published so far are held in the George Green Library at the University of Nottingham, but can only be examined there. Volume 10 includes a bibliography of all papers in Volumes 1-10 by volume and by author (Holdich & Pearce-Higgins, 1995).

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SECTION 2. CONSERVATION OF *AUSTROPOTAMOBIUS PALLIPES*

A BRIEF OVERVIEW OF THE LEGISLATION COVERING INDIGENOUS AND NON-INDIGENOUS CRAYFISH IN THE UK

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ABSTRACT

Legislation covering both indigenous and non-indigenous crayfish in the UK is summarised. The indigenous white-clawed crayfish, *Austropotamobius pallipes*, is covered by European and national laws. Three non-indigenous crayfish are covered by national laws in the UK.

Details are given of the licensing procedures for surveying and conservation of the white-clawed crayfish in the UK. Crayfish are considered to be 'fish' from the point of view of the Salmon and Freshwater Fisheries Act (1975). Consequently, a Crayfish Removal Byelaw is currently under review, which will be used to regulate the removal of all species of crayfish from waterways using traps (fixed engines). Consent is also required under Section 30 of the Act to introduce crayfish into any inland water, except fish farms.

Keywords: crayfish, indigenous, non-indigenous, legislation, UK

INTRODUCTION

The only crayfish indigenous to Great Britain is the white-clawed crayfish (*Austropotamobius pallipes*) (see Holdich, this volume). This species is endangered across much of its range and has been given protection under both international and national nature conservation legislation.

The number of white-clawed crayfish in the UK has declined due in part to issues such as habitat degradation, pollution and disease (notably crayfish plague). The main threat currently facing the indigenous white-clawed crayfish in the UK is the increasing spread of the non-indigenous crayfish species, particularly the signal crayfish (*Pacifastacus leniusculus*) (see Hiley, a, this volume; Sibley, this volume). Non-indigenous crayfish are now subject to various legislative constraints in order to control further feral crayfish entering the wild.

This paper summarises the main legislative provisions relating to indigenous crayfish and the legal provisions relating to non-indigenous species. It is clearly essential for anyone working with either indigenous or non-indigenous crayfish to be fully aware of the all the relevant legislative provisions.

WHITE-CLAWED CRAYFISH - EUROPEAN LEGISLATION

Bern Convention

The Convention on the Conservation of European Wildlife and Natural Habitats was adopted in Bern on 19 September 1979 and came into force on 1 June 1982. Its main objectives were to conserve wild flora and fauna and their natural habitats and to give a particular emphasis to endangered and vulnerable species. *Austropotambius pallipes* is listed on Appendix III of the 1979 Bern Convention. This requires signing parties to ensure that any exploitation of the species is regulated in order to keep the populations out of danger.

EC Habitats and Species Directive

In 1992 the then European Community adopted Council Directive 92/43/EEC on the conservation of natural habitats and wild fauna, known as the Habitats Directive (EEC 1992). This is an important piece of international wildlife legislation, intended in part to provide member states with a mechanism to meet their obligations under the 1979 Bern Convention. The Directive includes a range of measures including conservation of features in the landscape that are important for wildlife, the protection of species listed in the annexes from damage, destruction or over-exploitation, and the surveillance of natural habitats and species. The Directive requires the establishment of a European network of important high quality conservation sites that will make a significant contribution to conserving the habitats and species listed in Annexes I and II of the Directive. The white-clawed crayfish is listed under Annexes II of the Habitats Directive and therefore requires member states to designate Special Areas of Conservation (SACs) for this species. This aspect of the Directive is implemented in the UK via the provisions of the Habitat Regulations 1994.

The white-clawed crayfish is also listed on Annex V of the Habitats Directive, which means that Member States should take measures to ensure that the taking of white-clawed crayfish in the wild, as well as their exploitation, is compatible with their being maintained at a favourable conservation status. This aspect of the Directive was implemented via Statutory Instrument No. 288 in 1998 that added white-clawed crayfish to Schedule 5 of the Wildlife and Countryside Act as far as it related to taking from the wild and in respect of sale.

WHITE-CLAWED CRAYFISH - UK LEGISLATION

The Conservation (Natural Habitats, &c.) Regulations 1994

These Habitats Regulations implement the requirements of the Habitats Directive for white-clawed crayfish as far as it relates to the establishment of designated Special Areas of Conservation (SACs) as part of the Natura 2000 series (HMSO, 1994). Stewart (2000) describes how the UK has approached the requirement for designating SACs for white-clawed crayfish.

The Wildlife and Countryside Act 1981

In 1998 the white-clawed crayfish was added to Schedule 5 of the Wildlife and Countryside Act (HMSO, 1998). It has only received partial protection in relation to Section 9(1) as far as it relates to taking and in respect of Section 9(5). It is therefore an offence to intentionally take any white-clawed crayfish from the wild. Section 9(5) means that it is an offence to sell wild crayfish. It is currently not an offence to disturb or kill indigenous crayfish. Indigenous white-clawed crayfish are proposed for addition to Schedule 5 of the Wildlife (Northern Ireland) Order 1985.

Licences are available from English Nature[1] to allow the taking of indigenous wild crayfish for certain specified purposes. These include:

- Scientific or educational purposes
- Ringing or marking
- Conservation purposes

English Nature advises that taking wild crayfish can be interpreted to include handling wild crayfish and therefore any work involving contact with crayfish should be appropriately licensed.

English Nature Survey Licences

A survey licence can be issued by English Nature for scientific and educational purposes. A survey licence is needed where any survey method is aimed at finding white-clawed crayfish and involves handling them for counting and identification (even if they are released nearby shortly afterwards).

English Nature is working in partnership with other organisations to establish a National Crayfish Distribution Database. In the future licensees will be asked to complete a simple record sheet regarding the species of crayfish identified at particular locations. This record sheet will be returned to the licensing authority and ultimately relevant information will be available via the National Biodiversity Network Gateway (see Harding & Cooper, this volume).

Licences are not required for habitat appraisals, passive viewing or general ecological survey purposes where white-clawed crayfish are not the specific target species and where any such species are released immediately when taking is unintentional.

English Nature Conservation Licences

A conservation licence can be issued for the purpose of conserving white-clawed crayfish or introducing them to particular areas. Any work carried out under such a licence must be carried out for conservation purposes and therefore English Nature cannot issue a licence in order to rescue individuals or move them out of the way of development or maintenance operation unless this contributes to the conservation of the population concerned. A licence applicant must demonstrate that the licensed work will lead to the conservation of the species. This may therefore require extensive surveys in advance of any taking and reinstatement of habitat before introducing crayfish.

[1] Equivalent licence are available from the Countryside Council for Wales (CCW) and the Scottish Natural Heritage (SNH)

The booklet ‘Guidance on works affecting white-clawed crayfish’ (Peay, 2000) provides details on how to plan works on watercourse where white-clawed crayfish may be present. English Nature would expect licence applicants to follow these guidelines.

Moving crayfish to other sites

Licence applicants should demonstrate that the translocation site is suitable and that the introduction of additional animals would not have a detrimental effect on an existing population. A site with suitable habitat and which is plague-free should be chosen. A consent under Section 30 of the Salmon and Freshwater Fisheries Act, 1975, is required to introduce crayfish into any inland water, except waters on fish farms or garden ponds (see below).

Rescuing crayfish and replacing them after works

Licence applicants should provide evidence that conditions for crayfish at the site would be improved or at least remain suitable for white-clawed crayfish after completion of the work and that holding facilities were available until the release was possible.

NON-INDIGENOUS CRAYFISH SPECIES

The Wildlife and Countryside Act 1981

Section 14 of the Wildlife and Countryside Act makes it an offence for any person to (a) release or allow to escape any wild animals which is of a kind not ordinarily resident in or a regular visitor to Great Britain in a wild state or; (b) is included in Schedule 9 of the Wildlife and Countryside Act. The Wildlife (Northern Ireland) Order also makes it an offence to release wild animals which are not normal resident. There are currently no non-indigenous crayfish in Northern Ireland.

Three species of non-indigenous crayfish are listed on Schedule 9. These species are the signal (*Pacifastacus leniusculus*), the narrow-clawed (*Astacus leptodacylus*) and the noble (*Astacus astacus*) crayfish, and have been listed since 1992. These legal provisions have been relatively ineffective due in part to enforcement difficulties, and this has lead to a justification of the need for further legislation. The spiny-cheek (*Orconectes limosus*) and the red swamp (*Procambarus clarkii*) crayfish, which are also established in the wild (see Holdich, this volume), have yet to be added to Schedule 9.

A working definition of the term ‘wild’ in relation to crayfish includes any natural watercourse or other body of water from which crayfish can escape and move to another water body.

The Prohibition of Keeping Live Fish (Crayfish) Order 1996 (Crayfish Order)

New legislations on non-indigenous crayfish was provided by an Order made under the Import of Live Fish Act 1980. The Crayfish Order made it an offence to keep any non-indigenous crayfish without a licence in ‘no-go’ areas (Scott, 2000). The areas where licences are not required for signal crayfish have been specified in detail and relate to areas where signal crayfish are widespread. Such areas are generally in the south of England.

There is a general licence that allows the keeping of crayfish for direct human consumption provided certain specific operational procedures are followed. A general licence has also been issued for the keeping (in covered, indoor tanks) of the tropical Australian redclaw crayfish, (*Cherax quadricarinatus),* as it is believed that it could not breed in the wild. Scott (2000) gives full details of the implementation of this legislation for non-indigenous crayfish.

Crayfish farming

Compared with a few years ago there are now very few people farming crayfish, one reason for this is that more stringent legislation is in place, another is that large quantities of both signal and narrow-clawed crayfish can be harvested from the wild at present. Anyone carrying on a business of crayfish farming must register their business with CEFAS. Individual licences to keep crayfish and set up a crayfish farm will only be issued if they show that crayfish will be kept in secure, indoor, escape-proof facility.

SALMON AND FRESHWATER FISHERIES ACT (1975)

Crayfish Removal Byelaw

The Environment Agency intends to apply to the Department for the Environment, Food and Rural Affairs (DEFRA) for a crayfish removal byelaw to regulate the removal of all species of crayfish from waterways using traps (fixed engines). This has been necessitated by a legal ruling (Caygill v Thwaite (1885)) that confirmed that crayfish are legally classified as freshwater fish and therefore covered by the Salmon and Freshwater Fisheries Act (1975) that requires fixed engines to be authorised. Current byelaws enabling crayfish trap consents to be issued vary considerably across England and Wales so the Agency is proposing to introduce a single national byelaw authorising the use of crayfish traps subject to written permission of the Agency. The Agency has recently completed a public consultation exercise in which 120 individuals and organisations were directly consulted. The Agency is currently considering responses to the consultation.

This consenting process has the potential to overlap with the current licensing procedures under the Wildlife and Countryside Act, and together, the country conservation agencies and the Environment Agency will work to provide a joined-up service.

Introduction of indigenous crayfish to a water body

The other implication of crayfish falling within the definition of fish as defined by the Salmon and Freshwater Fisheries Act (1975) is that their introduction into a watercourse (except for fish farms as defined by the Salmon Act, 1986) is regulated by Section 30 of the Act and, therefore, requires the consent of the Environment Agency. However, the Prohibition of Keeping Live Fish (Crayfish) Order 1996 (Crayfish Order), means that non-indigenous crayfish cannot be released into the wild and, therefore, Section 30 will effectively only be issued for indigenous crayfish introductions.

All aspects of crayfish translocation and re-introduction are covered by the LIFE in UK rivers re-introduction protocol for white-clawed crayfish (see Kemp & Hiley, this volume), which will be used by English Nature and the Environment Agency in consenting any re-introductions for conservation purposes.

Protection of white-clawed crayfish - internal policy

Given the risk to white-clawed crayfish from transfer of crayfish plague spores from fish stocking, the Environment Agency has established a policy to safeguard crayfish. This states that when stocking waters with any fish within SACs and SSSIs designated for crayfish, stock fish should be sourced only from fish farms or waters within catchments with no history of crayfish plague and the absence of signal crayfish (e.g. see Hering, this volume). The same approach is also take when stocking other waters within the same catchment as SACs and SSSIs designated for indigenous crayfish, with the exception of totally enclosed waters. The policy also states that precautions should also be taken with regard to waters containing indigenous crayfish that are not designated.

The Use of Crayfish as Bait

The Environment Agency has created a byelaw regarding the use of crayfish as bait. This byelaw has made it an offence for any person to use crayfish as bait while fishing for salmon, trout, freshwater fish or eels. This byelaw applies to any species of crayfish whether alive or dead or any part of a crayfish.

CONCLUSION

Although the white-clawed crayfish is listed on key nature conservation legislation the numbers of the species in the wild is still in decline (see Sibley, this volume). In addition the legislation regarding non-indigenous species is unlikely to be able to prevent any further expansion in their range. It is clear, however, that the nature conservation legislation has had direct benefits for indigenous crayfish and helped raise awareness. However, the success of the UK indigenous crayfish will also depend on both proactive nature conservation efforts and a shift in practice and policy in many areas. Those involved in nature conservation measures must ensure that they comply fully with the relevant legislation and ensure that others who may have any impact on the species are aware of the legislative provisions.

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THE DISTRIBUTION OF THE WHITE-CLAWED CRAYFISH, *AUSTROPOTAMOBIUS PALLIPES*, IN EIGHT CATCHMENTS IN IRELAND IN RELATION TO WATER QUALITY

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ABSTRACT

Austropotamobius pallipes is fairly abundant in the Irish midlands where calcareous soils provide an adequate environment for this species. The white-clawed crayfish in Ireland also benefits from a ban on the importation of exotic crayfish species, which has so far ensured a limited impact of the crayfish plague. The water quality of rivers in Ireland is generally good, but a trend toward eutrophication has established itself in many catchments over the past decades.

A survey was carried out in eight catchments of the midlands to assess the distribution of *A. pallipes* in Ireland and to establish the range of water quality in which this species can be found. Crayfish were trapped in several rivers and water quality was assessed using biological indicators. The results indicate that the plague *Aphanomyces astaci* is probably responsible for a reduction in the geographical range of *A. pallipes* in Ireland. This crayfish species can thrive in moderate water quality, but was not found in low water quality.

Keywords: *Austropotamobius pallipes*, crayfish, plague, water quality, Ireland

INTRODUCTION

Austropotamobius pallipes is the native crayfish found in most of Western Europe. This species has drastically decreased its geographical range, mainly due to disease, interspecific competition and destruction of habitat (Holdich and Lowery, 1988; Holdich *et al*., 1999). Some of the best stocks now exist in Ireland where it is widely distributed in the lime-rich midlands (Lucey & McGarrigle, 1987; Holdich & Rogers, 1997; Holdich *et al*., 1999). *A. pallipes* has suffered greatly from the introduction of non-indigenous species in Europe (Gherardi & Holdich, 1999) and it is now an endangered species, listed in Annex II of the Habitats Directive. The Irish stock of white-clawed crayfish benefits from a ban on the introduction of exotic species of crayfish to the island. This means that there are no resident carriers of *Aphanomyces astaci* to infect the native crayfish. Nevertheless, the fungal plague did infect crayfish in Ireland. It was diagnosed in Lough Lene (Co. Westmeath, Boyne catchment) in 1987 (Matthews & Reynolds, 1990) and is probably responsible for the disappearance of several populations in nearby lakes (Reynolds, 1988). Crayfish that were once widely distributed throughout the Boyne catchment were only found in one subcatchment; this disappearance is also thought to be due to an outbreak of plague (Demers & Reynolds, 2002).

Water quality in Ireland is generally good. Toxic pollution is rare, with only 1% of streams classed seriously polluted in 1997 (Lucey *et al*., 1999). However, eutrophication is becoming more widespread with an increasing number of rivers classified as moderately polluted over the past decade (Bowman *et al*., 1996; Lucey *et al*., 1999). This trend is attributed to agricultural run-offs (manure and artificial fertilisers) and, more locally, to sewage discharge.

The white-clawed crayfish has traditionally been described as sensitive to pollution and considered as a potential bioindicator of water quality (Holdich & Reeve, 1991; Reynolds *et al*., 2002). Despite the decreasing water quality and the occurrence of the crayfish plague, the unique conditions present in Ireland offer a good opportunity to study the white-clawed crayfish. There are no competing crayfish species, either native or non-native, to curtail their range in Irish rivers. Furthermore, the impact of plague in Ireland is limited compared to continental Europe or Britain. This situation allows one to study the adaptability of this species in several types of habitat and to determine its requirements in terms of water quality.

This survey performed over three years (2000-2002) attempts to determine the range of water quality in which the white-clawed crayfish can be found and to update the information on the distribution of *A. pallipes* in Ireland. Data collected in 2000 relating to the Boyne and Liffey catchments were presented in part in Demers & Reynolds (2002).

MATERIALS & METHODS

Five hydrographic basins were visited for this project: the Liffey, the Boyne, the Suir, the Munster Blackwater, the Barrow, and the upper and lower Shannon (Fig. 1). Eight catchments of these basins were included in the study: the Liffey (14 sites), the Boyne (19 sites), the Multeen (Suir basin; 6 sites), the Awbeg (Munster Blackwater basin; 4 sites), the Barrow (9 sites), and the Inny (5 sites), Brosna (8 sites), Little Brosna (Shannon basin; 7 sites). The sites to be sampled were chosen to cover each catchment area as well as possible and on the basis of previous records (Lucey & McGarrigle, 1987). At each site, a physical description (flow, substrate, bank tree cover, etc.) of the site was made and chemical measurements (pH, conductivity) were recorded to ascertain the suitability of the habitat for crayfish.

Crayfish were sampled using two methods: trapping and netting. The traps used were Swedish August™ traps; these traps are bi-conical, made of plastic, with entrance funnels at either end and mesh apertures of 4 cm by 1 cm (minimum) to 1.5 cm (maximum). They were baited with liver or kidney and weighted down with rocks to prevent them from moving in the current. Ten traps were used at each site; they were usually set in pairs, attached to the bank. The traps would cover a stretch of river of approximately 20 metres in an area which was thought to offer good crayfish conditions. The depth at which the traps were set varied according to the physical characteristics of the river at each site. Traps were left under water for 48 hours. All crayfish caught were measured, weighed and sexed. All crayfish were released on site. Catch per unit effort (CPUE) is the number of crayfish per trap.

Hand nets (20x25cm opening) were used to sample smaller crayfish. Sexually immature (less than 25mm carapace length in male or female) and juvenile (unsexed) crayfish are only rarely caught with traps. Nets are used to sample through the vegetation, leaf litter and rocky substrate. Netting is not a quantitative method of sampling and is used only to establish that juveniles are present and thus that the population is breeding. Hand netting was performed for a standard period of 15 minutes after which, if no crayfish were found, juveniles and immature crayfish were considered to be absent from the site. All crayfish were sexed when possible and measured.

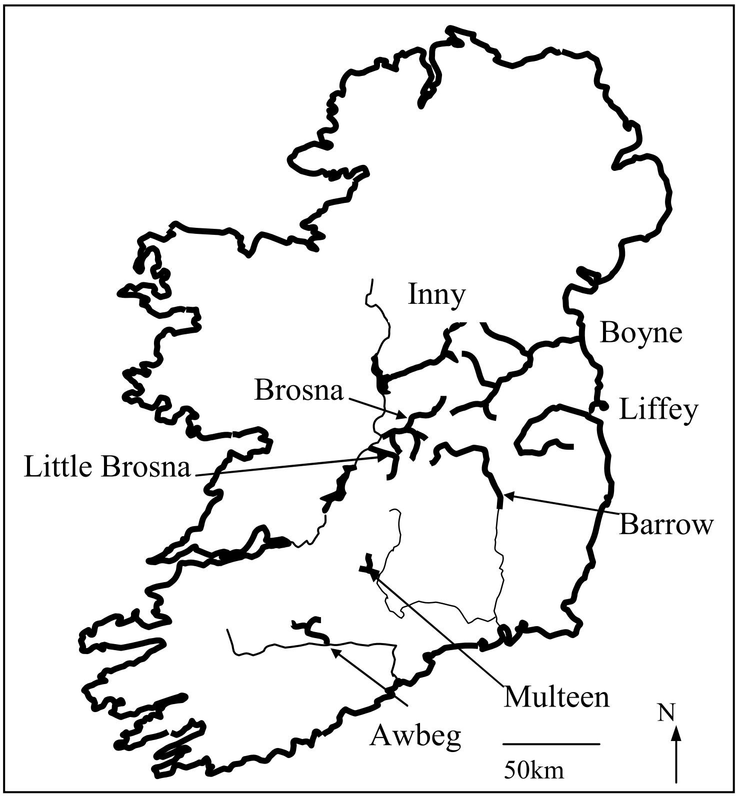


Figure 1. Location of the catchments surveyed for this research.

Three invertebrate samples were also taken at each site. Each sample was obtained with a 10 seconds “kick” sample. Rocks and vegetation were disturbed by the feet along a 1 metre transect for 10 seconds, and the water carrying organisms and detritus flowed through a 0.06 m^2 net (1 mm mesh size) held downstream. Everything collected during those 10 seconds was brought back to the laboratory for further identification. Two biological indices were calculated from these invertebrate samples. The Q value is the Irish biological index used by the Irish Environmental Protection Agency (Flanagan & Toner, 1972; Lucey *et al*., 1999), while the BMWP and its complement, the ASPT score, are used by the British water authorities (Chester, 1980; Armitage *et al*., 1983). For this study, the ASPT score was used instead of the BMWP, because it is less sensitive to sample size. The Q value is based on the tolerance of different groups of macroinvertebrates and ranges from 1 to 5.5 indicating excellent water quality and 1 indicating bad water quality. The ASPT gives a score to invertebrate families according to their tolerance to pollution and, although there is technically no upper limit, a score above 7.0 is generally consistent with good water quality. A score below 4.0 is consistent with poor water quality. This index is better suited to monitor organic pollution.

RESULTS

Crayfish were found in six of the eight catchments included in this survey (Fig. 2). Their range within each catchment was reduced when compared to previous records. *A. pallipes* was not found in the Inny river, the Little Brosna river, most of the Boyne catchment, the eastern branch of the Multeen catchment and the lower half of the Liffey river.

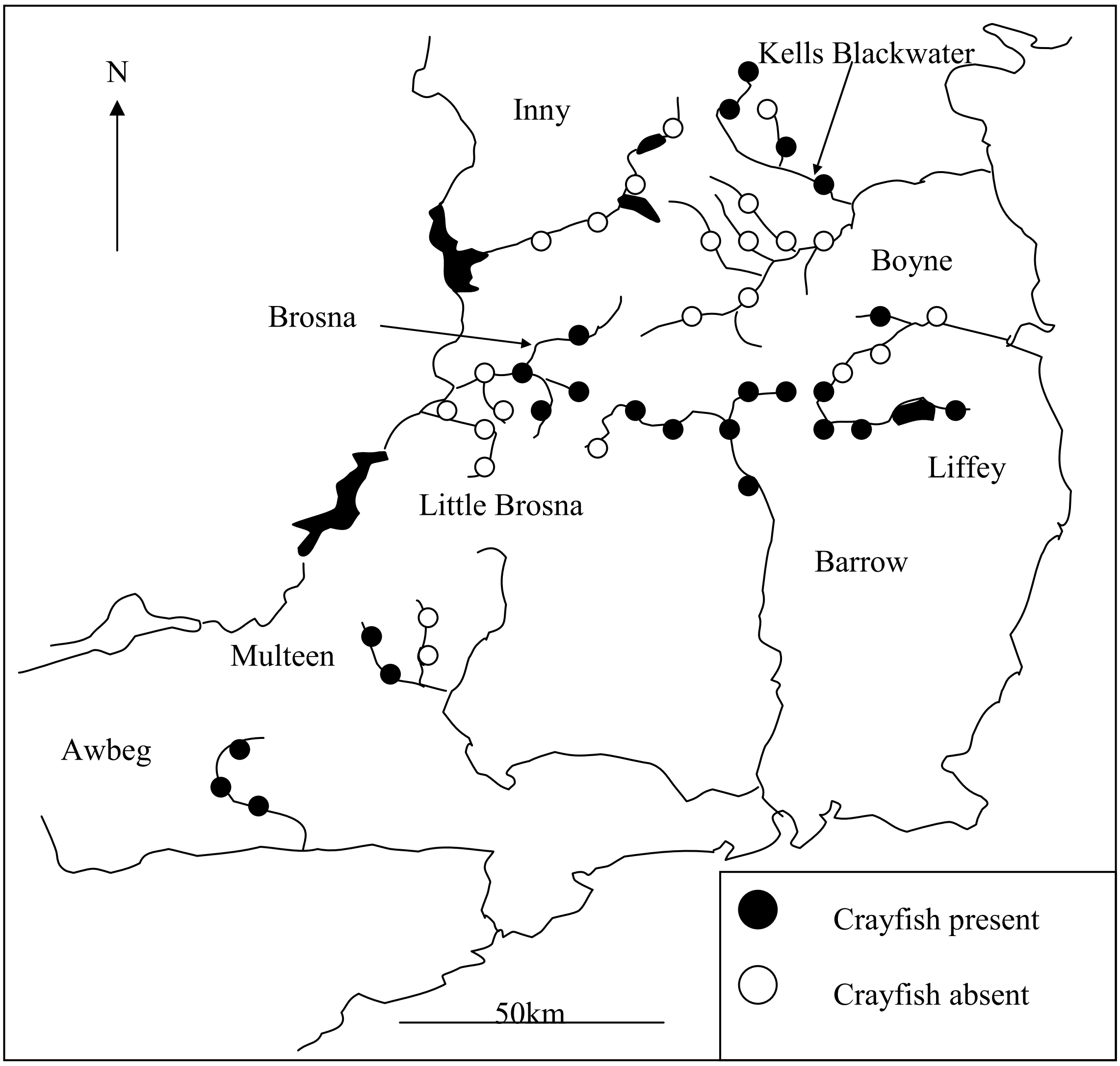


Figure 2. Crayfish distribution in the catchments surveyed (2000-2002). Not all sites are represented in this figure.

Catch per unit effort varied greatly between sites and between catchments. Most sites in the Barrow, the Liffey and the Brosna catchments had CPUEs above 1 (Table 1). The highest CPUE was found in the Barrow river (CPUE of 6.6), where 6 of the 9 sites had a CPUE above 1. Only one site in the Awbeg and in the Multeen catchments had a CPUE above 1, while all sites in the Kells Blackwater subcatchment had a CPUE of less than one.

Water quality at most sites surveyed was moderate to good (Table 2). Very few sites score a Q value of 4 (good quality) or less than 3 (low quality). The ASPT scores range across a wider scale, but like the Q values, indicate moderate water quality. No crayfish were found at sites that had a Q value of less than 3 or ASPT score less than 4.4.

Table 1. Catch per unit effort averages and range for each catchment where crayfish were found. The mean CPUE and range of CPUE are only for positive sites.

River	Number of sites	Number of positive sites	Mean CPUE	Range of CPUE
Liffey	14	7	1.8	0.1-4
Blackwater	7	5	0.3	0-0.8
Barrow	9	8	2.8	0.4-6.6
Multeen	6	3	1.0	0.1-2.2
Awbeg	4	4	0.8	0.4-1.3
Brosna	8	6	1.8	0.1-5.4

Table 2. Range of the biological indices according to sites with or without crayfish.

Index	With crayfish	Without crayfish
Q value	3 to 4	2 to 4
ASPT score	4.41 to 6.77	3.90 to 6.65

CPUE is not clearly related to water quality according to biological indices (Fig. 3). Many sites with varying CPUE (from 0 to 6.6) had a Q value of 3-4 and an ASPT score indicating moderate to good water quality.

DISCUSSION

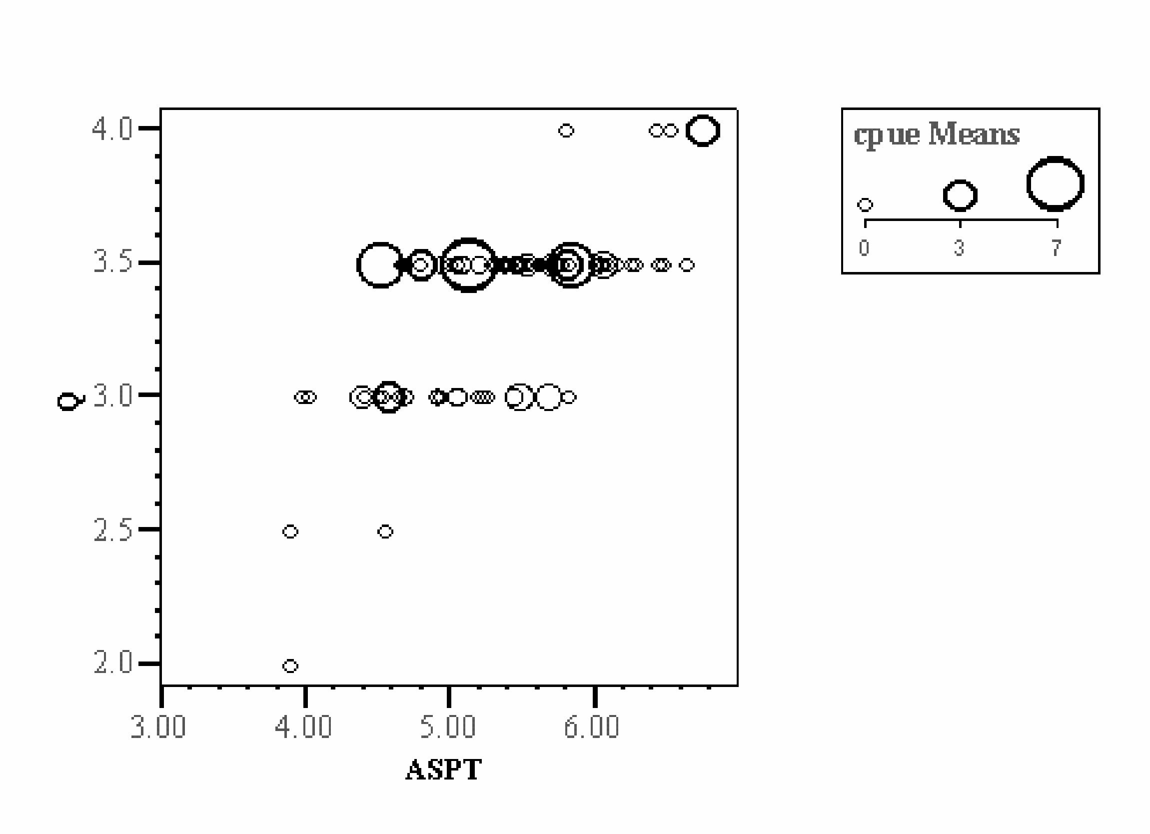
The distribution of the white-clawed crayfish in the catchments sampled for this survey was patchy and sometimes difficult to explain. Crayfish were known, often from casual observations, to live in all these river systems up to the mid 1980s (Reynolds, 1982; Lucey & McGarrigle, 1987), but four catchments presented an important restriction in the range of this species compared to previous records. Crayfish were not found in the Inny, Little Brosna and Eastern Multeen catchments during this survey using traps and nets as sampling methods. In the Boyne catchment, crayfish were only found in the Kells Blackwater subcatchment. Several causes for this disappearance are discussed below, but the most plausible for the Inny and the Boyne is an outbreak of the crayfish plague, caused by the fungus *Aphanomyces astaci*.

It is important to note that we cannot ascertain that crayfish have actually disappeared from the rivers sampled as trapping will not necessarily detect a population of crayfish at a low abundance. Certain factors, such as flow regime and habitat clustering, can reduce the efficiency of traps at catching crayfish. However, with the possible exception of one or two sites, the rivers sampled were not flashy and flooding was observed only once (crayfish actually took refuge in the traps). Furthermore, traps were placed near or in areas that seem to offer adequate shelter for crayfish.

Arterial drainage (dredging) was practised in several rivers of the Boyne catchment, with the aim of lowering the water table and allowing more land to be cultivated. The River Boyne drainage scheme started in 1969 and continued throughout the catchment until 1985 (O'Grady, 1998). After this date, dredging became less important but was still practised for periodic maintenance, and evidence of this was observed at one site in the Boyne catchment.

Dredging was also practised in the Brosna and Inny catchments, but in the 1950s and 1960s (Bruton & Convery, 1982). According to McCarthy (1977), *A. pallipes* disappears from a dredged area for several years, as does most of the invertebrate fauna. Thus, although arterial drainage has a negative impact on the crayfish population, individuals will move back into the dredged area after a few years (Lowery & Hogger, 1986).

Figure 3. Bubble plot of the biological indices (Q value and ASPT score) and of the CPUE. A Q value of 2.5 indicates a Q of 2-3 and a value of 3.5 indicates a value of 3-4.



Pollution does not seem to be the cause of the absence of *A. pallipes* in our traps in the Boyne, Inny and Little Brosna catchments. According to our invertebrate sampling all rivers in the Boyne catchment are moderately polluted (Q of 3 and 3-4, ASPT between 5 and 6), except at one site in the lower Boyne river (Q value of 2-3 and ASPT score of 4.55). Water quality was moderate also in the Inny catchment (Q of 3 or 3-4, ASPT between 4.50 and 6.30), and in the Little Brosna river (Q of 3-4, ASPT between 5 and 6). Previous records of the EPA (both biological and chemical) do not show evidence of serious pollution in the past decade at any of the sites visited but point towards eutrophication of these catchments (Lucey *et al*., 1999). The headwaters of the Inny river presented clear signs of eutrophication with extensive algal growth on the substrate. The biological indices give evidence of eutrophication, but indicate water quality suitable for crayfish according to the distribution of this species in other catchments (Table 1). Nevertheless, the degrading water quality might present an obstacle to the recolonization by crayfish of these rivers.

The fungal plague caused by *Aphanomyces astaci* was introduced to Europe with American crayfish species. The plague was diagnosed on sick individuals trapped in Lough Lene in 1987 (Matthews & Reynolds, 1990, 1992). This lake lost its entire crayfish population soon afterwards. The fungus is also believed to be responsible for the disappearance of crayfish populations from several other lakes in the Inny and Boyne catchments (Reynolds, 1988). Lough Lene and other lakes in the area do not have clearly defined drainage basins and can drain, through the fissured limestone, both to the Inny and the Boyne catchments. It is therefore possible that from these lakes, the disease infected individuals in the Deel river, and thus spread throughout the Boyne catchment, as well as the Inny river, potentially spreading through the Shannon catchment (Fig. 4). The possible spread of the disease throughout the Shannon basin is less likely because crayfish are generally scarce or absent from large lakes (Reynolds, 1997), including Lough Ree, situated at the mouth of the river Inny (A. Demers, unpublished data).

In a case study by Westman & Nylund (1978) in Finland, the disease travelled roughly 3 km a year upriver, although it was not clear whether the spread was natural or helped by fishermen. The Boyne and Shannon catchments are popular for trout and salmon angling and it is possible that spores were introduced by visiting anglers at several places in the catchments (Reynolds, 1988). In the first outbreaks of crayfish plague in Britain, described by Alderman *et al*. (1984), no crayfish survived downstream of the initial infection site within a few days and mortalities spread slowly upstream. Alderman *et al*. (1984) reports that a population stretching along 60 km of a river disappeared within three weeks. These authors also note that such mass mortalities remained unnoticed by the public. Crayfish in the Little Brosna could have become infected by crayfish in the main Shannon channel, although earlier crayfish records only exist for the headwaters of this river (Lucey & McGarrigle, 1987). If the crayfish population in the Little Brosna was actually confined to the headwaters, then pollution events rather than plague might have caused the population density to decrease below detection level. The Little Brosna basin is mainly used for agriculture and the EPA records show a steady decrease in water quality over the past decade (Q value of 3 at most sites, moderate water quality; Lucey *et al*., 1999).

If the plague is indeed responsible for the absence of crayfish in the Little Brosna and did spread through the Shannon catchment, the Brosna catchment population might have escaped the outbreak because of a gap in their distribution (lower Brosna river, Fig. 2) that would in fact isolate the Brosna population from the rest of the Shannon. The crayfish population in the Kells Blackwater subcatchment might still exist today for the same reason. There are no records of crayfish existing downstream of Trim, a few kilometres upstream of the Blackwater inflow, before the plague outbreak. The Blackwater population might have been isolated from the rest of the Boyne population and thus would not have come into contact with sick individuals. It is important to note at this point that only the mainstream Inny river was sampled in the catchment and that no tributaries were visited. In the late 1990s, crayfish were found in the headwaters of a small tributary of the Inny, the river Rath (Reynolds, unpublished). They may have escaped infection by the plague because of a gap in their distribution between the main Inny river and the headwaters. Such a situation is fairly common in France and Spain where populations of *A. pallipes* are restricted to headwaters of streams, sometimes at high altitude (Carral *et al*., 1993; Grandjean *et al*., 2000).

No crayfish were found in the eastern branch of the Multeen River, but were found in the western branch. The fact that crayfish were found in one branch, and indeed seem to be most abundant near the confluence of the two branches, makes a plague outbreak an improbable cause for the loss of the eastern branch populations. The biological indices indicate moderate to good water quality throughout the whole catchment and no visible signs of eutrophication were present. In a survey of Irish rivers, Lucey *et al*. (1999) indicated that most of this catchment had good to excellent water quality up to 1996. Nevertheless, local residents informed us of pig slurry effluents contaminating the river on several occasions a few kilometres upstream of one of the sites. It is possible that such a pollution event could have killed the crayfish population in the eastern branch, if it occurred in the headwaters.

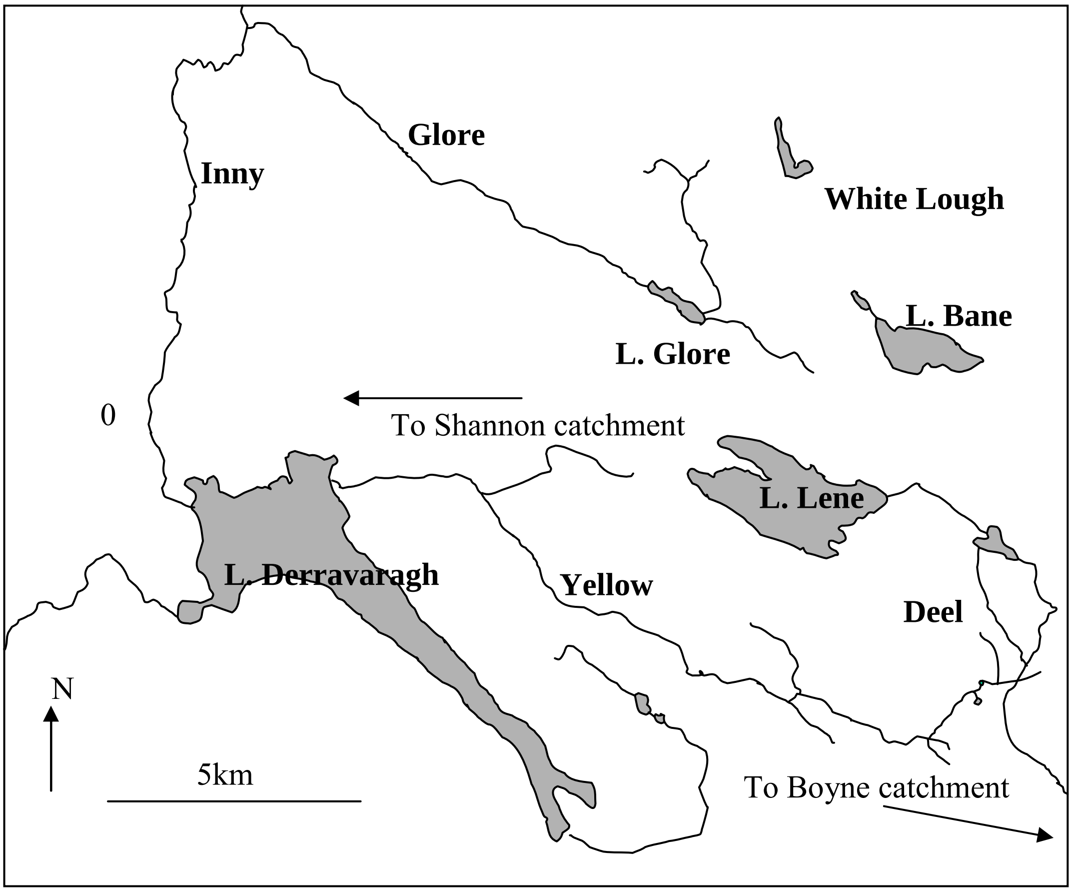


Figure 4. Map of the possible original sites of introduction of *Aphanomyces astaci* in the Boyne and Inny catchments. White Lake lost its crayfish population in 1985, while Lough Lene, Lough Bane and Lough Glore lost their crayfish population in 1987.

Pollution (e.g. in the form of eutrophication), or low water quality, does affect crayfish to a certain extent. The effect is often localised, as only certain areas within the catchments sampled exhibited low water quality. Evidence of the effect of water quality on crayfish distribution is found in the 2000 data from the Liffey and Kells Blackwater (Demers & Reynolds, 2002). Crayfish were not found in the lower half of the Liffey river and the distribution of *A. pallipes* stops at a site with low water quality (Q value of 2, ASPT score of 3.91) just downstream of a large sewage treatment plant. Another site where low water quality might explain the absence of crayfish is in the headwaters of the Moynalty River, in the Kells Blackwater subcatchment. The biological indices record a low water quality at this site (Q of 2-3, ASPT of 4.56). The site offered an otherwise adequate habitat for crayfish and *A. pallipes* was found a few kilometres downstream.

CONCLUSIONS

This survey suggests that there is a lower limit of water quality at which crayfish can survive, but this species is not confined to waters of good quality, being quite numerous in waters of moderate quality. This research also indicates the likely extent of the effects of *A. astaci* in Ireland and underlines the necessity for further detailed surveys to assess the current distribution of *A. pallipes*.

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RETURN OF THE NATIVE CRAYFISH TO A WELSH RIVER

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ABSTRACT

The upland rivers of rural mid-Wales supported thriving populations of *Austropotamobius pallipes*, the native white-clawed crayfish, until a dramatic decline began to occur around a decade ago. Crayfish plague, caused by the fungus *Aphanomyces astaci,* although at times a common problem in England, was not the main cause of decline in Wales. So what was the cause?

Excess sediment deposition and sheep dip pollution are thought to be two of the main factors causing deterioration in the aquatic life of upland Welsh rivers. The decline and apparent recovery of *A. pallipes* populations in the Afon Edw, a tributary of the River Wye coincide with changes in sheep dip use as specified by the Environment Agency.

In an effort to measure the amount of sediment being deposited into the Edw, specialised traps were positioned along the length of the river. Results collected so far suggest that excess sediment deposition remains a threat to *A. pallipes* and other organisms in the Afon Edw despite measures taken to reduce it.

Keywords: crayfish, Wales, sheep dip, sediment, decline, recovery

INTRODUCTION

The current nationwide decline in *A. pallipes,* the native white-clawed crayfish, is commonly attributed to the well-publicised encroachment of the North American signal crayfish, *Pacifastacus leniusculus*, which can eliminate the native crayfish by means of crayfish plague and increased competition (Holdich & Rogers, 2000; Hiley, a, this volume; Sibley, this volume). The upland rivers of rural mid-Wales supported thriving populations of *Austropotamobius pallipes* (Holdich, 1993) until a dramatic decline began to occur around a decade ago. Although surveys carried out by the Environment Agency have shown that crayfish plague was present in a few locations within the Welsh region of the Wye Catchment, cases appeared to be isolated and did not spread (Coley, 2000; Holdich, a, this volume). Other factors may therefore be responsible for the decline of *A. pallipes* in upland rivers of mid Wales. The upland rivers of rural mid-Wales supported thriving populations of *Austropotamobius pallipes*, the native white-clawed crayfish, until a dramatic decline began to occur around a decade ago.

Frequent heavy rain is common in the uplands of mid-Wales, and most of the catchment areas are heavily stocked with cattle and sheep (Environment Agency, 1999). These factors result in excess silt deposition and sheep dip pollution, both of which may be detrimental to *A. pallipes* populations (Slater & House, 2001).

Livestock on farms adjacent to rivers have always been allowed free access to the waterways, and cause poaching and bank erosion as well as silt deposition and organic pollution. As a result, fish populations and the general health of the rivers are thought to be suffering. Excess silt entering the river may eventually get permanently deposited on and within the riverbed. Gaps between and underneath stones are filled and in extreme cases the entire riverbed becomes coated in silt. *A. pallipes* use gaps under stones as vital refuges (Rogers & Holdich, 1995; Slater & House, 2001). Where there are no gaps, *A. pallipes* is rarely found (Foster, 1990). Concern was raised that a similar fate was befalling fish, which have also dramatically declined in numbers over the last decade. Fish, particularly salmonids, lay their eggs in hollows they make in the bed gravel (Jones, 1959). When no gaps are present due to silt deposition, oxygen levels (from water flowing through the stones) are reduced, and fish eggs are killed. In 1999, the Wye Foundation, in association with a number of other organisations, set up the Wye Habitat Improvement Project (WHIP) to rectify this problem. Selective coppicing and fencing was carried out along stretches of the River Edw, a 16 km tributary of the Wye near Builth Wells, mid-Wales.

Fencing was intended to prevent livestock from eroding the banks. At specific points along the river, livestock were allowed controlled access to the water to drink. Although fencing of banks is thought to benefit fish, crayfish and other invertebrates, also rely on clear riverbeds (Environment Agency, 1997). Coppicing, particularly of alder (*Alnus glutinosa*), may reduce the overall biodiversity of the habitat. For example, a detrimental impact may be felt by birds and other organisms that rely on bank side trees for shelter, food or shade and particularly crayfish that, as omnivores, will consume tree leaves (Parkyn *et al*., 1997). Further research will be required to investigate whether the project has been successful overall.

In order to measure the amount of silt entering and moving along the river, the authors installed a series of silt traps along the River Edw as described by Naden *et al*. (2002). Captured silt was measured in September and November 2002, and will be further monitored every two months throughout 2003.

Sheep dip pollution is another possible cause of the dramatic decline of *A. pallipes* in rural Wales. In the past, after sheep had been dipped, they were often released into fields adjacent or near to waterways to drip dry. The insecticide could then enter the ground or pass directly into the watercourse. The frequent heavy rain that occurs in the uplands would wash excess insecticide off the animals and from the ground, eventually ending up in the rivers (Environment Agency, 1999).

Treatments were sometimes carried out so close to waterways that when leakages occurred, pollution of these waterways was inevitable. In 1999, the Environment Agency introduced Groundwater Regulations in order to ensure that dipping treatments were carried out at safe distances from any watercourses and that freshly dipped sheep were not allowed to roam freely but were restricted to a safe area. The regulations also allowed for the safe disposal of unused dip. They hoped that this would help to eliminate any further pollution incidents (Environment Agency, 1999).

In recent times, organophosphate (OP) sheep dips were widely used. Over a number of years, concern raised about the harmful symptoms displayed by farmers from continued, long term handling of OPs led to a, temporary ban in late 1999. Another group of insecticides, synthetic pyrethroids (SPs) were introduced for sheep dipping in the early 1990s. SP usage increased dramatically after OPs were banned in 1999. Although SPs appear to be much less harmful to humans than OPs, they are, unfortunately, 100 times more toxic to many invertebrate species, including *A. pallipes* (Coley, 2000). One teaspoon of SP can destroy the crayfish population of a small lake (D. Jerry, pers. com., 2002). SPs break down quickly, which makes chemical detection difficult when not measured immediately after an incident. If a period of more than a few days has elapsed since an incident, biological indicators must be used to try to identify the cause and severity of the pollution. *A. pallipes* is very sensitive and is therefore a good indicator of pollution. Unfortunately they take a number of years to grow and mature and so are particularly vulnerable within the first few years of life (Foster, 1990). This makes their recovery a slow, uncertain process.

With this information in mind, in Summer 2002, we conducted a detailed search of the River Edw and its fine tributaries. These results together with those of past surveys were collated to look for any trends in the *A. pallipes* population size. Possible reasons for such trends are discussed.

METHODS

The main part of this study focuses on the Edw catchment, a tributary of the Wye in mid-Wales. The River Edw joins the River Wye at the grid reference SO 075 470.

Crayfish survey

Austropotamobius pallipes is protected under Schedule 5 of the Wildlife and Countryside Act 1981. All individuals working on this survey were therefore licensed by the Countryside Council for Wales and access permission was always sought.

Crayfish searches were carried out by stone turning with kick sampling (standard procedure, following methodology used by Foster (1990) and Slater & House (2001)). In each stream, searches were carried out in a downstream direction. If a hand or fingers could fit underneath the edge of a stone it was considered suitable for crayfish presence, and a search was conducted. A kick sampling net was placed immediately downstream of the stone, which was lifted to allow any crayfish underneath to escape and swim into the net. If none emerged, kick sampling was carried out. For any crayfish caught, the following data were recorded: date of capture, location, sex, carapace length, weight, number of missing appendages and disease status, e.g. plague or porcelain disease

Stone turning at each site was carried out for one man hour. This enabled the calculation of CPUE (catch per unit effort), which equals the number of crayfish caught per man hour. The entire length of the Edw and its fine tributary streams were searched in this way.

Silt deposition experiment

Seven sampling stations were established along the length of the River Edw. Each station comprised of four silt traps and either a cattle drinking area, a sheep crossing or a tributary stream entry point. At each station, two silt traps were positioned upstream and two downstream of the feature (dinking area etc). Of each pair, one trap a flowerpot trap and one was a basket trap.

Silt samples were collected, sealed and labelled in the field. Once in the laboratory, bags were transferred to 1-litre wide neck plastic sample bottles. Silt was filtered and sorted using stacked sieves. Oven dried sample weights were measured and recorded.

RESULTS

Crayfish survey

A search for *A. pallipes* throughout the Edw catchment carried out in Summer 2002 revealed 60 individuals, with a highest CPUE of 15. This compares with only seven individuals (two of which were dead) and a maximum CPUE of 2 in 2000 (Slater & House, 2001) but was still much lower than a CPUE of 46.5 found during a crayfish survey on the River Edw in 1988 (Foster, 1990).

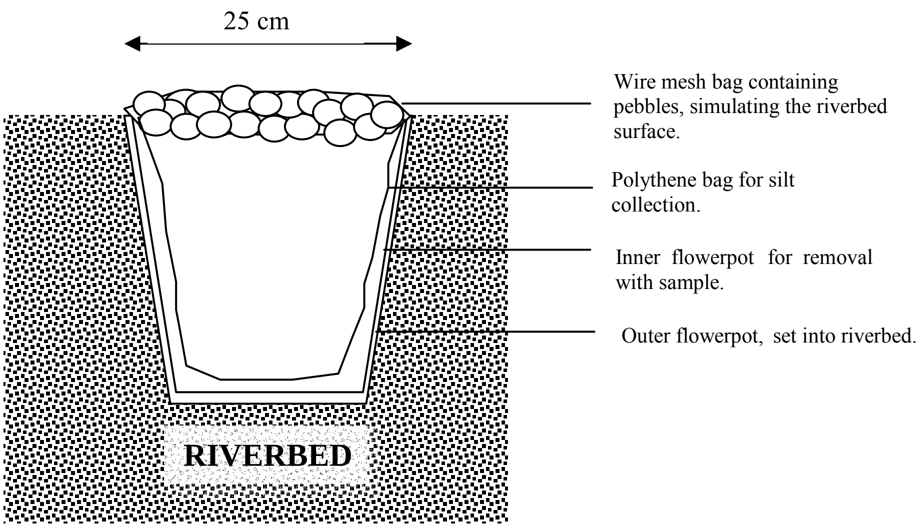

Figure 1. The flowerpot trap which captures riverbed surface silt.

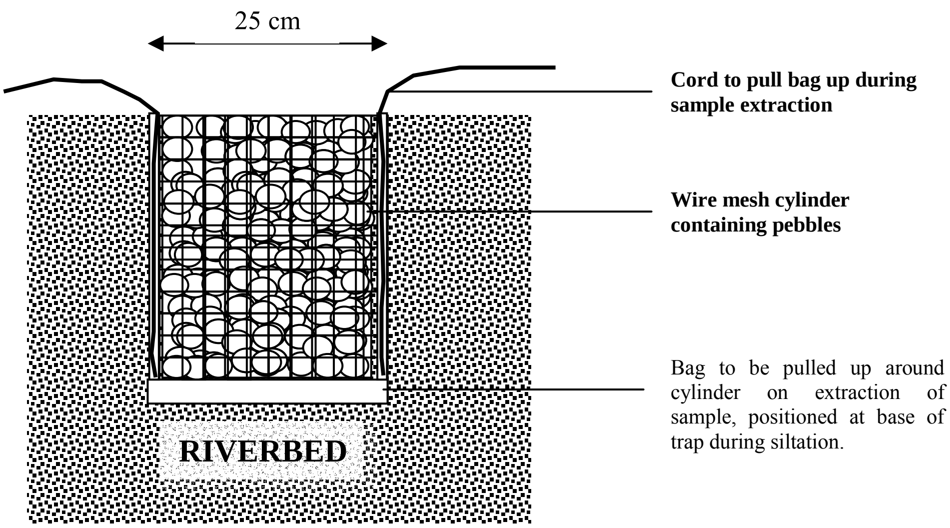

Figure 2. The basket trap which captures intra-bed plus surface silt.

In September 2002, more silt was collected in traps positioned downstream than upstream of livestock access points (Aberedw and Llanbadan-y-garreg). However, at Cregina, more surface silt was collected upstream than downstream of the tributary entry point (Table 1).

In November, some silt traps were lost due to flooding resulting in a loss of data. The use of a metal detector to locate the missing traps proved unsuccessful. A full set of results was collected only from Llanbadan-y-garreg, the site of the sheep crossing. Here, much more surface and intra- bed silt was found in November than in September (Fig. 4).

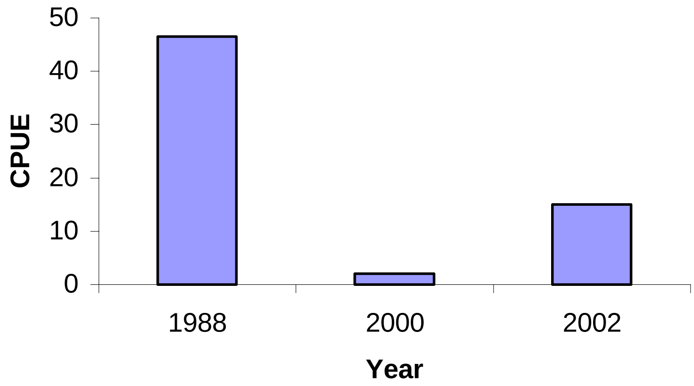

Figure 3. Maximum CPUE (catch per man hour) of *A. pallipes* on the River Edw during surveys of 1988, 2000 and 2002.

Silt deposition experiment

	SEPTEMBER				NOVEMBER			
	Surface		Surface & Intrabed		Surface		Surface & Intrabed	
SITE	U	D	U	D	U	D	U	D
A	11	292	54	205	*	*	928	780
B	1	14	2	34	2154	1439	1061	34
C	8	4	19	44	*	797	9115	840

Table 1. Dry weight and rate of deposition of silt collected from transects up and down stream of riparian features in September and November, where site A = Aberedw (cattle drinking area), site B = Llanbadan-y-garreg (sheep crossing), site C = Cregina (tributary stream), U = upstream and D = downstream.

Incidental finding

Another important observation was made while collecting the first set of silt samples in September 2002. A crayfish was discovered under riverbed stones situated close to one of the basket traps. The stones in the immediate vicinity of each trap were relatively free of silt in comparison with the rest of the river due to the disturbance caused when initially installing the traps. This discovery was significant as it indicated that where there were gaps under and between stones, i.e. where little silt was absent, crayfish were likely to be found.

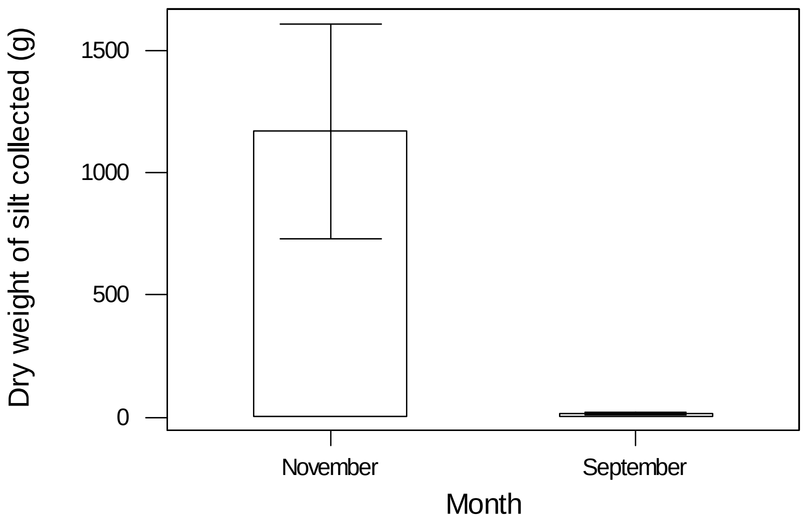

Figure 4. Comparison of dry weights of surface and surface plus intra-bed silt collected in November and September at Llanbadan – y-garreg (sheep crossing).

DISCUSSION

Crayfish survey

In 1988, crayfish were abundant in the River Edw (Foster, 1990). At around the same time, organophosphates (OPs) were the main insecticides being used as a sheep dip (Environment Agency, 1999). OPs are less toxic to freshwater invertebrates such as *A. pallipes* than other sheep dip insecticides and the Edw's crayfish population survived this situation even when minor pollution incidents did occur. The dramatic fall in *A. pallipes* numbers within the following 12 years indicated by the discovery of just seven individuals in 2000 despite an extensive survey (Slater & House, 2001), may be attributed, in part, to changes in the types of sheep dip being used. The OP ban in 1999, and a subsequent increase in synthetic pyrethroid (SP) use (Environment Agency, 1999) may have had a devastating impact on *A. pallipes* populations due to their much higher toxicity to invertebrates. However, as SPs break down relatively quickly (Coley, 2000) it is almost impossible to confirm that they were responsible for the observed dramatic decline in *A. pallipes* numbers. The Environment Agency's Groundwater Regulations introduced late in 1999, controlled how unused sheep dip was disposed of and restricted the movement of freshly treated sheep dip. This would undoubtedly have reduced or even prevented any further SP pollution incidents (Environment Agency, 1999). Three years later, in Summer 2002, the *A. pallipes* population of the Edw appeared to have partially recovered possibly indicating the beginnings of a slow recovery for *A. pallipes* in the Edw (Slater & Howells, 2003). However, the population has not yet recovered sufficiently to be classed as safe or stable.

Silt deposition experiment

Excess silt deposition, another factor thought to have had a detrimental impact on native crayfish populations, is thought to have been reduced in the Edw by fencing (Slater & House, 2001). The potential degree of improvement to the crayfish habitat has been experimentally tested by assessing the difference in silt deposition above and below livestock entry points.

September's results show that where livestock entered the river, more silt was collected in the down than upstream traps, indicating that the sheep and cattle increased levels of silt deposited within and on the surface of the riverbed. This was expected as it was observed while samples were being collected that cattle regularly entered the river at the drinking site. The bank was poached and large quantities of silt, faeces and urine began to flow downstream as soon as the cattle entered the river. A similar situation was observed at the sheep crossing. Therefore, although fencing was controlling bank damage, downstream flow from remaining entry points meant that silt deposition was still high.

In September, less surface silt was found in the trap down stream than upstream at Cregina, where a tributary stream enters the Edw. It is seems likely that the extra flow created by the stream was washing away some of the surface silt from the riverbed including the area where the trap was located, or that the tributary carried a lower silt load and so "diluted" the silt load of the main river. Tributary entry points may therefore be likely crayfish habitat, and might merit more intensive surveying.

More silt found in silt traps in November than September probably resulted from heavier rainfall in winter months, as compared to September when dry weather caused the water levels of the rivers to drop right down.

Seasonal and geographical variability in silt deposition is likely to have a marked influence on crayfish distribution. Further crayfish surveys in conjunction with habitat assessment, particularly including silt monitoring should enable a clearer understanding of crayfish distribution and causes of population change.

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WHITE-CLAWED CRAYFISH IN THE RIVER ISE, NORTHAMPTONSHIRE

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ABSTRACT

Until the early 1990s the River Ise in Northamptonshire held an important population of native crayfish *Austropotamobius pallipes* and the SSSI on the river included them in the citation. A major crayfish plague event occurred on the river in 1990. No native crayfish were found in the Ise following this, leading to the belief that the native crayfish were extinct.

In 2001, incidental findings were made of native crayfish, prompting fresh surveys. None were found in a survey of the SSSI stretch in 2001. In 2002, the Environment Agency surveyed the river near Rushton and found an isolated population. This paper examines the findings of the survey.

The population was found to be restricted to 250 m. Nine individuals were captured. Crayfish habitat up and down stream was fragmented. Twenty-five per cent of individuals captured showed signs of porcelain disease. No symptoms of crayfish plague were observed.

Possible explanations for the apparent reappearance of native crayfish are discussed. It is probably the first recorded case in the UK of a natural recolonisation after a plague event. The importance of this newly identified population is evaluated and a prioritised list of proposed actions is provided. The Environment Agency is of the opinion that the potential exists for there to be native crayfish along most of the River Ise, at below detectable density.

Keywords: River Ise, plague, crayfish, survey, recolonisation

INTRODUCTION

Up until 1990 the River Ise, a tributary of the River Nene in Northamptonshire (see Fig. 1), supported a population of the native white-clawed crayfish, *Austropotamobius pallipes.* The crayfish population is included in the 1988 SSSI notification of the river between Geddington and Barford Bridge (SSSI shown in Fig. 2).

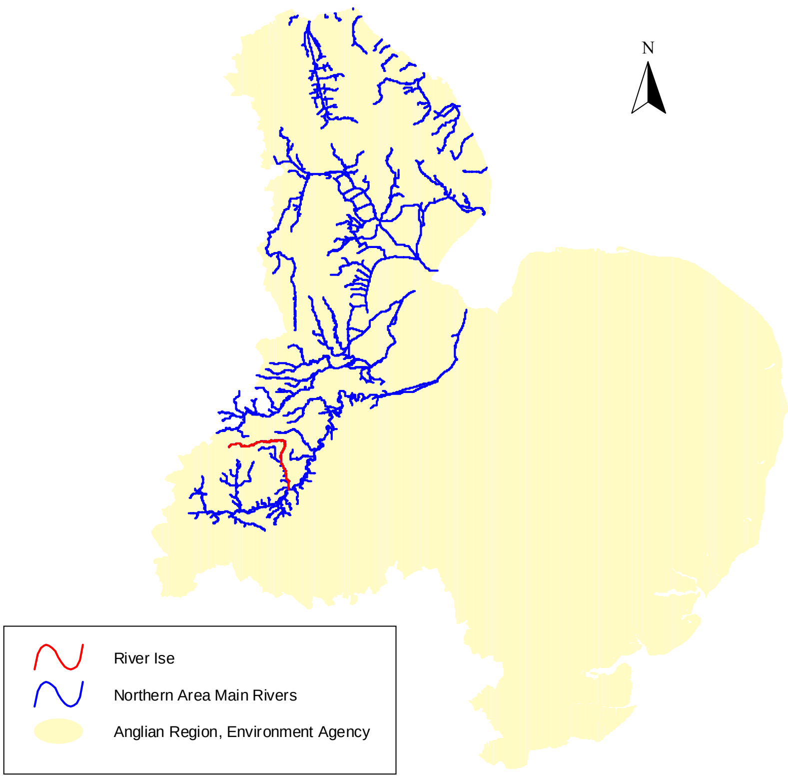

Figure 1. River Ise location in the Environment Agency's Anglian Region.

In July 1990, a severe crayfish mortality occurred throughout the SSSI section. Samples of dead crayfish were analysed by CEFAS in Weymouth for the crayfish plague pathogen, *Aphanomyces astaci,* with positive results (see Holdich, this volume).

Between October and December 1991, English Nature (then NCC) commissioned a survey for crayfish at sites along the Ise and within the SSSI. The survey was carried out manually, using a pond net. No crayfish were found although the usual range of other animals remained. It was then assumed that the entire population had been eradicated and no further efforts were made specifically to find crayfish in the river. Invertebrate sampling by the Environment Agency and Newton Field Centre throughout the Ise was undertaken regularly during the 1990s, but with no crayfish found.

Signal crayfish have been introduced to Britain from America and can carry crayfish plague (see Holdich, this volume). However, the cause of the outbreak is unknown but is unlikely to be as a result of direct interaction between native and signal crayfish, *Pacifastacus leniusculus,* as the latter species has never been recorded anywhere in the River Ise. The nearest known population of signal crayfish is in the River Nene upstream of the confluence with the Ise. It has been widely suggested that the outbreak may have been caused by the introduction of contaminated water associated to a fish stock transfer, or by anglers using contaminated equipment. However, no supporting evidence has been forthcoming.

In November 2000, a single, apparently healthy, male adult crayfish was found at the ford in Geddington immediately after the river had been in flood (see Fig. 2). The Newton Field

Centre confirmed this as being a native crayfish and this was corroborated by Environment Agency biologists.

On the basis of this find, the Environment Agency commissioned NEWCO (Northamptonshire Environmental & Wildlife Consultancy) to once again survey the SSSI section of the River Ise for white-clawed crayfish. This was carried out during late summer 2001, mainly in the River Ise SSSI. A manual search method with a pond net was used. Despite habitat being suitable in places, no crayfish were found (Gerrard, 2001).

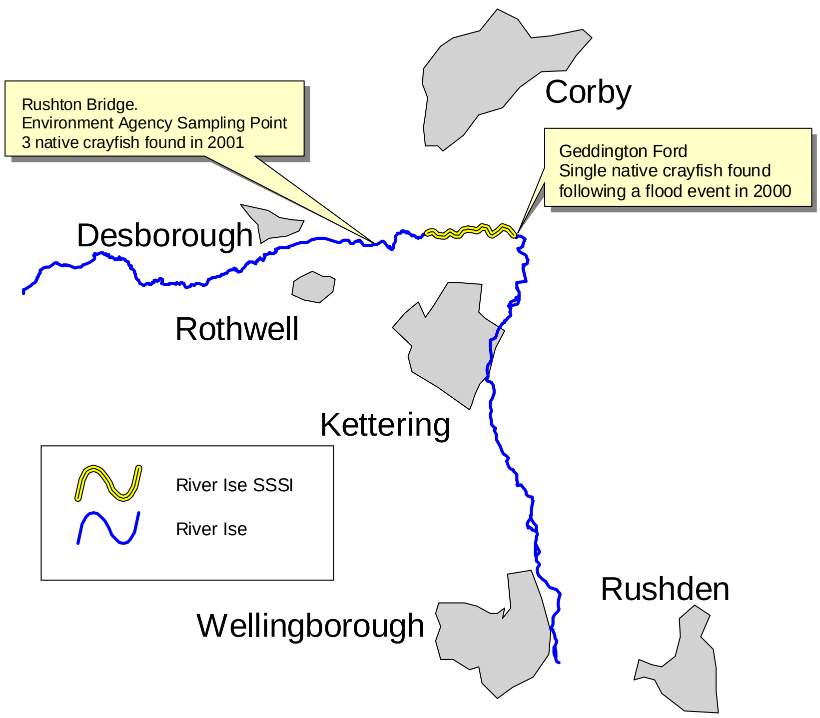

Figure 2. Location of recent incidental records of native crayfish on the River Ise.

Shortly afterwards a number of juvenile native crayfish were found by Environment Agency Biologists undertaking routine invertebrate sampling in the Ise at Rushton, approximately 3 km upstream of the SSSI at Barford Bridge. This was the first time crayfish had been recorded at this location. Therefore it is unclear whether crayfish plague ever affected this part of the river in 1990.

The Environment Agency carried out a crayfish survey of the River Ise from Barford Bridge upstream to Desborough in September 2002. The aim was to identify the boundaries of the population and to assess the need for habitat enhancement. This paper outlines the findings of that survey and the Agency's future priorities for the River Ise crayfish.

METHODOLOGY

On 2nd September 2002, three Environment Agency teams of 3-4 staff were used to survey 6 km of the River Ise between Barford Bridge (SP 860 831) and Desborough (SP 815 827). Each team was led by a licenced crayfish handler.

The suitability of the habitat for crayfish was recorded over the whole length and searched thoroughly for presence/absence of crayfish with kick sampling. Where the substrate comprised of cobbles, large pebbles or other suitable crayfish refuges it was recorded as good habitat. Sampling effort was directed towards those places most likely to contain crayfish (stones/ debris/ tree roots/ aquatic and marginal vegetation). Any observations such as burrows, otter spraints etc. were recorded as map annotations.

Stretches where it was not possible to survey (e.g. too deep, access difficulties etc.) were noted. Digital photos were taken of representative stretches. Where crayfish were found, a record was made of the sex and carapace length, plus any abnormalities (missing claws, porcelain disease etc.) and the location marked on maps.

The 500 m up and down stream of Rushton Bridge were subject to a more detailed survey, since this was where crayfish were found most recently. Each 500 m section was divided into 100 m subsections. The survey was time limited to a minimum of 20 minutes and maximum of 30 minutes per 100 m. It was carried out on a pro rata basis (i.e. if two people sampled, the time allocated was halved). River Corridor Survey (RCS) sketch maps were also made. The teams were under instructions to stop searching if five crayfish were caught in any 100 m stretch, in order to avoid unnecessary disturbance.

RESULTS

Habitat Assessment

Much of the downstream part of the survey was not possible, as the water was considered too deep to survey. The remaining length was surveyed and shows a fragmented distribution of good crayfish substrate, the rest being dominated by sub-optimal or poor crayfish substrate. The poorer habitat tended to comprise of fine silts or small gravel, often with luxuriant emergent plants.

Sewage debris was observed by all teams, (including upstream of the sewage treatment works at Rushton), inferring that somewhere upstream there is a sewage outfall that requires upgrading.

The longest continuous stretch of good substrate (250 m) was around the Rushton Bridge area, where crayfish had previously been recorded. Unoccupied but suitable areas of habitat were recorded nearby, both up and downstream. Further downstream, there is potential for habitat improvements to facilitate downstream migration and to link the good habitat at Rushton to the SSSI stretch. Many of the areas identified as having good substrate appeared to be as a result of debris falling in to the river from collapsed structures (e.g. old bridges).

At various points along the surveyed stretch, small holes consistent with the appearance of the burrows created by signal crayfish (see Sibley, 2000; Stanton *et al*., this volume) were recorded. It was not widely understood prior to the survey that white-clawed crayfish could tunnel in a similar fashion to signal crayfish (see Tero *et al*., this volume). A learning point is the need to ensure that in future, crayfish burrows are recorded.

Crayfish details

Details of the individuals that were captured in the survey are shown in Table 1 below. In total, seven live crayfish were caught on the actual survey, with a further five that escaped before details could be recorded and one dead individual. A brief visit on the 4th September found another two live individuals. All were captured within a 250 m stretch, centred around the Bridge at Rushton.

Table 1. Details of crayfish found during the survey.

Juv.	Female	Male	Escaped	CL (mm)	Other comments
	✓			25	healthy
		✓		21	healthy
✓				9	healthy
		✓		25	1 claw missing
		✓		31	healthy
			✓		small
			✓		small
			✓		small
		✓		34	healthy
			✓		small
				41	dead, porcelain disease.
	✓			22	porcelain disease
			✓		medium size
	✓			32	porcelain disease. Recorded on a follow up visit, 4.9.02
		✓		33	healthy, soft shell. Recorded on a follow up visit, 4.9.02

Of all the individuals that were examined, six were apparently healthy. One was missing a claw, but otherwise healthy. Two live individuals were showing symptoms of porcelain disease and one had apparently died of the disease. Of the live population, this represents about 25% that are showing symptoms of porcelain disease.

Mean carapace length was 27.3 mm. Only one individual was found smaller than 20 mm, although four of the five that escaped are described as “small”.

DISCUSSION

The results of this survey indicate that there is a small population of native crayfish in the Ise, despite the crayfish plague that affected the river in 1990. It is unclear why the population at Rushton was not recorded in any of the previous routine sampling work. One explanation could be that it is the result of a recent human introduction, but that seems unlikely. It is possible that they have been at Rushton for the past 10 years but were consistently missed during the Environment Agency's twice yearly invertebrate sampling. Crayfish can be difficult to detect until they get to a relatively high density. A signal crayfish population introduced to the South River Gwash in 1988 was not detected by routine sampling until the middle 1990s, despite being close to an Environment Agency sampling point (R. Chadd, pers. comm., 2003).

It is also possible that a population of crayfish exists further upstream but were too remote from the plague incident to be affected. This could have acted as reservoir for colonisation of the Rushton site. If this is the case then it is probably the first recorded case in the UK of natural recolonisation by white clawed crayfish after a plague event.

Anecdotal records exist of crayfish further upstream than Rushton (R. Chadd, pers. comm., 2002). Survey work associated to road building suggests there is suitable habitat in this area (Middlemarch Environmental, 2002). Further survey work is required to determine whether or not they are present.

In addition, it is unlikely that the individual found at Geddington was washed all the way down from Rushton. This suggests that there are other areas in the river supporting crayfish, but at such low densities that they have not been detected. This is the current view being taken by the Environment Agency.

The finding of 25 per cent of crayfish with visible signs of porcelain disease is a high proportion (see Holdich, 2001; Tero *et al*., this volume). However, this is taken from a sample number that is far too small for statistical confidence. Additionally, individuals suffering from porcelain disease may well be easier to capture in nets than healthy individuals, which could in part account for the high proportion found.

It must now be considered what position to take regarding this population. It is after all only a very small stretch (250 m). The level of effort that should be put in to positive measures should be relative to the value and importance of the population in the context of other populations in the Northern Area of Anglian Region (Environment Agency Boundaries).

The River Witham has by far the largest populated length and numbers of crayfish in the Area and is obviously top priority (see Tero *et al*., this volume). There are three other sites in the area with native crayfish, the Chater, the Welland, and the Welton Arm. Two of these are in the Nene catchment, the Ise and the Welton Arm, but the Welton site is much smaller than the Ise. Part of the Ise is one of the few riverine SSSIs in the area. Therefore, it is suggested that the Ise is treated as holding an important crayfish population for the Area. Geographically, the area of river requiring attention is that between its headwaters and Geddington. However, habitat improvement directly adjacent to the Rushton population should receive highest priority.

Improvements to the River Ise would contribute to Biodiversity Action Plan (BAP) targets. The Agency is the BAP contact point for crayfish. Habitat enhancement and other measures designed to help crayfish would not only benefit crayfish, but many other species considered of conservation importance (e.g. grayling, otter).

Taking this position infers that some action is necessary. Recommendations and suggested priorities are detailed below.

RECOMMENDATIONS

PRIORITY	ACTION	COMMENT
High	The Agency should take the position that the crayfish population upstream of Geddington on the Ise requires protection when giving advice.	Advice on projects and consultation comments should take the requirements of crayfish into consideration. This action applies to the stretch of the Ise between Geddington and its headwaters.
High	The Agency should seek improvements targeted at crayfish and other BAP species and habitats on the Ise.	This action applies to the stretch of the Ise between Geddington and its headwaters. Highest priority for this work to be at and immediately adjacent to the site at Rushton.
High	Survey for crayfish upstream of Desborough	The Ise upstream of Desborough still requires survey. Middlemarch (2002) indicated suitable habitat that has not been properly assessed in this stretch. It should not be necessary to go any further upstream than Arthingworth (SP 752 811), as it is prone to drying from here up. This amounts to a further 7 km of river. The priority stretch (approx 3 km) is between Newbottle Bridge and Desborough, as its environmental and habitat conditions are thought suitable and there are also old anecdotal records of crayfish in this area (Richard Chadd, pers. comm., 2002).
High	Ensure that future surveys fully record possible crayfish burrows and symptoms of porcelain disease.	To date, it has not been common practice to record the burrows created by crayfish, as it was not a known characteristic associated to them. Although porcelain disease was properly recorded in this survey, it is suspected that this has been under-recorded in the past, as surveyors were not familiar with the symptoms.
High	Ensure others are aware of the crayfish population on the Ise, in order to positively influence land management, and development.	If FWAG and DEFRA are aware that the Agency considers the Ise as an important site for crayfish, it may be possible to encourage more sympathetic land management, particularly if incentives are targeted towards this aim (e.g. through the countryside stewardship scheme). Other actions associated to this should include local involvement.
High	Organise a protocol for managing a suspected plague event (Gerrard, 2002)	Steps have already been made towards this recommendation. A protocol could be applied widely, not just to the River Ise. Protocol development should be done in liaison with the national crayfish BAP steering group.
High	Target the facility causing sewage debris to enter the river for improvements.	This action would have wider benefits than just improving the situation for crayfish, and could be done under AMP or the Water Framework Directive.
Medium	Contact fishing lake owners	Upstream of Rushton Bridge are off -line fishing lakes that discharge back in to the Ise directly upstream of the crayfish population. Discussion with the owners may help to avoid the introduction (deliberate or accidental) of signal crayfish in to the catchment.

Medium	Place crayfish refuges in areas of poor substrate quality.	This could be done strategically, in order to link up the existing population with other suitable areas and to allow recolonisation of the downstream SSSI. It should be noted that expansion of the colony may take some time and might need to be done in conjunction with other work aimed at widening the distribution along the river if it is to succeed.
Medium	Target land management practices.	Upstream of the Rushton population, many of the arable fields were apparently contributing to the problems of sedimentation in the river. Again, improvements to this situation (e.g. buffer strips) would have wider benefits for the biodiversity of the river in general. However, this is a much more long term and complex action, but ties in with the target of raising the profile of the crayfish population.
Low	Investigate tributaries and ponds for crayfish	Gerrard (2001) recommended that tributaries and ponds should be investigated. It would not be unreasonable to expect to find crayfish in some of these, particularly in areas close to populated stretches.
Low	Crayfish trapping	Gerrard (2001) recommends trapping to ensure areas that are too deep for manual searches are investigated. This would give a more comprehensive understanding of crayfish distribution in the Ise, where long lengths were not properly surveyed because they were too deep. However, this method was recently used on the Chater and was not found to be a successful method.
Low	Identification of structures that could prevent native crayfish from spreading.	Gerrard (2002) suggests that this should be carried out, with reference to identifying structures that are stopping recolonisation of the SSSI. The habitat maps that have already been done do give some indication of the locations of weirs etc.
Low	Identification of signal crayfish sites in the Nene catchment close to the junction with the Ise (Gerrard, 2001).	Determining how close signals are to populating the Ise may affect the decision on what course of action is most appropriate. However, the Ise does not join the Nene for another 20 km downstream of Geddington, and therefore it is not an urgent task.
Low	Identification of work that could prevent the establishment of signal crayfish in the Ise (Gerrard, 2002)	Although this too could affect the decision on what to do with the Ise population, it is already known to be a very difficult task. There is probably more to be gained from tackling this task through raising awareness and PR than concentrating unduly on mechanisms to stop the upstream migration of signal crayfish.

CONCLUSIONS

The Environment Agency has determined that an isolated population of white-clawed crayfish is present in the River Ise despite the fact that crayfish plague affected the river in 1990. It is unclear how they have survived, or why follow up surveys failed to detect them for 10 years. It could be that the river is slowly being recolonised from an unknown upstream population that survived the crayfish plague.

The absence of signal crayfish, the size of the population relative to the only other in the Nene catchment, and the SSSI status of the river all give this population significance, and justify putting effort in to improving the favourable condition status of the river for crayfish.

Of high priority for the Agency in relation to this is to modify its advice on various proposals (e.g. developments in the catchment), in order to take into account crayfish requirements. The Agency will ensure the surveys are continued upstream in search of further isolated populations of native crayfish.

The Agency will also seek riverine improvements such as habitat enhancement and investigate the cause of sewage effluent entering the river. Local awareness of the native crayfish population is considered important and discussions with appropriate organisations to encourage more sympathetic land management are planned for 2003.

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A MODEL FOR THE SELECTION OF REFUGIA FOR WHITE-CLAWED CRAYFISH

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ABSTRACT

The Crayfish Habitat Suitability Index (CHSI) model was developed to objectively rank potential sites to be used for relocating existing populations of crayfish thought to be in immediate danger and to aid the crayfish reintroduction process. Adapted from the US Fish and Wildlife Service who had developed a Habitat Suitability Index (HSI) for many species, the model's main aim was to objectively rank sites, which on initial inspection were all considered to be more or less suitable.

The model is a numerical index that represents the capacity of a given habitat to support a selected species by estimating the habitat conditions in the study area and comparing it to the optimum habitat conditions for that species. To establish optimum habitat conditions for white-clawed crayfish a detailed review of scientific literature, practical reports and crayfish surveys was undertaken.

An Excel spreadsheet was designed to calculate the CHSI for six potentially suitable crayfish watercourses in the Peak District using a linear approximation assuming 0.0 for non-optimal habitat parameters and 1.0 for optimum values. Site data for 13 variables specific to the habitat requirements for the white-clawed crayfish were collected by surveys from 30 possible refugia on the six watercourses and these were modelled according to their suitability under the general headings of water quality, channel substratum and canopy cover.

The CHSI values generated were believed to represent the relative potential of the watercourses to support a crayfish population. Although interpretation is one of comparison, the use of the CHSI has enabled ranking of possible refuge sites and the best sites were identified by use of this scientifically robust procedure.

The model is simply a computer model of recorded variables, it could be further improved by increasing the range of variables and weighting of factors for different river catchments. Application of the model is possible for processes such as selecting crayfish sites for refugia introduction.

Keywords: crayfish, model, ranking, refugia

INTRODUCTION

When moving crayfish to new sites it is important to assess the sites in a scientific way to be able to decide which site might be best to move them to. An astacologist can subjectively select potential re-introduction and refugia sites by weighing up the relevant information available but ranking the sites in an order (i.e. best to worst) and selection of the most suitable site is a matter of opinion.

The aim of the CHSI was to improve selection of sites to be used for refugia for existing populations of crayfish thought to be in immediate danger and to aid the crayfish introduction process by objectively ranking sites, which were all considered to be more or less suitable. The guide for the model was adapted from the US Fish and Wildlife Service (USFWS, 1981) who have been developing a Habitat Suitability Index (HSI) for many species since 1974 mainly for use in impact assessment and project planning. A HSI can be defined as a numerical index that represents the capacity of a given habitat to support a selected species by estimating the habitat conditions in the study area and comparing it to the optimum habitat conditions for that species (USFWS, 1981). In this project the model was adapted to evaluate and quantify habitat parameters for a selection of watercourses in the Peak District in order to assess their suitability for use as refugia for the white-clawed crayfish. It was beyond the scope of this project to place any weighting to the environmental factors (variables) although this would be incorporated into any future development of the model.

METHOD

The HSI model produces a 0.0-1.0 index assuming that a direct linear relationship exists between the HSI value and carrying capacity. The minimum value of a HSI is 0.0, which represents totally unsuitable habitat and a maximum value of 1.0 that represents optimum habitat.

In order to develop a Crayfish Habitat Suitability Index (CHSI) a detailed review of scientific literature, practical reports and crayfish surveys were undertaken to establish optimum habitat conditions for 13 variables specific to the white-clawed crayfish under the general headings of water quality, channel substratum and canopy cover based on literature cited for each variable (Table 1).

An Excel spreadsheet was designed to calculate a CHSI for each site surveyed. The relationship between the selection of habitat variables and crayfish habitat quality are represented graphically. Examples of graphs are shown in Fig. 1 where optimum suitability is represented by a suitability value of 1.0 and unsuitability by a value of 0.0. The graphs are based on the assumption that the suitability of a particular habitat variable can be represented by a two-dimensional response surface and is independent of other variables that contribute to habitat suitability. Data sources and assumptions are listed in Table 1.

The authors selectively selected six potentially suitable crayfish watercourses in the Peak District as they fulfilled some or all of the following criteria:

- They were not adjacent to known signal crayfish poulations.
- There were tributaries of rivers that had previous records of white-clawed crayfish populations. (The River Lathkill was excluded from this project as a reintroduction programme is currently taking place on this river).
- They were easily accessible.

These were Hoo Brook, Warslow Brook, Beeley Brook, Via Gellia, Clough Brook and Cressbrook Dale. It was considered impossible to rank these sites other than by opinion because they all appeared more or less suitable.

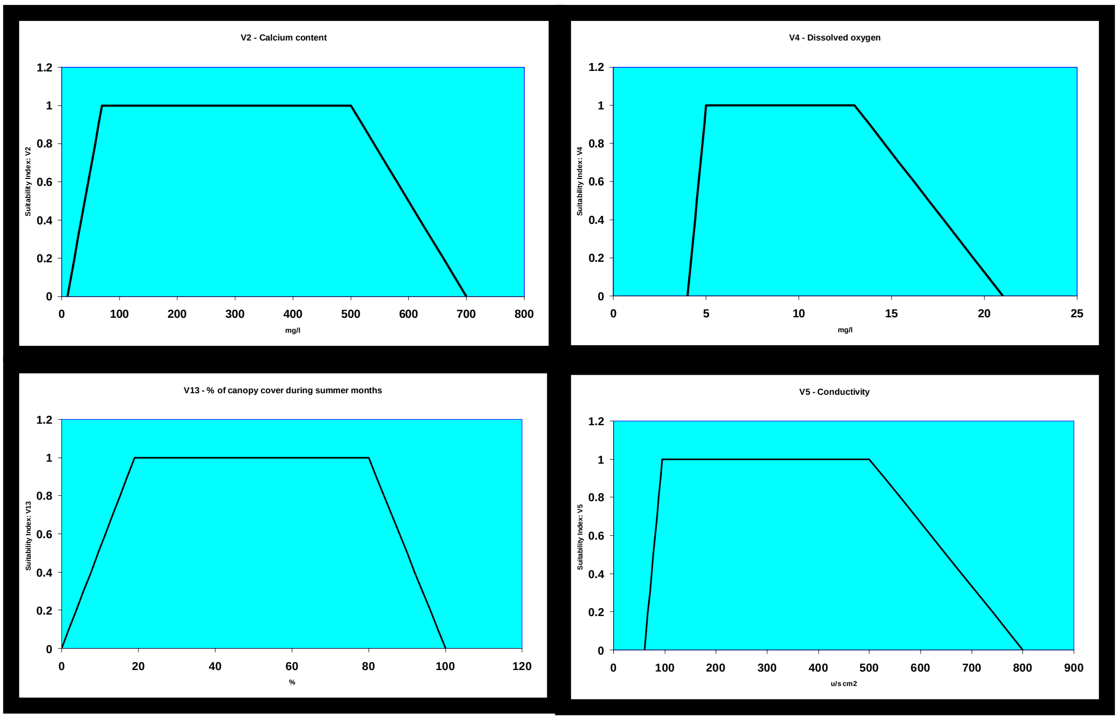

Figure 1. Examples of graphical representations of crayfish habitat variables.

Table 1. Data sources and assumptions of CHSI.

Variable	Source	Assumption
V1 - pH	Holdich & Rogers (2000) Jay & Holdich (1977) Smith *et al.* (1996)	Optimum pH levels for *A. pallipes* is between 7.0 and 9.0.
V2 - Calcium content	Brewis & Bowler (1982) Pratten (1980) Holdich & Rogers (2000)	*A. pallipes* fail to grow and moult below 10°C and growth declines at temperatures over 20°C. Reproduction is adversely affected at temperatures outside 10-20 °C.
V3 – Temperature	Reynolds (2002) Holdich & Reeve (1991) Greenaway (1974) Holdich & Rogers (2000)	*A. pallipes* require a water calcium content of at least 10 mg 1^{-1} although the higher the better.
V4 – Dissolved oxygen	Naura & Robinson (1998) Gibbons (1997)	*A. pallipes* require moderately well oxygenated water for survival. Optimum oxygen levels are between 5-13 mg l^{-1}
V5 – Conductivity	Foster (1995)	Minimum value of conductivity where crayfish are present - 93 µS cm^{-1}. Conductivity increases with increase in crayfish abundance.
V6 – Bedrock V7 – Boulders V8 – Cobbles V9 – Pebbles V10 – Gravel V11 – Sand V12 - Silt	Smith *et al.* (1996) Holdich & Rogers (2000) Naura & Robinson (1998)	The presence of bedrock, boulders and some cobbles are a positive attribute for *A. pallipes*. Cobble only substratum and the presence of small pebbles, sand and silt have a negative effect on crayfish presence.
V13 – Canopy cover	Smith *et al.* (1996) Holdich & Rogers (2000) Naura & Robinson (1998) Foster (1993)	The presence of overhanging trees and their roots provide shade, a food source and shelter, especially for juvenile crayfish.

Site data for the variables considered specific to the requirements of white-clawed crayfish were collected by surveys from five sites on each watercourse.

The results from each site were entered into an Excel spreadsheet to calculate a suitability index value (SI), which were then combined into component indices for water quality, substratum and canopy cover using the following equation:

Water quality (WQ) = $(SI_{pH} \times SI_{Calcium} \times SI_{Temperature} \times SI_{Dissolved\ oxygen} \times SI_{Conductivity})^{1/5}$

Substratum (S) = $(SI_{Bedrock} \times SI_{Boulders} \times SI_{Cobbles} \times SI_{Pebbles} \times SI_{Gravel} \times SI_{Sand} \times SI_{Silt})^{1/7}$

Canopy cover (CC) = $SI_{Canopy\ cover}$

CHSI = $(WQ \times S \times CC)^{1/3}$

RESULTS

The Crayfish Habitat Suitability Index values given in Table 2 are compared to show which are the most suitable of the six watercourses surveyed for possible refugia for white-clawed crayfish. The nearer the index score is to 1.0, the more suitable the watercourse is for white-clawed crayfish based on the variables used for this project.

Interpretation is one of comparison.

Table 2. CHSI for watercourses surveyed.

Variable	Hoo Brook	Warslow Brook	Beeley Brook	Via Gellia	Clough Brook	Cressbrook Dale
Total water quality	0.83	1.0	0.92	0.90	0.99	1.0
Total substratum	0.91	0.87	0.79	0.49	0.78	0.60
Total canopy cover	0.95	1.0	1.0	1.0	0.73	0.76
Total CHSI	**0.90**	**0.96**	**0.90**	**0.76**	**0.83**	**0.77**

DISCUSSION

The CHSI values are believed to represent the relative potential of the watercourses to support a white-clawed crayfish population. Warslow Brook generated the highest CHSI value (0.96) indicating this would be potentially the best site for crayfish re-introduction or refugia. Fig. 2 illustrates one of the sampling sites on Warslow Brook and close observation does confirm that it displays good crayfish habitat, e.g. large boulders to provide hides and adequate overhanging vegetation, and would be considered a good site in an astacologist's opinion. Thus the scientific methodology used to rank refugia in the model does appear to confirm opinion, i.e. it appears to work.

CONCLUSION

The model and use of the CHSI has enabled ranking of the refugia sites and the best sites have been identified. Scientifically robust procedures rather than opinion were used to reach the result, therefore the concept has wide application, e.g. for selecting refugia and for incorporation at a suitable stage in the crayfish re-introduction process.

Figure 2. An example of good crayfish habitat on Warslow Brook with a CHSI value of 0.96.

A model based on this concept could be further improved by ranking of other factors, e.g. pollution, and may also be refined by balancing or weighting of the variables. These improvements could produce a useful, practical tool for crayfish conservation biology.

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THE SLOW QUIET INVASION OF SIGNAL CRAYFISH (*PACIFASTACUS LENIUSCULUS*) IN ENGLAND - PROSPECTS FOR THE WHITE CLAWED CRAYFISH (*AUSTROPOTAMOBIUS PALLIPES*)

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ABSTRACT

This paper discusses the reasons why colonising populations of signal crayfish (*Pacifastacus leniusculus*) are so difficult to detect, and why it has taken so long to recognise the threat that they pose to the native species (*Austropotamobius pallipes*) – with or without the plague fungus (*Aphanomyces astaci*).

The story of the virtual extermination of the native red squirrel by the introduced grey squirrel appears to be in the process of re-enactment; this time our native white-clawed crayfish is being exterminated by the introduced signal crayfish. The popular idea that the crayfish plague disease is the main cause of the extermination of our native species is here shown to be false - competitive exclusion in the absence of disease may be just as important.

How did the signal crayfish establish itself so widely? Part of the answer is that we cannot detect the early stages of colonisation because of the limitations of our survey methods. It may take a population of signal crayfish ten years or so to become sufficiently numerous to be detected during regular surveys. The colonising vanguard of signals, spreading at perhaps 1 km yr^{-1}, is virtually undetectable and almost impossible to stop. Prospects for the survival of most of the remaining colonies of our native crayfish appear to be poor in the medium to long term. The seriousness of the threat to our native species was not appreciated initially, since at the time when crayfish farming was becoming popular in England, the native crayfish was not a protected species.

Keywords: crayfish, signals, natives, colonisation, control, population density, viable population, refuges

INTRODUCTION

The white-clawed crayfish (*Austropotamobius pallipes*) (Fig. 1) is the only English representative of the group of freshwater crayfish, many species of which are found in other countries with temperate to tropical climates (Taylor, 2002).

Austropotamobius pallipes is a cold-water species that tends to be confined to smaller upland, base rich, watercourses wherever it has to compete with other species. In England it is sometimes found elsewhere, e.g. in base poor waters, larger rivers and stillwaters, although its abundance in these can vary enormously from year to year, apparently due to natural but unknown causes. Occasionally native crayfish become so abundant that they cause nuisance to anglers by taking their baits, then seem to disappear a year or so later. While some disappearances can be proved to be due to plague or signal crayfish competitive invasion, there may also be false disappearances due to natural fluctuations in abundance such as are found in other organisms, e.g. red tides, lemmings, etc. Pixell Goodrich (1956) describes several incidences where native crayfish underwent cycles of abundance and decline during the late 19th and early 20th centuries, long before plague disease arrived in the UK. Over the last thirty years there have been many well-authenticated incidents of crayfish plague disease (Alderman & Polglase, 1988; Holdich *et al*., 1995b; Holdich, this volume).

Due to the difficulties with sampling there are few quantitative records in any rivers, therefore the effects of pollution, plague disease and alien introductions may be exaggerated.

The white-clawed crayfish has been a protected species (Schedule 5 of the Wildlife and Countryside Act 1981; IUCN Red Data List; Bern Convention; The European Habitats Directive requires designation of Special Areas of Conservation for the species) since 1981 (Holdich & Rogers, 1999). Prior to this time it was used for occasional food and as bait in sport fishing. It is not suitable for commercial farming due to its slow growth rate and relatively small size at maturity, compared with the price that it commands.

The signal crayfish is the most successful of the handful of alien crayfish species introduced to England over the past 50 years (Holdich *et al*., 1995b). In the 1970s and 1980s it was farmed profitably, especially as a sideline to fish farming. It is faster growing and larger than the native species. Government grants are still available for diversification into signal crayfish farming. Partly due to the increasing wildcatch of signal crayfish following their successful colonisation of many English river systems (at the expense of the native crayfish population), it has been increasingly difficult to grow them at a profit (Rogers & Holdich, 1995; Holdich, 1999). The gross annual turnover of crayfish farming in the UK was around £100 000 in 1996, which makes it a very small business compared with trout farming that turned over around £27.4 million in the same year (Hiley, 1996). In 1996 it became an offence to keep signal crayfish without a licence, and at the same time new farms were required to be escape proof, while existing signal crayfish farms in Special Areas of Conservation were given a licence to continue operating (Holdich & Rogers, 1997; Scott, 2000; Oldaker & Chambers, this volume).

Because some of the signal crayfish introduced to the UK carried the crayfish plague fungus, which affects them rather little but causes 100% mortality in white clawed crayfish, there were sporadic outbreaks of the disease in many English rivers (Holdich, this volume) resulting in the loss of the native species from them. Farmed signal crayfish and the transport of plague spores on angler's fishing nets were both blamed for these outbreaks. It became normal to blame signal crayfish for plague disease, and also to assume that whenever native crayfish populations were destroyed, that plague disease was responsible. The slow but inexorable replacement of native crayfish by non-diseased signal crayfish throughout every river system that they accessed failed to be generally appreciated. One of the difficulties is that sampling methods for crayfish are incapable of detecting low numbers, such as occur during the early years of a colonisation.

SAMPLING METHODS ARE INADEQUATE

Although there have been recent improvements in methods, there are still no reliable means of detecting crayfish populations below a density of 0.2 animals m^{-2} (Peay, 2002). If crayfish are captured one can be reasonably certain that a viable (i.e. self-sustaining) population exists, but failure to capture does not have the opposite meaning. The secretive habits and irregular distribution of both native and signal crayfish, exploiting inaccessible interstitial areas of rocky riverbeds, bridge walls etc. make them very difficult to capture effectively. Even at Grassington on the R Wharfe, where signal crayfish reach abundances of 20 m^{-2} in suitable habitats, there are large areas of unsuitable rock and gravel in which crayfish cannot be found.

Figure 1. Native British crayfish, *Austropotamobius pallipes*.

Figure 2. Alien signal crayfish, *Pacifastacus leniusculus*.

Trapping, a method similar to commercial harvesting, tends to capture only large individuals and in some instances no crayfish enter the traps even though substantial populations can be found by other methods. Nevertheless trapping remains an accepted method of estimating crayfish populations. Hand searching, e.g. 15 minute stone turning covering an area of $5m^{-2}$ should detect a density as low as 1 per $5m^{-2}$ of 2-3 year old crayfish (Peay & Hirst, this volume). The introduction of night search (observation of crayfish during their nocturnal activity) in 1995 made it possible to detect populations of crayfish as low as one per 100 m^{-2} given clear water no deeper than 0.5 m and safe wading conditions. By combining these methods the colonisation and subsequent increases in abundance of signal crayfish have been tracked in the River Wharfe in Yorkshire (Peay, 1997).

The lack of suitable sampling methods has delayed the appreciation of the seriousness of the threat of signal crayfish to white clawed crayfish.

WHITE CLAWED CRAYFISH CAN BE REPLACED BY PLAGUE-FREE SIGNAL CRAYFISH

In 1995 an exclusive population of signal crayfish was present in the River Wharfe (Yorkshire) up and downstream of Kilnsea Village, after their introduction to the fish farm in the village (approximately 1980). To either end of this zone were mixed populations of white-clawed and signal crayfish, grading with distance into exclusive populations of white-clawed crayfish. It was discovered (Peay 1997; Peay & Rogers, 1999) that the signals-only and mixed zones were moving downstream at 1 km or more each year (as found in other rivers, e.g. Guan & Wiles, 1997). The upstream colonisation appears to be going more slowly; however, the river upstream of Kettlewell, where the author found a mature pair of signal crayfish in 2002, becomes torrential and not well suited to either species. It is therefore virtually impossible that the signal crayfish in the R Wharfe are infected with the plague disease, otherwise the adjacent native crayfish, especially downstream, would have succumbed and been exterminated.

There are signal crayfish populations in nearby ponds and tributaries of the main River Tees. Although native crayfish were reported to be present in the river no crayfish of either species were found in a 1997/8 study aimed at detecting plague disease. Caged native crayfish were therefore used as “canaries” in the ponds and the river, but no signs of plague disease were found. The same study found no plague disease in a pond containing signal crayfish adjacent to the R Ure. (Hiley, a, in prep.). Therefore, in contrast to Lang & Wylde (2000), reporting on the By Brook in Wiltshire, plague-free signal crayfish populations seem to be widespread in some parts of the UK.

All available information supports the above finding that when signal crayfish colonise, they replace white-clawed crayfish completely. (e.g. Holdich & Domaniewski, 1995; Holdich *et al*., 1995a). The natural habitats of the two species are similar, though it appears that the signal crayfish may have a wider range than the native species; therefore there may be no habitats in which the white-clawed crayfish has a competitive advantage.

Figure 4. Typical upland crayfish habitat, River Dibb, tributary of River Wharfe, Yorkshire, England.

BOUNDARIES TO THE SPREAD OF SIGNAL CRAYFISH

The spread of signal crayfish probably has no boundaries other than those of the river system itself. In Yorkshire the total loss of white-clawed crayfish from the River Ure, a candidate SAC site for the species under the Habitats Directive, is almost inevitable due to recent findings of signal crayfish in the Tanfield area of the river. The populations of native crayfish in the tributaries and connecting rivers Rivers Swale, Nidd and Ouse would also seem to be doomed. The way in which the River Wharfe, as described above, is losing its population of native crayfish is being carefully monitored. The rate of invasion is slow, but it is inexorable once it starts.

During the investigation of eradication methods (Peay & Hiley, 2001), it was established that dams and weirs checked but did not prevent the spread of the species. Signal crayfish readily walk on land and can thus go round such obstacles (see Holdich, this volume). To be effective a weir would need to be combined with extensive wing-walls to either side on the land, for an unknown distance and of such a size that no flood could by-pass them.

The animals can survive out of water for up to three months in a humid atmosphere (author’s own observations) and are found grazing out of water at times. They have been observed to travel several 100 m over land in one night. Few if any crayfish farms are fenced well enough to prevent such escapes. Most rearing ponds have a through flow of water and, short of filtering all of the outflow water 100% of the time through a 1 mm mesh to prevent fertile eggs and newly-released young escaping, there is no practical means of stopping signal crayfish walking out down the outflow stream into the adjacent watercourse.

A mature female signal crayfish was found in a static ditch below a 2 m high vertical outflow weir of a pond in 1996. When overflowing rainwater raised the level of water in the ditch the crayfish could have accessed a gravely stream that led down to the R Tees. The colonisation of a larger stream below a similar pond in the same area was observed to be in progress during 1997. Some ponds may have no obvious outflow, but virtually all ponds in England overflow during extreme rainfall. This water, along with contained crayfish, may find its way to a watercourse. The only truly safe pond may be one that is connected to a heavily polluted watercourse, so that all escapees are killed before they can access clean water. The steady downstream advance of signal crayfish at 1 km a year is strong evidence that crayfish do not drift. So, it is unlikely that escaping signal crayfish would use the current to move rapidly through a polluted watercourse, though they may walk out onto land and avoid it in that way.

The conclusion is that there is no such thing as a confined population of signal crayfish in a river catchment. That being so, efforts to remove signal crayfish from affected rivers may be thwarted by repeated colonisation from adjacent commercial populations.

The presence of large and expanding populations of signal crayfish increases the chances of casual, illegal introductions being made from affected rivers to watercourses and waterbodies not presently containing signal crayfish. It is a popular pastime, for example on parts of the River Wharfe, to collect signal crayfish for fun or for barbecues. It is not a great stretch of the imagination to see some of these crayfish being released to other watercourses in ignorance of the consequences. The law forbidding the unauthorised keeping and transfer of signal crayfish is not well enough known to prevent such introductions. Thus it is vital that a reliable control method is discovered, if it exists.

OTHER EFFECTS OF SIGNAL CRAYFISH

High densities of signal crayfish, being burrowers and omnivores, can have radical impacts on the entire river ecosystem, affecting macroinvertebrates, macrophytes, fish (Lang & Wylde, 2000) and riverbed characteristics (Holdich *et al*., 1995b). S. Peay and the author found population densities of around 20 signal crayfish m^{-2} in favourable habitats at Grassington (River Wharfe) in 1999, whereas densities of 2.9 white-clawed crayfish m^{-2} were found in similar conditions at Barden (Peay, 1997). Since signal crayfish growth rates are faster than white-clawed crayfish, their food requirements for the same standing crop are probably greater, increasing their ecosystem effects further. Native crayfish rarely burrow (see Gerrard *et al*., this volume; Tero *et al*., this volume), so this activity of signal crayfish represents a substantial change to the habitats for other organisms.

RECOGNISING THE SERIOUSNESS OF THE THREAT OF SIGNAL CRAYFISH

The seriousness of the threat to the native species was probably not appreciated at the start of introductions of signal crayfish to England. Delays of six or more years between an introduction and the finding of signal crayfish in a watercourse might be reassuring, because of the difficulty of detecting low-abundance populations. The subsequent sedate pace at which the species spread would confirm an apparent inability to colonise far. Its ability to cross land barriers was not appreciated and this causes the most difficulty in proposing ways in which existing populations, which have not already colonised adjacent watercourses, can be prevented from doing so.

The concept of Minimum Viable Population Density or MVPD helps to explain why colonising populations undergo a lag of 6-10 years before they can be detected, lulling the observers into a false sense of security. This concept is also a key to finding effective control methods, for it defines the maximum number of signal crayfish that can be left in a river without any further population increase.

Defining Minimum Viable Population Density (MVPD)

The smallest abundance or density of signal crayfish necessary to allow increases in numbers and continued colonisation could be called the MVPD. The following argument suggests that the MVPD for signal crayfish is far lower than the detection limit of any known survey method.

Allowing for increased wandering activity of male crayfish during searching for a mate, e.g. a nightly range of 100 m^{-2} (S. Peay, pers. comm.), and assuming the female uses a pheromone attractant effective over 1 m^{-2}, there would need to be just one fertile female per 100 m^{-2} per night in order for mating to be successful. If the pheromone was effective over 10 m^{-2}, one fertile adult crayfish of either sex per 500 m^{-2} would be required. This apparently viable population, two per 1000 m^{-2}, is well below the detection limit of any known survey method (0.2 m^{-2}, Peay, 2002). There may be density dependent factors acting for example on young crayfish such that the MVPD is higher than this, but no information is available. Thus for present purposes an apparent density of zero is the target figure for control methods.

Successful colonisation should follow the escape of less than ten individuals into a kilometre of a 5 m wide river. There is no evidence to suggest that dispersal would be prevented, i.e. the invading crayfish permanently confined to a zone of a river, at population densities above this level.

Apparent lag between introduction and appearance of signal crayfish

A lag is often noticed between the introduction of signal crayfish to an enclosed water and their subsequent appearance in a river. At 3 years old the crayfish can breed, producing around 100 young per pair. Saturation might be reached following second generation breeding 3 years later, at which time the pressure to migrate is likely to increase as food and shelter resources become limiting. Subsequently, the escapees would need to breed, taking perhaps a further 6 years to reach saturation.

In a watercourse 2 m wide and 200 m long, 80 large animals would have to escape to be detected by hand search or other casual observation. If a smaller number escaped, a 3-6 years lag might occur before the escape was detected, at which time the population density in that area could be around 12 m^{-2}, i.e. 4800 crayfish. It makes little difference to the outcome, using the above logic, if a single egg-bearing female escapes, or a larger number.

CONTROL AND EXTERMINATION METHODS

Control methods are re-examined in this section in the light of knowledge given elsewhere in this paper.

Because of the lack of knowledge of MVPD and the slow but inexorable rate of replacement of native crayfish by signal crayfish, whether or not infected with plague fungus, attempts at control of signal crayfish have fallen far short of the required effectiveness. Furthermore, several years have passed during which signal crayfish have colonised many more rivers.

To measure the success of control methods, the purpose of control may be defined as "to prevent further colonisation of signal crayfish and consequent harm to white-clawed crayfish". Control methods that do not involve extermination must, *de facto*, imply a permanent commitment to conduct whatever is required, which should constrain the extravagant use of resources on inefficient methods.

By permanent deployment of poisons plus spot treatment of outbreaks, the urban rodent populations of the UK are kept to an 'acceptably' low level, in the recognition that while elimination from a small area, e.g. a building, is practical, recolonisation is inevitable. Only if a means of exterminating the entire rat/mouse population of the mainland UK was possible, with perfect prevention of new introductions, would it be sensible to cease rodent control. This should be borne in mind when contemplating, for example, intensive trapping exercises for signal crayfish.

Removal by trapping

Traps are selective for large individuals, and usually only a small proportion of those. No signal crayfish population has ever been threatened with extermination by commercial over-exploitation. The abundance of natural food and shelter in a river mean that traps do not represent an irresistible attraction to crayfish.

Removal by hand collection

All materials likely to shelter crayfish have to be turned over or moved aside to expose the animals, which are then captured by hand or in a net. 0+ and 1+ signal crayfish are very difficult to capture, especially in warmer weather, because of their rapid escape reactions. Not all available habitats can be inspected in most watercourses due to depth, water colour and the deep burrows made by signal crayfish. Serious ecological harm may result from frequent overturning of the riverbed. Unless the method produces rapidly declining numbers of captures with each repeat, it is clearly futile. It should be repeated annually for several years to confirm that no new specimens are being found, once apparent extermination has been achieved. On the R Derwent at Ayton (Hiley, b, in prep.) intensive hand collections were shown to have removed 10% of the native crayfish population in a rescue exercise in which all available habitats were apparently searched.

Removal by habitat destruction

The complete destruction of crayfish habitats may be possible by dewatering and mechanical excavation. Dewatering alone would not succeed unless maintained for well in excess of 3 months, because of the excellent survival rate of signal crayfish out of water. Neither of these methods is practical in all but the smallest of ponds and streams.

Removal by predators

The normal predators of crayfish, such as fish, mink, otters, people and birds are restricted in the proportion of the population that they can access, thus ensuring the survival of populations of both native and signal crayfish in nature. If it were possible to stock a reach of signal crayfish infested river with a dense population of, for example, eels of all sizes, it is likely that the crayfish population would be severely reduced (but not below MVPD perhaps). Confining the predators to the reach would be difficult and they would certainly cause the virtual extermination of most of the other freshwater life. Predators such as mink tend to select the larger crayfish.

Signal crayfish were found to have passed through a series of ponds at West Tanfield in Yorkshire, heavily stocked with large trout, suggesting that either the aggressive behaviour of signal crayfish is a partial defence or that they may have walked around the ponds on land at night.

Removal by disease

The crayfish plague fungus could be used to exterminate white-clawed crayfish if introduced into the smallest headstreams deliberately, throughout a river catchment. However, it would then be difficult to prevent its spread to other catchments. It may be similarly difficult to confine a disease specific to signal crayfish. Searching for, or genetically engineering, a disease to control signal crayfish may therefore not be advisable because of the potential threat to commercial signal crayfish throughout Europe.

Removal with toxicants

If it were possible to apply a substance toxic only to signal crayfish, and denature it before it reached the wider environment, it would represent a perfect control method. Such a substance is not known. Holdich *et al*. (1999) reviewed various possible methods for control of signal crayfish, finding that there were no toxicants, other than the well-known insecticides, with a history of use against crayfish of any description. There were many references concerning the dangers of pesticides and other toxicants to wild crayfish. A subsequent investigation of the literature confirmed that while several insecticides had been used on occasion to ‘control’ crayfish in rice fields, the insecticides tended to be of the persistent type (e.g. fipronil - aapco.ceris.purdue.edu/doc/min2002/attach/02apr29/attachi3.html). Furthermore, several documents and websites state that there are no pesticides approved for crayfish control (e.g. morgan.botany.uga.edu/wayne/messages/555.html). It has been concluded that no trials like those described in this paper have ever been conducted. With a non-specific toxicant, much of the invertebrate and fish life of the pond or river reach would be incidentally destroyed. Escapes of the crayfish onto the land and into burrows that may not contain the toxicant would need to be prevented or dealt with. Subsequent recolonisation by the natural fauna from adjacent regions would proceed, as in recovery from pollution incidents.

Preliminary laboratory tests with a range of common chemicals that can be easily degraded have shown that very effective control may be achieved with 1 hr contact (Hiley, b, this volume). However, further work is needed to specify the chemicals, concentrations and exposure times that would be most appropriate in field situations. By this means the environmental effects can be strictly limited to the target area.

The use of toxicants is limited by two factors. Firstly there is unlikely to be public acceptance of the deliberate poisoning of more than a small pond or a few 100 m of river. Secondly once a kilometre or more of river is treated, the chance of exterminating another invertebrate species increases markedly. There are probably no English rivers in which the existence of all rare species of invertebrate has been completely charted, so the raw data are not there to warn of such problems.

Once signal crayfish have spread around 1 km from the point of introduction it may be concluded that there is no feasible means of preventing them from colonising the entire watercourse system.

SAVING THE ENGLISH POPULATIONS OF *AUSTROPOTAMOBIUS PALLIPES*

Since there are no effective ways of preventing the spread of signal crayfish, their addition to the UK fauna and consequent virtual extermination of native white-clawed crayfish is inevitable. A sensible option is to accept that situation. Why spend substantial sums of money on signal crayfish control methods that are bound to fail when those sums could be spent creating and safeguarding native crayfish refuges?

Refuges for white-clawed crayfish could be created in isolated catchments, e.g. tributaries of heavily polluted rivers, rivers that intermittently flow through permeable strata, etc. Some still waters that are presently too acidic for crayfish could be treated with limestone and stocked. Rivers that are suitable for crayfish but have lost both species for various reasons may be restocked with native crayfish (Kemp & Hiley, 2002, this volume)

CONCLUSIONS

If there are signal crayfish anywhere within a river catchment, all white-clawed crayfish will eventually be exterminated. Signal crayfish will alter the ecosystems they colonise, causing breaks in long-run monitoring data.

Control of signal crayfish other than by complete extermination is futile. Only the use of toxicants shows any hope of being effective for such a purpose.

Casual introduction to as yet uncolonised waters is impossible to prevent, with the extent of current signal crayfish invasion of English waters.

The value of the signal crayfish industry in England is trivial compared to the costs of signal crayfish control.

The creation of refuges is the only means of assuring a continued presence of white-clawed crayfish in England.

As with the case of the grey squirrel, serious environmental change has resulted from the deliberate introduction of an alien species.

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Short communication

AUSTROPOTAMOBIUS PALLIPES - THE WHITE-CLAWED CRAYFISH BIODIVERSITY ACTION PLAN STEERING GROUP

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The white- clawed crayfish *Austropotamobius pallipes* is the only species of crayfish native to Britain. Once widespread, this species has been in steady decline and can no longer be found in many parts of the country. As a result it was considered a Priority Species by the Government who went on to publish an Action Plan to help prevent any further decline. A copy of this action plan can be found by following the link from the web page: www.ukbap.org.uk/plans/species/

The Steering Group was formed in 1998 with the task of ensuring that the action plan is implemented by the various responsible organisations. The Lead Contact for the Steering Group is the Environment Agency, the Lead Partner role is currently vacant. Progress on the BAP is reported to the JNCC every three years. The Steering Group representatives are:

Jonathan Brickland for British Waterways
Jon Bass Centre for Ecology and Hydrology
Alasdair Scott for Centre for Environment, Fisheries and Aquaculture Science (CEFAS)
Mike Howe for Countryside Council for Wales
David Fraser for English Nature
Julie Bywater and Peter Sibley for the Environment Agency
David Rogers for the International Association of Astacology
John Colton of Kingcombe Aquacare for the commercial sector
Adrian Hutchings of Sparsholt College
David Holdich for The Wildlife Trusts and CRAYNET

Areas of work covered by the steering group are:

- Suggest research proposals to the relevant agencies where gaps in current knowledge are identified
- Seeking resources for achieving the BAP
- To collate existing information to produce a crayfish handbook
- Give advice on the eradication and/or control of alien invasive species
- Liaison with the BAP targets group
- Links with LBAPS
- Give advice on the relocation/reintroduction of native crayfish
- Give advice on the implications of legislation on crayfish work

Keywords: BAP, steering group, native crayfish, alien crayfish, targets, reporting

Short communication

BUGLIFE - PUTTING THE BACKBONE INTO INVERTEBRATE CONSERVATION

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'Buglife - The Invertebrate Conservation Trust' is a new conservation charity set up by conservationists and invertebrate specialists concerned by the rate of extinctions of invertebrate species and declines in invertebrate populations.

Although these insects, spiders, snails, worms, crustaceans and their relatives make up more than 98% of all animal species, they have been largely neglected by conservation efforts, leaving a major gap to be filled.

As the first dedicated voice for conserving all invertebrates, Buglife represents the best chance to get invertebrates onto the same political and public agenda as birds and plants.

Freshwater invertebrates face particular challenges and the white-clawed crayfish is a species in steep population decline and potentially even threatened with extinction (Shardlow *et al.*, 2002). Society should commit adequate resources to finding a solution to the current problems facing our crayfish.

The aims of Buglife:

To prevent invertebrate extinctions and maintain sustainable populations of invertebrates in the UK, by:

- undertaking and promoting crucial study and research,
- promoting sound management of land and water to maintain and enhance invertebrate biodiversity,
- supporting the conservation work of other entomological and conservation organisations,
- promoting education and publicising invertebrates and their conservation, and influencing invertebrate conservation in Europe and worldwide.

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Keywords: crayfish, conservation, Buglife

Short communication

HABITAT FOR WHITE-CLAWED CRAYFISH AND HOW TO RESTORE IT

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This project was undertaken for English Nature and the Environment Agency as part of the Species Recovery Programme (SRP). It is one of a series of guidance papers and protocols that provide practical advice on measures to conserve white-clawed crayfish (*Austropotamobius pallipes*) in the UK, prepared by various authors for the SRP and for the Life in UK Rivers Project. The aim of this project was to describe the characteristics of good habitat for white-clawed crayfish and give guidance on when and how measures should be undertaken to improve habitat for crayfish.

The basic requirements for white-clawed crayfish are suitable habitat to provide refuges; an adequate food supply; access to other crayfish for breeding; suitable water quality; freedom from competition by alien crayfish, and freedom from crayfish plague. Inadequacy on any of these points can lead to the absence of a population of white-clawed crayfish.

Food supply is seldom limiting, except, possibly at the limits of crayfish populations in catchments with upland headwaters. Crayfish can survive mild organic enrichment, but are mainly found in water of biological class A or B. The recovery time of the macroinvertebrate fauna used in biological water quality monitoring is much less than that of white-clawed crayfish, which are slow to increase in abundance and slow to recolonise areas from which a population has been lost, so it is possible for localised losses of crayfish due to intermittent pollution to go undetected. Alien crayfish and crayfish plague are now well known to lead to loss of white-clawed crayfish where all other factors are highly suitable.

In some rivers the population of white-clawed crayfish in a catchment appears to be fragmented into at least partially isolated sub-populations. There may be partial barriers to the movement of white-clawed crayfish, such as a major weir or waterfall, a fast-flowing flume or culvert, an extensive seasonally dry reach or one with poor quality water. It should be noted that some of the methods used to survey crayfish are only effective in high-density populations and populations may be present, but at an abundance too low to be detected. Although isolation is usually seen as a problem for populations, ironically, low rates of contact between sub-populations may help to reduce or prevent the spread of crayfish plague where an outbreak occurs in part of a catchment. Note, however, that features that may be a barrier to white-clawed crayfish are not necessarily barriers to colonisation by signal crayfish *(Pacifastacus leniusculus)*.

Refuges are an important feature of habitat quality for crayfish and can be a limiting factor, especially where channels are highly modified and lacking in diversity. The project report gives details of the important features of refuges for crayfish and why each feature is necessary, based on the ecology of the species. Key features include refuges being submerged; big enough for the crayfish; stable; aerated and in suitable condition, and available for occupation. The report tables the advantages and disadvantages to white-clawed crayfish of life in different types of rivers and other waterbodies. The species can live in a surprising diversity of conditions, from upland rivers, to chalk streams, lowland clay rivers, canals and gravel pits.

The guidance gives a step-by-step method for assessing the scope for improving habitat. This is shown in the project report using a series of flow charts, tables and text. Key questions include: why do you want to improve habitat for crayfish, what is unfavourable about existing conditions, what improvement work do you want to do and is the work appropriate for this river? A further key point is: do you have the resources to do the work and monitor whether it has been successful?

The recommended approach is to plan any project carefully. It emphasises the need to consider the major issues at catchment level, before jumping into the channel to provide refuges. Issues such as pollution, siltation, low flows and alien crayfish need to be considered at the start. Habitat restoration in a degraded channel will not improve a population of crayfish if pollution events kill the colonists every couple of years. Recommendations are given on how to tackle the big issues, where it is feasible to do so. The report addresses the potential conflict and synergy between making improvements for white-clawed crayfish and other management objectives.

Practical information is given on how to create refuges for crayfish in the channel, using natural materials and artificial ones. Examples include placing stone on the bed or along banks, increasing refuges in banks using woody material and incorporating refuge features into hard structures such as concrete facing of banks. This information is likely to be of use to anyone needing to restore or improve a length of river following engineering works. Seven case studies are described and illustrated, showing works undertaken in various rivers and stillwaters.

The new report is intended as a sequel to Peay (2000) and is set out in similar style as a simple guidance note. It is likely to be of interest to staff from the statutory agencies, river managers, ecological consultants and engineers. The report is published by the Environment Agency. Details are available from www.eareports.com.

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Keywords: crayfish, habitat, refuges, restoration

Short communication

A PROTOCOL FOR REINTRODUCING WHITE-CLAWED CRAYFISH

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The project was undertaken as part of the LIFE in UK Rivers Project - a joint venture involving English Nature, Scottish Natural Heritage, Countryside Council for Wales, Environment Agency, Scottish Environmental Protection Agency and Scottish and Northern Ireland Forum for Freshwater and Environmental Research and the financial support of the European Commission's LIFE Nature Programme. It is one of a number of documents providing guidance on methods of conserving white-clawed crayfish (*Austropotamobius pallipes*) in the UK, prepared by various authors for the Life in UK Rivers Project and for the Species Recovery Programme (SRP).

White-clawed crayfish have been lost from many British watercourses in recent years due to a combination of factors such as competition from alien crayfish species, infection with crayfish plague and physical or chemical habitat deterioration. They have a relatively slow reproduction rate and do not readily recolonise new areas. If white-clawed crayfish are lost from an entire watercourse or an extensive reach of river, the population may not regenerate naturally. If populations could be re-established at suitable sites, this could serve to enhance the long-term survival prospects of the species. The aim of the protocol was to provide direct practical assistance to those planning, approving or carrying out re-introductions of white-clawed crayfish in Britain and Northern Ireland. The key issues addressed in the protocol are outlined below.

The role of reintroduction in species recovery programmes in Britain is the subject of a great deal of debate. The protocol is based on the guidelines published by the International Union for the Conservation of Nature (IUCN) in 1995, adopted in the JNCC publication Biological Translocations: a Conservation Policy for Britain (2001). Crayfish reintroductions are likely to be acceptable only when the principal aim is to establish a viable, free-ranging population of crayfish, within its former natural range and into suitable habitat.

The protocol gives a step-by-step approach to planning and carrying out crayfish reintroductions using a series of flow charts and supporting text. The reintroduction process is broken down into four key stages comprising feasibility, preparation, implementation and post-release activities.

The feasibility stage provides a mechanism for assessing the viability and acceptability of proposed reintroduction programmes on a species and site-specific basis. The suitability of the proposed receptor site and donor populations are considered along with potential risks to human health and safety and whether or not sufficient resources are available to carry out the project.

Many watercourses and waterbodies within the former range of white-clawed crayfish may no longer be suitable for supporting the species. Only receptor sites in a catchment with historic records of white-clawed crayfish are generally considered to be suitable, and only when no current populations of crayfish are present or likely to colonise the site naturally. The key consideration is the status of alien crayfish species in the catchment. North American signal crayfish (*Pacifastacus leniusculus*) are highly invasive and outcompete the native species at all sites where they both occur (see Hiley, b, this volume). If alien crayfish species have been previously recorded in continuously connecting watercourses within 50 km (by water) of the proposed receptor site, reintroduction will not result in the long-term establishment of a white-clawed crayfish population at the site, and as such it is unlikely to be suitable. In addition, the proposed receptor site must meet the ecological requirements for white-clawed crayfish (Holdich & Rogers, 2000; Peay, this volume; Watson & Rogers, this volume) including physical habitat and water quality, and there should be no known risk of sporadic pollution incidents.

Donor populations should be sourced from as close to the receptor site as possible, and ideally from the same catchment. Populations should be free of crayfish plague and of high enough density to enable crayfish to be readily 'harvested'. The incidence of porcelain disease in the population should be less than 10%. Populations that are due to be disturbed, for example during engineering works, may provide an excellent source of donor stock.

Health and Safety Risk Assessments should be undertaken to ensure no unacceptable risks to human health and safety are associated with the project, and sufficient resources should be available to complete all stages of the reintroduction, in terms of both funding and staffing.

If reintroduction is found to be appropriate it will be necessary to consult with and obtain the agreement of relevant partners/conservation agencies. Before the reintroduction is carried out necessary licenses and appropriate permissions must be obtained and any necessary site preparation works undertaken. A decision should be taken in consultation with nature conservation agencies as to whether to publicise the project.

The protocol contains guidance on selecting suitable stock for re-introduction. Ideally an equal number of male and female crayfish should be taken. A range of size classes should be harvested, although very large and very small individuals should be avoided.

The numbers of crayfish harvested will vary, but between 50 and 100 individuals are likely to be sufficient to enable a population to become established. No crayfish showing signs of disease should be taken and no more than 10 % of the favourable habitat patches at the donor site should be disturbed.

When transporting and storing crayfish it is important to keep the length of time for which they are held to a minimum. Interim storage facilities should be used if storage exceeds 18 hours. Aggression can be minimised by keeping crayfish cool, separating crayfish into size classes and providing abundant cover. Berried females should be transported separately to minimise the risk of egg shedding.

At the receptor site crayfish should be introduced to stable refuges in favourable habitat patches at a density of 1 individual per m^2 of favourable habitat patch.

If stable refuges are not easily accessible then they can be created following appropriate guidelines (see Peay, this volume). Appropriate measures should be taken to avoid the spread of crayfish plague and accurate records should be kept of the reintroduction process, i.e. whether or not it went according to plan.

The reintroduced population should be monitored annually for the first 3 years following reintroduction then at 5, 7 and 10 years from the re-introduction date. All works undertaken and copies of all records held should be reported to the relevant statutory agencies.

The crayfish reintroduction protocol is likely to be of interest to staff from the statutory agencies, river managers, ecological consultants and engineers. The report will be published early in 2003 by the Life in UK Rivers Project. Details are available from the Project website at http://www.englishnature.org.uk/lifeinukrivers/.

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Keywords: crayfish, reintroductions, protocol, LIFE Project, habitat

Short communication

MANAGING THE RISK TO THE BRITISH WHITE-CLAWED CRAYFISH FROM FISH INTRODUCTIONS INTO THE RIVER DOVE SAC

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The River Dove (Derbyshire) is heavily stocked each year with hundreds of brown trout to support its popular game fishery. The river also supports a healthy population of white-clawed crayfish (*Austropotamobius pallipes*). When the river became designated as a candidate Special Area of Conservation (cSAC) under the Habitats Directive increased measures were necessary to ensure that any activity including fish stocking did not pose a threat to the crayfish.

Fish stocking may pose a risk to crayfish in two ways: by increasing the risk of live alien crayfish being introduced to the river with fish or, by accidentally introducing crayfish plague spores (*Aphanomyces astaci*) with either the water or the fish themselves (Alderman *et al*., 1987; Oidtmann *et al*., 2002).

In the light of this risk, the Environment Agency established a national policy of only consenting fish introductions to crayfish SACs and SSSIs (Sites of Special Scientific Interest) from catchments free of signal crayfish (*Pacifastacus leniusculus*), or with no history of crayfish plague. Although in many instances it is reasonably certain whether a catchment contains signal crayfish, or has previously been subject to plague, instances arise where although the presence of signals is unlikely, their presence cannot be discounted. When presented with a proposal to stock fish into the River Dove from a fish farm within a catchment of questionable status with regard to signal crayfish, the Environment Agency was unable to unequivocally determine that the fish stocking would not adversely affect the SAC, as is required under the Habitat Regulations (1994). This was due to the fact that despite the absence of signal crayfish from the farm in question and its catchment, previous anecdotal reports of such crayfish in the catchment were known.

To provide confirmation of the absence of plague being present in the catchment of the fish farm a ‘canary’ group of native crayfish were placed at the outflow of the farm. The survival of these animals has been used to indicate the risk of plague or alien crayfish being present in the catchment to be acceptably low.

Initially, two cages, with a total of five adult crayfish taken from Markeaton Brook (Derbyshire) were used. They were left down ‘permanently’ under licence from English Nature. Before each fish introduction, the caged crayfish were checked to see if they were still alive, with no signs of distress. At the first check only two crayfish remained and it is not known why the others died. Subsequently, six more crayfish (supplied by Peter Sibley) were introduced, three in the outflow cage and three in the inflow cage. These are still alive and more fish introductions have recently been approved.

This situation requires continual monitoring as the source of fish for introductions changes, as does the distribution of alien crayfish and the risk of plague.

Furthermore, caged 'canary' crayfish are far from being an ideal bioassay for plague due to the lag period between contamination and manifestation of the disease, and this should only be used as an additional indicator of plague absence where a high degree of confidence of absence of signal crayfish, or plague has already been determined.

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Keywords: crayfish, fish introductions, cages, River Dove, plague, Habitats Directive

Short communication

SIGNAL AND NATIVE CRAYFISH IN BROADMEAD BROOK, WILTSHIRE

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Signal crayfish (*Pacifastacus leniusculus*) have existed in the upper reaches of the Broadmead Brook in Wiltshire (Fig. 1) since 200 individuals were introduced at West Kington in 1981 (Holdich & Reeve 1987, 1989; Reeve, 1990). The population has expanded upstream and downstream since this introduction, however, giving rise to concerns that it may potentially threaten the native, white-clawed crayfish (*Austropotamobius pallipes*) population further downstream. The native crayfish in the Broadmead Brook have not yet succumbed to crayfish plague and are currently free of the disease. However, as signal crayfish appear to out-compete the native species (Holdich & Domaniewski, 1995), the native population could still be under threat.

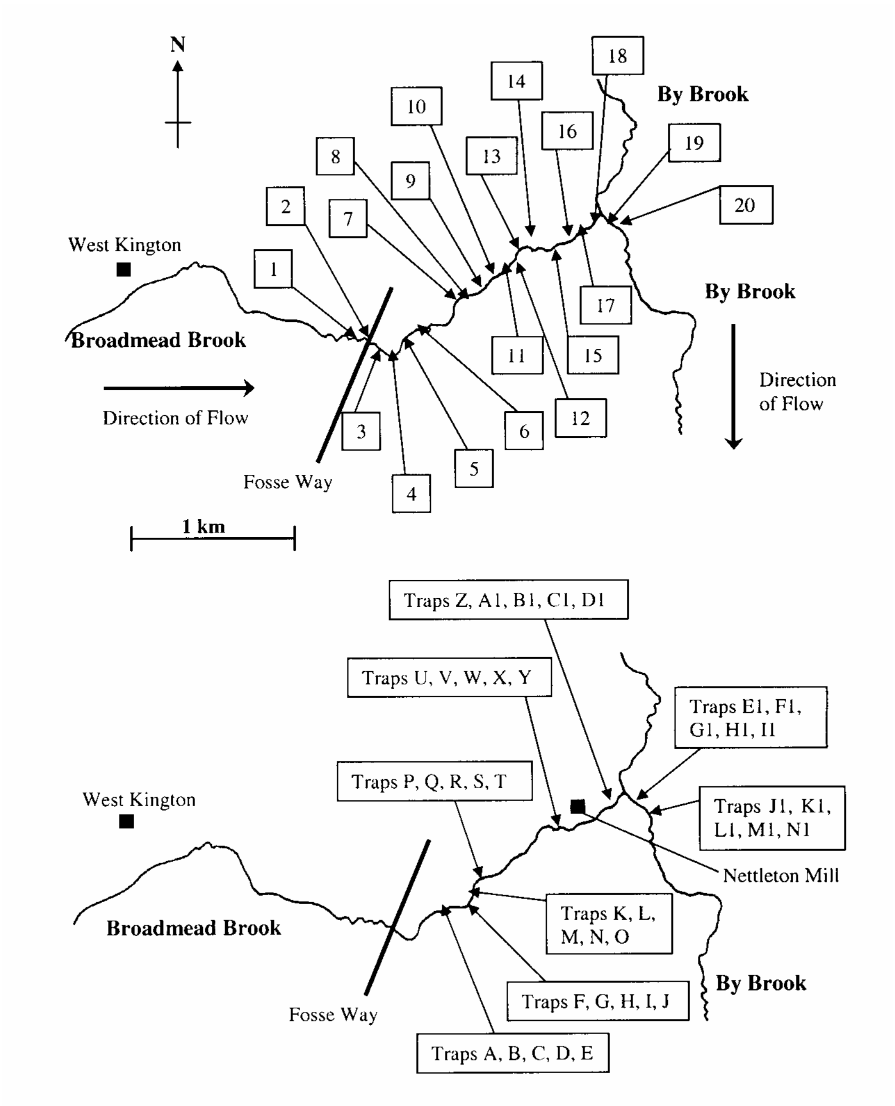
A thriving population of signal crayfish developed at West Kington from 1981 to 1987. By 1987 there was strong evidence that the population had begun to expand upstream and downstream (Holdich *et al*., 1995). In 1998, a survey along the Broadmead Brook showed that the two population were meeting at the point in the Broadmead Brook by the Fosse Way (Fig. 1) (Lang & Wylde, 2000). Since 1998 signal crayfish have been trapped at Nettleton, 1 km downstream of the Fosse Way, suggesting that the population is continuing to advance dowstream (M. Frayling, pers. comm.). To confirm such reports the Environment Agency, in consultation with English Nature and Wiltshire Wildlife Trust, decided to carry out a survey to map the current distribution of the two species and establish the extent of this advance

Mapping surveys were carried out in July and August 2001. The principal aim of mapping was to locate the leading edge of the advancing signal crayfish population. Two survey methods were used to map the distribution of crayfish: stone- turning and trapping. The upper map in Fig. 1 shows the location of stone turning sites (1-20) and that below the location of the trapping sites (A- N1).

The 2001 survey revealed that the two species still coexist, however, lower numbers of native crayfish recorded suggests that they are increasingly under threat. Furthermore, the 2001 survey revealed that signal crayfish now inhabit the whole length of the Broadmead Brook, which had not been recorded by previous surveys, representing a downstream colonisation of approximately 1.7 km since 1998.

The majority of the Broadmead Brook now supports a coexisting population of signal and native crayfish. Over time it is likely that the numbers of native crayfish will be suppressed further. Relocation of these native crayfish to another waterbody, free from signal crayfish, to mitigate for the reduction in population on the Broadmead Brook is an option that we recommend is explored further. Further details of this study can be found in Spink & Rowe (2002).

Figure 1. Schematic map of crayfish survey sites on Broadmead Brook and By Brook, Wiltshire. Upper: stone-turning survey. Lower: trapping survey.



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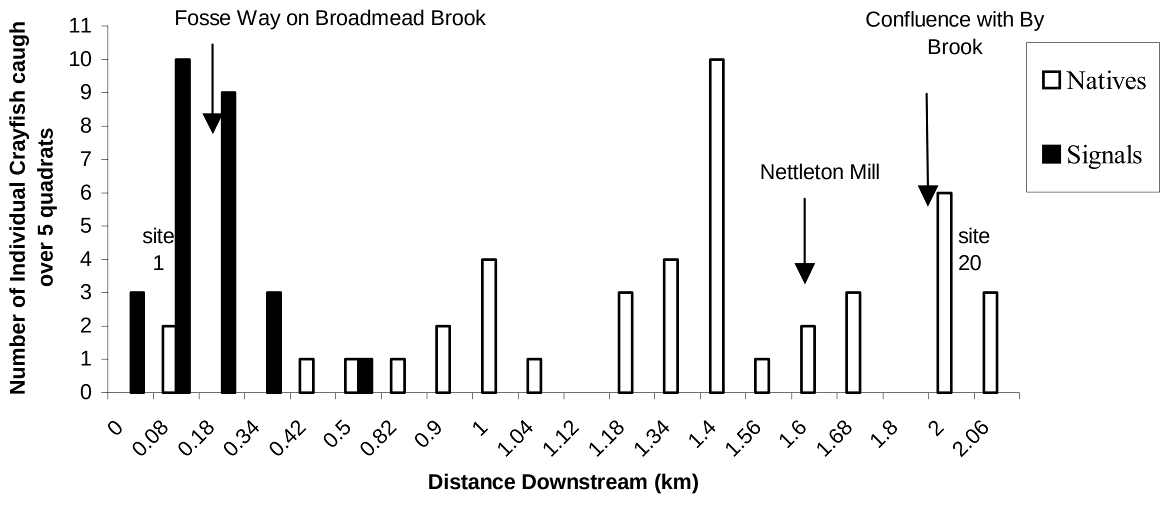
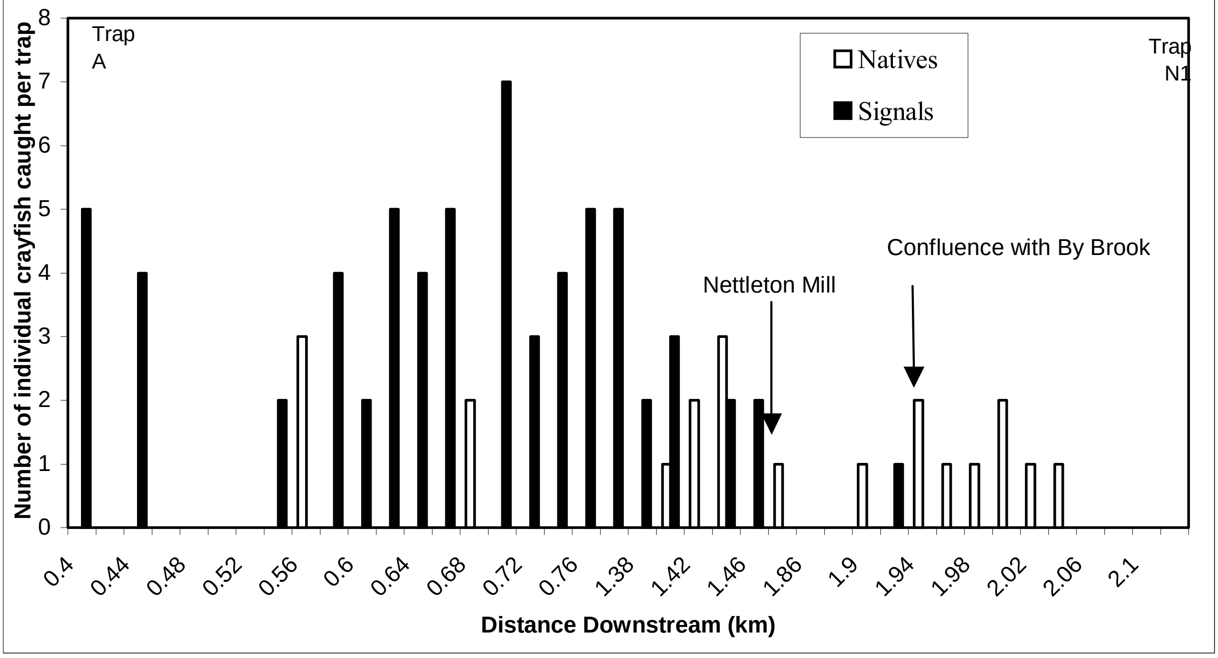
Keywords: native crayfish, signal crayfish, distribution, expansion, Broadmead Brook

Figure 2. Crayfish recorded on Broadmead Brook and By Brook in 2001, for native white-clawed crayfish *Austropotamobius pallipes* (open bars) and signal crayfish *Pacifastacus leniusculus* (closed bars). Above: stone-turning survey. Below: trapping survey





SECTION 3. MANAGEMENT AND RESEARCH

OBSERVATIONS ON EXPERIMENTAL TRAPPING OF *AUSTROPOTAMOBIUS PALLIPES* (LEREBOULLET) IN A WESTERN IRISH STREAM

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ABSTRACT

During the months of January to May 1999, some experimental trapping of crayfish was carried out on the Kilchreest River in east County Galway. Individuals were trapped by means of baited traps and hand collections. All trapped individuals were sexed and measured. Analysis of the data indicated that while a few immature individuals were captured by hand, none were captured in the baited traps. Of the adults captured in traps a higher percentage of males (67% overall) than females was usually recorded, and of the females 66% were berried. Measurements of the trapped individuals indicated that males were on average larger than the females, with the berried females being larger than the unberried. Differences between trapping methods were also noted, with those individuals trapped by means of the baited traps being significantly larger than those trapped by hand collections.

Keywords: *Austropotamobius pallipes*, crayfish, Ireland, trapping methods, baited traps

INTRODUCTION

The white clawed crayfish, *Austropotamobius pallipes* (Lereboullet), once widely distributed throughout western Europe, is currently in serious decline throughout much of its range (Holdich, 2002, this volume). This decline is due to a number of factors including pollution, habitat change and competition from introduced crayfish species. However the spread of the fatal plague fungus, *Aphanomyces astaci* Schikora, most likely resulting from introductions of species such as *Pasifastacus leniusculus* (Dana) (the signal crayfish) for aquaculture purposes, has been most detrimental to the status of *A. pallipes*.

Ireland currently contains some of the best remaining stocks of *A. pallipes*, and it is the only species of crayfish to be found in this country (Holdich & Rogers, 1997; Reynolds, 1997). They are widespread in the central region of the country where there is underlying calcareous bedrock. They live in large rivers and tributaries, which are not polluted (Reynolds, 1982), in the Grand Canal and in many lakes. They are rarely found in lakes greater than 1000 hectares in area (Moriarty, 1973).

Although *A. pallipes* is protected in Ireland by national and European legislation, and the introduction of non-native crayfish species is prohibited, some stocks have still been decimated by the crayfish plague, possibly introduced by the use of contaminated fishing gear (Reynolds, 1988). However, such occurrences of the plague in Ireland are rare and the continued healthy status of most Irish stocks makes them of special importance to the conservation of the species.

The general distribution, biology and ecology of the crayfish in Ireland have been, and continue to be much studied and much of the past work has been well documented and reviewed (Lucey & McGarrige, 1987; Holdich & Rogers, 1997; Reynolds, 1979, 1982, 1988, 1997).

There were two main aims of the current study. The first was to assess the current status of the crayfish stocks in the Kilchreest River system, with a view to obtaining a brood stock for the initiation of experimental crayfish farming. The second main aim was to evaluate potential capture methods for these wild crayfish, with the main target being the berried females.

STUDY AREA

The sampling of crayfish during this study was carried out at four sites on the Kilchreest River. This river rises in the Slieve Aughty Mountains, Co. Galway. It initially runs northward before turning in a general south-west direction. Further downstream the river becomes isolated as it disappears underground, and it is unsure whether it then forms a tributary of the River Fergus system or whether it empties to the sea in the vicinity of Kinvara, on the southern shore of Galway Bay.

The sites sampled were chosen as they were on stretches of the river that had previously been noted to contain good crayfish stocks. Also it was felt that the isolated nature of the river would guarantee a disease-free stock. Irish National Grid References for each of the four river sites sampled are as follows: site 1, M583145; site 2, M581148; site3, M542137; site 4, M572149. The river at these sites varied between 4.5 m to 8 m in width and during low flow conditions, depths ranged from a minimum 0.1 m at the bank to a maximum of 0.6 m in the centre of the stream. The river bed was mainly rocky, interspaced with pockets of sand. All four sites were located near bridges.

METHODS

Three methods of trapping crayfish were employed during this work. The first method involved the use of specifically built pipe traps that were baited with beef liver. These pipe traps were constructed from a 0.5 m length of Wavin PVC piping, 160mm in diameter. The pipe ends were then covered with wire mesh (15 mm x 19 mm chicken wire netting) funnels, which allowed a 5 cm opening into the trap. Bait was suspended in the centre of the trap.

The second method involved the use of wire traps, again baited with beef liver. The wire traps were similar in overall dimensions to the pipe traps. They were constructed from chicken wire netting (15 mm x 19 mm mesh size) and consisted of a 0.5 m long cylinders, with a diameter of 220 mm. The openings to the traps were identical to those used in the pipe traps and again the bait was suspended in the centre of the traps. Traps were generally set 10 m to 20 m apart, on rocky substrates along the banks of the river, the centre portion of the river generally having too great a flow to allow for access.

The third method, hand collections, was employed in late April and May and at this time flows had dropped sufficiently to allow access to the full width of the river channel. These collections involved turning over of any moveable large stones and rocks at the survey sites and collecting by hand any crayfish that were thus exposed.

All captured individuals were weighed and a measurement made of their carapace length. This was considered preferable when measuring the crayfish as it can be more accurately measured than total length. This is due to problems introduced by abdomen flexibility with the latter measurement. Juveniles, unberried females and approximately 90% of males were then re-released. These males were batch marked prior to their re-release using a portable soldering iron to create a small burn mark on pre-selected areas of the carapace.

RESULTS

During the months of March and April 1999 extensive trappings were carried out, using both the wire and pipe baited traps, at the four sites on the Kilchreest River. On each occasion the traps were left in the water overnight prior to emptying. The results of captures from these traps are presented in Table 1. All trapped individuals were sexed, weighed and a measurement made of their carapace lengths. As only the berried females and approximately 10% of males were being retained, all other individuals were marked by means of a burn mark prior to their re-release. Analysis of this data indicated that, of the 509 trapped individuals, the majority (84%) were male. Only 72 (14.1%) individuals were berried females. In total only 10 marked males were recaptured during the trapping exercise. No juveniles were trapped.

Subsequent to the trapping exercise, and as spring was progressing and water levels dropping, it was decided to try hand collections as a means of capturing a greater number of individuals, in particular berried females. On three occasions in late April and early May hand collections were carried out (Table 2). All visible individuals were captured resulting in the total capture of 363 individuals. Of these 117 (32%) were berried females. Two subsequent collections were made in early May, although on these occasions the berried females (n=121) were exclusively selected.

Analysis of the sizes of trapped individuals (Fig. 1) indicated that overall berried females were significantly smaller than the males, but larger than the unberried females (Mann Whitney U tests, $p<0.05$). Also some differences occurred in respect of the trapping method (Figs 2a, b and c), with individuals of all sexes captured by hand collections being significantly smaller (Mann Whitney U test, $p<0.05$) than those captured in the pipe and wire traps. The latter two trapping methods yielded similar sized individuals (Mann Whitney U test, $p>0.05$).

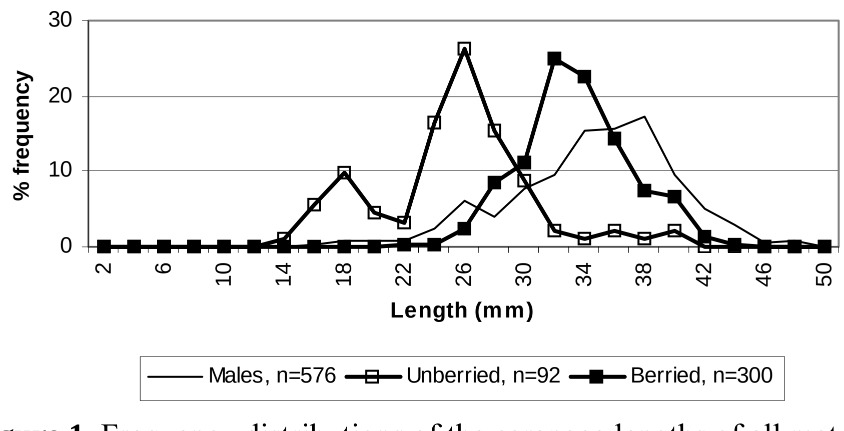

Figure 1. Frequency distributions of the carapace lengths of all mature individuals trapped.

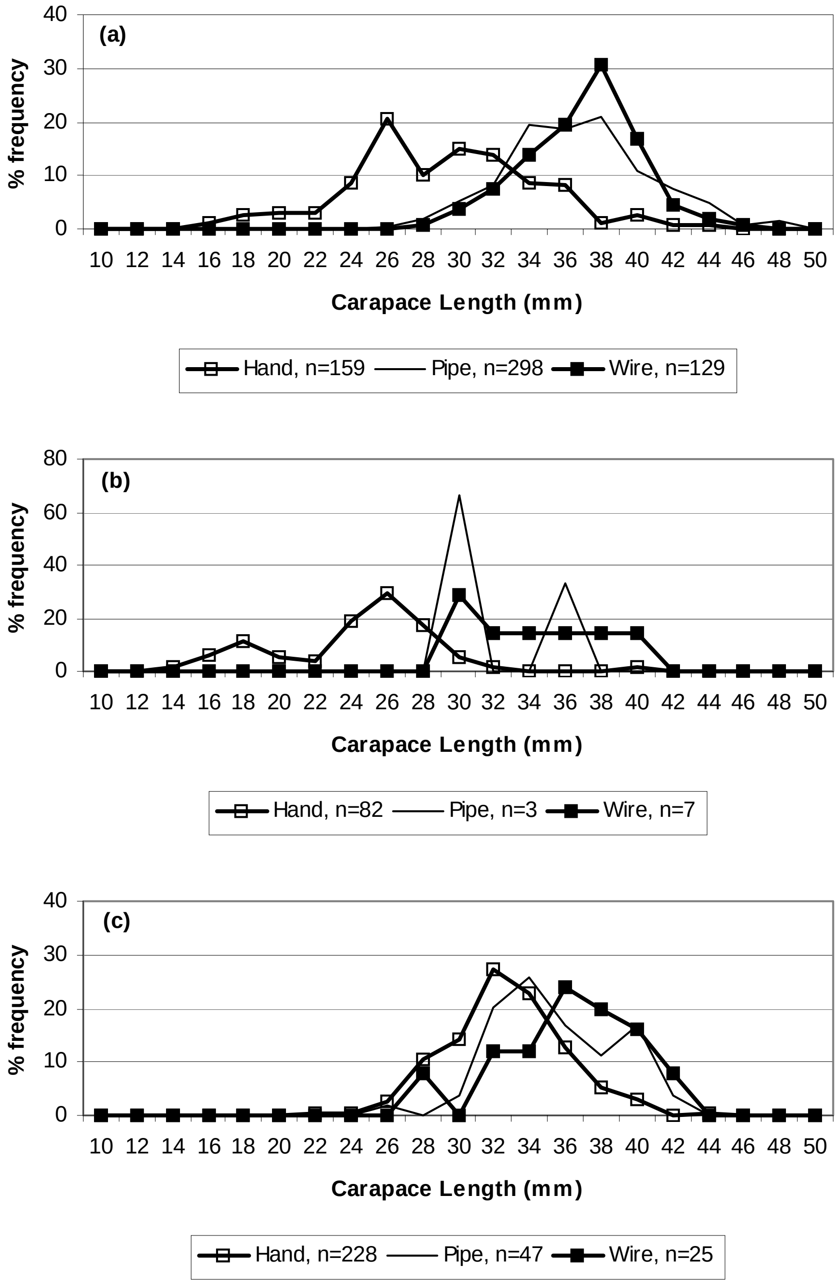

Figure 2. Length frequency distributions of the carapace lengths of males (a), unberried females (b) and berried females (c) captured by each of the trapping methods.

DISCUSSION

Population structure

The sizes of crayfish captured were similar to those captured during other studies on Irish populations of crayfish (Moriarty, 1969, 1971; Woodlock & Reynolds, 1988; Reynolds & Matthews, 1993). As would be expected in the adult proportion of a crayfish population the males were largest in size, followed by the berried females and lastly the unberried females. Male crayfish can continue to moult twice a year during their lifespan but reproducing females can only undergo one annual moult as they are carrying eggs during the spring moult period, thus their smaller size (Lowery, 1988).

Table 1. Overall results of experimental trapping of crayfish using the pipe and wire baited traps.

Site number	Date set	Date lifted	Trap type	No. traps	Total catch	Males	Females	Berried females	Immature	Recaptures	% berried
1	4-Mar	5-Mar	Pipe	10	11	9	-	2	-	-	18.18
2	4-Mar	5-Mar	Wire	10	1	1	-	-	-	-	0.00
1	9-Mar	10-Mar	Pipe	21	53	41	1	11	-	-	20.75
1	11-Mar	12-Mar	Pipe	21	49	42	-	7	-	-	14.29
1	11-Mar	12-Mar	Wire	10	2	1	-	1	-	-	50.00
1	15-Mar	16-Mar	Pipe	21	73	66	-	7	-	4	9.59
1	15-Mar	16-Mar	Wire	10	27	25	-	2	-	-	7.41
1	18-Mar	19-Mar	Pipe	21	28	24	-	4	-	2	14.29
1	18-Mar	19-Mar	Wire	20	29	20	2	7	-	1	24.14
2	24-Mar	25-Mar	Pipe	21	13	13	-	-	-	-	0.00
2	24-Mar	25-Mar	Wire	20	17	16	-	1	-	-	5.88
1	25-Mar	26-Mar	Pipe	21	34	31	1	2	-	-	5.88
1	25-Mar	26-Mar	Wire	20	19	15	1	3	-	-	15.79
1	26-Apr	27-Apr	Pipe	21	18	12	1	5	-	1	27.78
1	26-Apr	27-Apr	Wire	20	25	14	2	9	-	1	36.00
3	27-Apr	28-Apr	Pipe	21	16	15	-	1	-	-	6.25
3	27-Apr	28-Apr	Wire	20	13	11	2	-	-	-	0.00
4	28-Apr	29-Apr	Pipe	21	53	45	-	8	-	-	15.09
4	28-Apr	29-Apr	Wire	19	28	26	-	2	-	-	7.14
		Total for all traps		348	509	427	10	72	0	9	14.15

The average rate of capture of crayfish in the baited traps, when expressed in terms of a catch per unit effort (CPUE) of number of individuals per trap per night, were similar to results recorded in other Irish studies (Moriarty, 1973; Reynolds & Matthews, 1993). This, coupled with the fact that there was a very low recapture rate of marked males, would seem to indicate that the Kilchreest River contains a healthy stock of crayfish.

Trapping methodologies

Various differences were recorded between the trapping methods used, both in terms of the numbers and sexes of individuals trapped. In general males dominated the catches, with berried females, making up between 0% and 50% of the trapped individuals on any occasion (overall average, excluding hand collections specifically aimed at berried females, 20.5%). In general these results would reflect the natural habits of the crayfish, with female crayfish, in particular berried females being less active than males (Lowery, 1988). Juvenile or immature crayfish were generally absent from the samples, due mostly to their small size and associated difficulty of capture using the trapping methods employed during this study. This greater trapability of males has been recorded in many other studies (Moriarty, 1973; Reynolds & Matthews, 1993). It was concluded that the best method for capturing berried females was to carry out hand collections, which specifically targeted these individuals.

Table 2. Overall results of hand collections of crayfish.

Site number	**Date**	**Fishing method**	**No. minutes**	**Total catch**	**Males**	**Females**	**Berried females**	**Immature**	**Recaptures**	**% berried**
3	28-Apr	Hand	180	51	31	15	2	3	-	3.92
4	29-Apr	Hand	360	50	24	13	9	4	-	18.00
4	5-May	Hand	310	262	104	54	96	8	1	36.64
4	6-May	Hand*	495	68	-	-	68	-	-	100.00
1	7-May	Hand*	270	53	-	-	53	-	-	100.00
Total for all collections			1615	484	159	82	228	15	1	47.11

* Specifically selecting berried females

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WHITE-CLAWED CRAYFISH *AUSTROPOTAMOBIUS PALLIPES* IN THE RIVER WITHAM

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ABSTRACT

A survey of the Upper River Witham catchment in Lincolnshire for white-clawed crayfish *Austropotamobius pallipes* was carried out by the Environment Agency between 2000-2001. Total survey length was approximately 60 km. A near continuous distribution of white-clawed crayfish was found for 30 km of the stretch. Direct abundance comparison with other rivers was not possible. Habitat selection was not as fastidious by native crayfish as expected, with high numbers even in perceived poor habitat.

It is suggested that numbers are high enough for the Upper Witham to be considered scientifically important at a national level. It has a wide variety of habitats suitable for crayfish and meets most of the attributes and targets required to maintain a favourable conservation status for this species.

A non-plague related crayfish mortality on the Upper Witham is discussed. Possible explanations are explored. Circumstantial evidence suggests the cause to be a natural event possibly with a link to moulting, although porcelain disease cannot be ruled out.

Other observations incidental to the survey work and mortality investigations are discussed. This includes apparent burrowing behaviour by native crayfish and recolonisation rate following a pollution event.

Further work is detailed, including the application of the survey data, the establishment of a protocol for dealing with crayfish mortalities and encouragement of habitat improvements through work with landowners.

Keywords: River Witham, mortalities, crayfish, survey, burrows, recolonisation

INTRODUCTION

The River Witham arises to the south of Grantham in Lincolnshire and flows northwards to Lincoln and then southeast to the Wash near Boston. The Upper Witham refers to the stretch between its source at South Witham (SK 922 195) to Long Bennington (SK 835 458). The geology of the catchment is mainly limestone and clay. It can be viewed as being influenced to a moderate degree by groundwater and hence the flows are moderated when compared to a "flashy" river whose flow is dominated by surface water run-off (Smith, 2000). The very top of the headwaters is prone to low flows and in the summer months they can dry up completely.

The Upper Witham and its tributaries have retained much of their conservation importance, despite the pressures of land drainage, urbanisation and intensive farming. Headwaters contain brown trout, grayling, bullhead and stoneloach. Downstream, this changes to a typical lowland coarse fish community, with roach, bream, chub, pike etc.

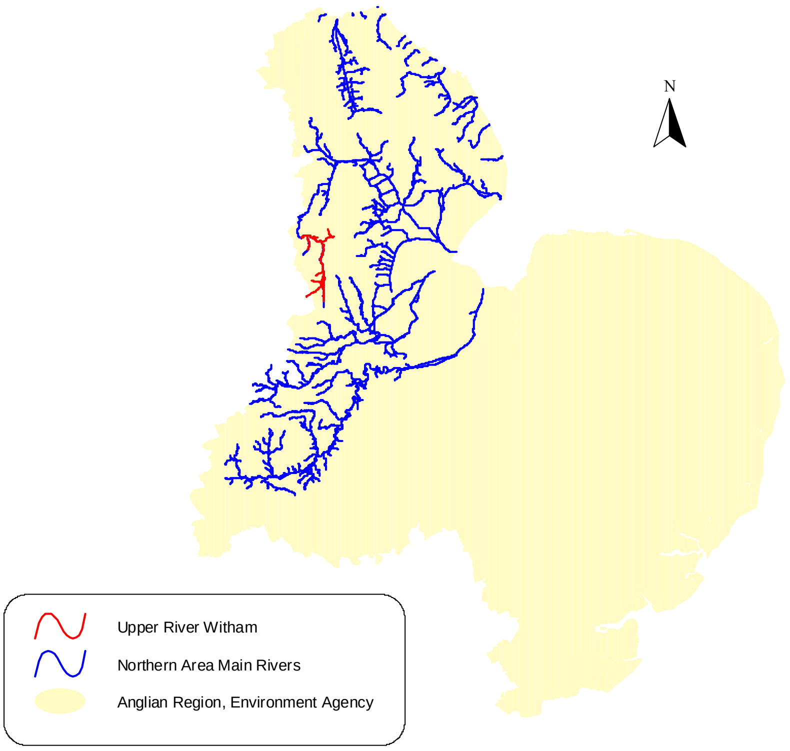

Figure 1. Upper Witham location in the Environment Agencys Anglian Region.

The Cringle Brook, which joins the Witham south of Grantham, probably has the most diverse macroinvertebrate fauna in lowland Eastern England (Richard Chadd, pers comm., 2002).

Water quality in the Upper Witham is generally classified as "good", with some localised or temporary exceptions. Most of these have now been addressed through improvements to sewage treatment works. The Upper Witham is also covered by a Nitrate Vulnerable Zone (NVZ) designation. Compliance with the targets for the NVZ has been good, although the Cringle Brook tributary had a nitrate failure in 1997, thought to have been caused by agricultural run off. A pollution incident of ammonium nitrate occurred in April 2002, when liquid fertiliser accidentally got in to the river. Elevated ammonia levels were detected 35 km downstream. It led to a fish kill of trout, chub and dace, although other species such as roach and bream were apparently unaffected. Soft-bodied macroinvertebrates were also affected. One dead native crayfish was found, but so were live specimens.

Signal crayfish, *Pacifastacus leniusculus*, are present within the catchment. They have completely replaced the native white-clawed crayfish from the River Bain, a tributary of the lower Witham, since their introduction in the mid-1980s. This population is remote from the upper Witham, separated by 70 km of waterways, 50 km of which would require signal crayfish to colonise in an upstream direction.

Prior to 2000 the presence of white-clawed crayfish, *Austropotamobius pallipes,* in the upper Witham was only known from incidental species records from sources such as routine Environment Agency biology surveys and as an undocumented bye catch during Agency fishery surveys. The range and the importance of the River Witham and its tributaries to the species was unknown, but it was understood to be the only remaining population of white-clawed crayfish in Lincolnshire. Given the protection under Schedule 5 of the Wildlife and Countryside Act 1981 and the Agency's responsibilities as contact point for the species under the Biodiversity Action Plan, it was viewed that the level of information on crayfish distribution in the Witham as insufficient. To establish the distribution of white-clawed crayfish in the River Witham the Agency commenced a series of surveys in 2000 and continued them through 2001.

SURVEY METHODOLOGY

The principal aim of the surveys was to determine the presence or absence of native crayfish along the river. 500 m sections formed the basic structure and each of these was divided in to five sub-sections, each 100 m long.

An experienced ecologist, under licence from English Nature, surveyed each sub-section using a standardized methodology. Sampling effort was directed towards those habitats most likely to accommodate crayfish. The crayfish were sought by manual stone turning and searching amongst debris etc. and by sweep netting the marginal and aquatic vegetation. The effort applied to each sub-section was limited to 20 minutes. However, where at least five specimens were found within this time searching was ceased to limit disturbance to the site (presence to within 100 m having been established). Data, including carapace length, gender and condition of each crayfish found was taken.

All 500 m sections were recorded on sketch maps, using the River Corridor Survey methodology, combined with a representative photographic record.

Timing of the surveys was between September and October of 2000/01, with the exception of a short section through Grantham, which was done in June 2001.

SURVEY RESULTS

Crayfish distribution

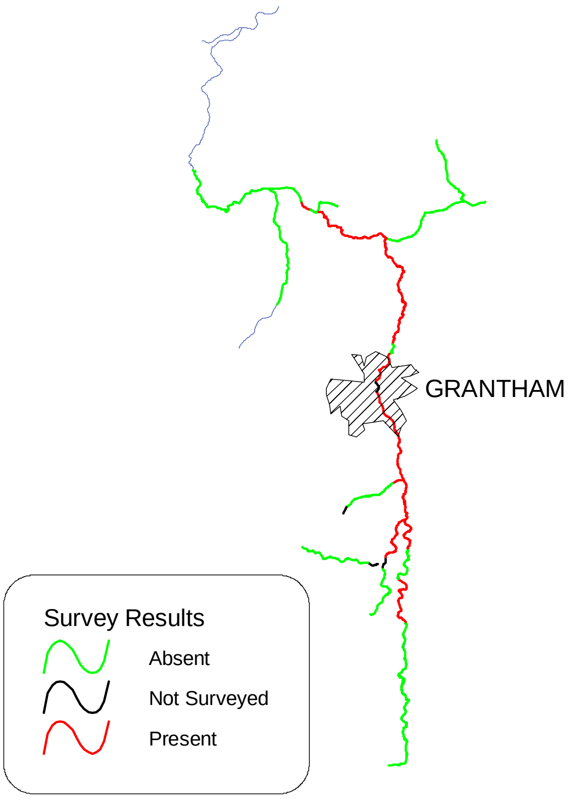

Figure 2. Results of native crayfish surveys on the River Witham 2000-01.

One hundred and thirteen sections, over almost 60 km, have been surveyed for the presence of crayfish in the upper catchment of the River Witham. It has been established that white-clawed crayfish inhabit an almost continuous stretch of the River Witham for a distance of 30 km (see Fig. 2). They were even found through urban Grantham. No signal crayfish have been recorded from the river.

Crayfish are not recorded through some sections because surveying them was not possible. In Grantham itself, the main reason for this was the numerous weirs that made the river too deep to wade safely. Trapping was not considered appropriate, as water voles are still relatively common on the Witham.

Suitable crayfish habitat was recorded at most of the surveyed sections. Only at a small number were habitat conditions recorded as poor for crayfish. This was on account of low flows (the top of the headwaters), lack of refugia and cattle poaching.

DISCUSSION

Use of survey data

The information collected has already been used for a number of purposes. The Agency and other public bodies now use the information to advise on developments in and adjacent to the river. For example, prior to replacing bank-side piles protecting a new housing development crayfish were translocated up stream and the toe of the piles was faced with limestone to make improvements to their habitat. Also, habitat improvement works carried out by Grantham Angling Association have taken into account the needs of crayfish.

The results have provoked some discussion regarding the size of the crayfish caught. The recorded sizes are slightly bigger than normal, with carapace lengths of 80 mm and above common, leading to polite enquiries as to the possibility of mistaken identity. The Agency is confident that all the records are for native crayfish and this has been independently confirmed.

Native crayfish in the Upper Witham were not as particular in habitat selection as expected, with reasonable numbers recorded even in less suitable habitat types, including relatively shallow riffles, turbid water and canalised stretches with ruderal vegetation. This casts doubt on the level of confidence that can be put on to the suitability of a habitat from visual inspection alone and suggests that best practice is to keep an open mind.

The scientific importance of the Witham population

In order to independently assess the scientific importance of the Witham population, the Environment Agency and English Nature commissioned Dr D. M. Holdich, an aquatic biology consultant. Data from the Upper Witham surveys, other reports relevant to the Witham and selected works carried out on other riverine populations of white-clawed crayfish were examined. In addition an assessment was made of the degree of known threat from the signal crayfish *Pacifastacus leniusculus*.

The Upper River Witham was judged a very suitable environment for the native white-clawed crayfish over much of its length. It contains a wide variety of habitats suitable for crayfish and meets most of the attributes and targets required to maintain a favourable conservation status for this species.

The level of survey work makes it one of the most intensively studied for crayfish in the UK (Holdich, 2002). A comparison of the relative abundance of native crayfish with other rivers was not possible due to the surveying method used, i.e. limited to manual searching. As previously mentioned, trapping cannot be carried out on the Upper Witham because of the presence of water voles. However, even using manual searching, some 100 m sections have yielded numbers comparable to “good” crayfish numbers in other parts of the UK.

The signal crayfish in the Witham catchment are not thought to pose a threat because of the distance separating them from the Upper Witham. The same situation exists for populations in the River Soar and River Trent catchments (Holdich, 2002).

Holdich (2002) determined that the Upper Witham is important at a national level, given that it contains strong populations of native crayfish. SSSI guidelines state that all sites with populations of species listed on Schedule 5 (such as native crayfish), qualify for SSSI consideration, particularly where there are strong populations of scarce species. The Upper Witham is not directly affected by non-native species, unlike some of the cSAC rivers (e.g. the Wensum). Holdich (2002) concluded that considering all the evidence available, the scientific importance of the Upper Witham for native crayfish is high.

Recolonisation following a pollution event.

The results show recovery of sustainable populations of white-clawed crayfish following pollution events is slow. This is illustrated well in Fig. 3, which shows the effects on crayfish distribution following a pollution event that occurred just north of the village of Easton in 1993. Elevated levels of ammonia, large amounts of organic matter and chemicals such as technazine (an anti-sprouting agent) were recorded (Holdich, 2001). Dead fish and a dead crayfish were found near to the outfall pipe. The event itself destroyed the population of native crayfish over a length of 3 km. Seven years after the crayfish kill, recolonisation had only occurred in the first 1.3 km dowstream, leaving 1.7km still unpopulated. This illustrates the long periods needed for re-colonisation after such an event and the reluctance of colonies of our native crayfish to expand. In this instance, the Environment Agency suspects that poor habitat is contributing to the slow recolonisation and is considering habitat improvements along the remaining stretch (P. Smith, pers. comm., 2002).

Mortalities

In 2001, two mortalities of over 20 white-clawed crayfish occurred at Great Ponton on the River Witham. The first mortality was reported on the 31 May 2001 and the second on the 8 August 2001 by Grantham Angling Association. It may be of relevance that adult crayfish moult twice a year, normally late April/early May and August/early September (Holdich, 2001).

Hydrographic data did not show the river to be in spate on either occasion, and the weather at the time of the mortalities was not abnormally hot.

Environment Agency staff investigated both incidents but reached no firm conclusions. Dr. D. M. Holdich was subsequently asked to look at the data to pursue the investigation. It focused on four possible options, pollution, disease, overcrowding and moulting stress or a natural event.

There was no evidence of a pollution event. Water and sediment samples were analysed and found to be normal. No other species were affected and not all crayfish were killed. It would be expected that another crustacean, *Gammarus pulex*, would also have suffered mortalities if pollution was the cause, but this was not found to be the case. Pollution was therefore considered to be an unlikely explanation.

The initial concern was that the deaths were due to crayfish plague but this now appears very unlikely. Live crayfish collected the first time a mortality was observed were kept for 10 days and showed no symptoms. Additionally, live crayfish are still abundant in the river and there is no evidence of signal crayfish present (although other disease vectors cannot be ruled out).

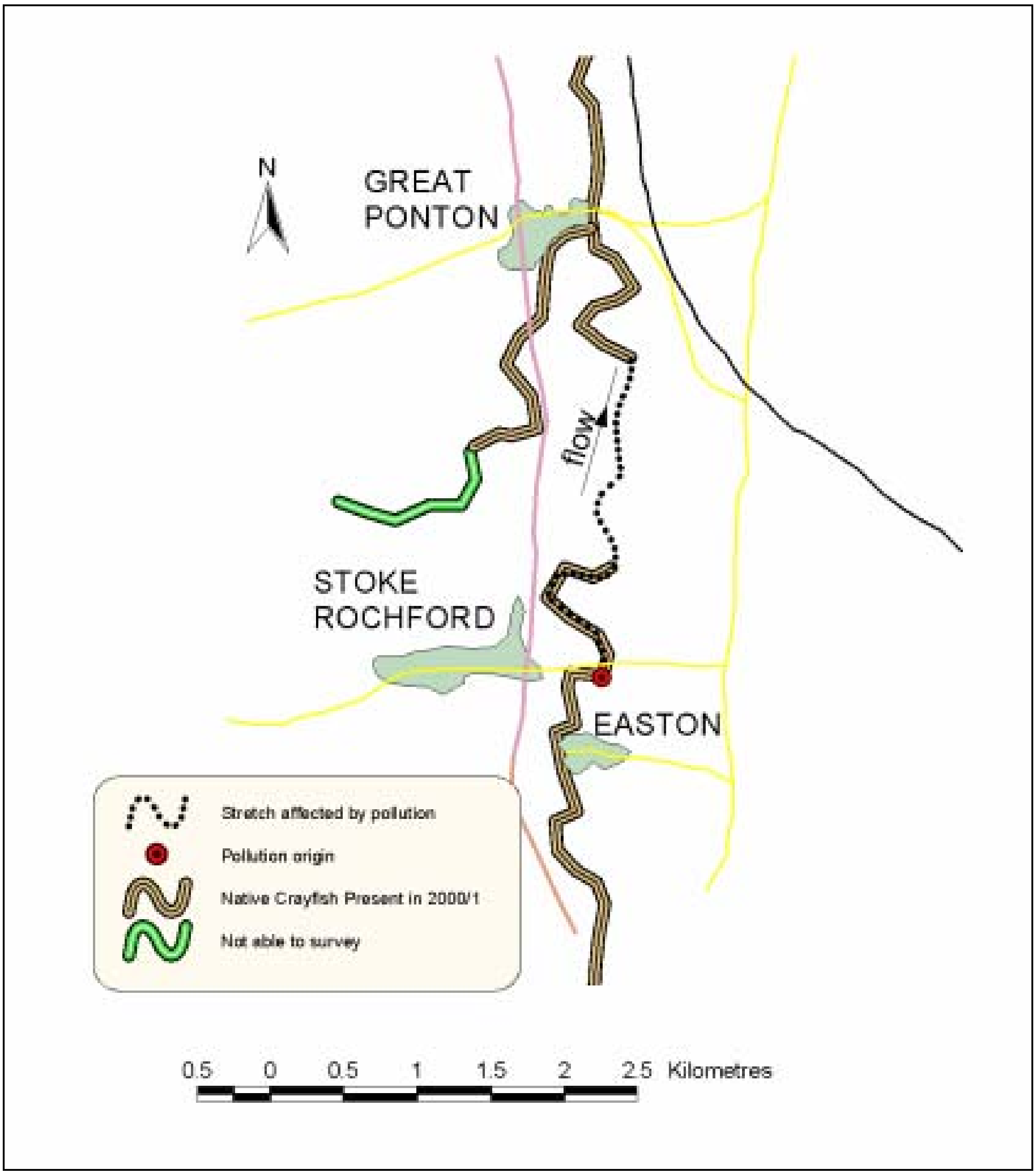

Figure 3. Recolonisation by crayfish following a pollution incident.

Subsequently a large proportion of the population has been found to have porcelain disease but the link remains unclear, since it is not a fast acting disease and therefore it is unusual to observe it as a cause of mass mortalities (Holdich, 2001). However, the possibility remains that it could have been a contributory factor.

Other diseases cannot be ruled out either, especially if they were at a sub-clinical level that only affected the crayfish at a time of high stress, such as moulting. Similar mortalities have been observed during moulting events elsewhere (Holdich, 2001). The crayfish that died were large and possibly reaching the end of their lives. The mortalities were close to the moulting periods of adult crayfish. The synchronous moult of an older cohort, combined with a latent disease or overcrowding stress, cannot be dismissed as the cause out of the list of possible explanations. Holdich (2001) suggests that this is the most likely explanation, and that it is not necessarily a problem. Such an event can be beneficial to a population if it contains a lot of large, dominant individuals, which compete for resources and suppress younger cohorts.

Suggested actions following a mass mortality

For the Environment Agency, the key lesson that emerged from this has been that it needs to improve the way it is organised to deal with a serious pollution or disease threat to crayfish. A draft protocol has been put together to start discussions at a local level. The initial aim of any response would be to try and assess the extent of the mortality, any obvious cause and to collect data for later analysis.

Suggested actions at this early stage for the protocol and ongoing work include:

- Promotion of the Environment Agency emergency contact number to the public for crayfish incidents.
- Ensure calls to the Environment Agency go to the correct members of staff who can assess the severity and response needed.
- Collate a list of trained staff to respond. This could be from a number of organisations but needs to properly consider the health and safety issues.
- Collect water, sediment samples and invertebrate samples.
- Collect dead crayfish specimens, keep in individual bags and label with location, etc.
- Take crayfish measurements and other data as soon as possible.
- Any dying crayfish found to be placed on ice and the need to send them away for confirmation of plague to be assessed. If dead freeze for future reference.
- Consider the need to collect live specimens (with a view to studying symptoms of crayfish plague and/or for future re-introduction purposes).
- Collect general data on river and weather conditions.
- Take photos.
- Ideally at least two groups should go out to a mortality. One group should go to the known site and one upstream to work down towards the known site. If there is a large population spot checks along the length will be needed.
- Ensure disinfection/decontamination of Personal Protective Equipment (PPE) and equipment as a priority.
- If appropriate inform English Nature and contact crayfish experts for further advice. This may well be whilst out in the field.

Burrowing behaviour

During the mortality investigations of crayfish in the River Witham, burrows were observed in the banks. On one occasion, a crayfish was found in a burrow. Most are too small to have been made by a water vole and are similar to the crayfish burrows created by signal crayfish (see Sibley, 2000; Stanton *et al*., this volume). A subsequent visit by David Holdich, Philip Smith and Jeama Stanton in summer 2002 confirmed the presence of white-clawed crayfish in some burrows. They concluded that the burrows were most likely made by the crayfish themselves.

Figure 4. Burrows above and below the water line on the Upper Witham, framed by a 0.25 metre square.

The suggestion of white-clawed crayfish exhibiting burrowing behaviour is supported by observations made by crayfish experts working in other areas and the absence of any records of signal crayfish (or other candidates such as mitten crab) in the Upper Witham.

Future Work

The knowledge we have gained will help to raise the local significance of a declining species and promote its protection from pollution, habitat destruction and displacement by introduced species.

Those sections of river and the tributaries with the greatest potential for habitat improvements will be targeted to provide conditions conducive to the expansion of the Witham crayfish colony.

The Agency has commissioned FWAG (Farming and Wildlife Advisory Group) to talk to landowners and farmers adjacent to the river. The aim is to raise awareness of the importance of crayfish and their habitat needs. Improvement schemes that come from this will be encouraged. The potential for establishing an off-line population is being discussed. It is also intended to run workshops for the relevant landowners, including field trips to catch specimens for them to see.

Further awareness raising initiatives are planned. The Agency is creating a leaflet for local people about crayfish in the Witham, part funded by English Nature and the Lincolnshire Biodiversity Action Plan Partnership.

Now that the initial survey work is completed, the Agency will establish a monitoring scheme for the Upper Witham. This will include a more detailed examination of how widespread porcelain disease is in the Witham population.

CONCLUSIONS

In a survey of almost 60 km of the Upper Witham, white-clawed crayfish were found in a near continuous stretch 30 km long. Large crayfish of over 80 mm carapace length were not uncommon. Habitat preferences were difficult to evaluate as crayfish were common even in habitat types that would normally be considered as sub-optimal (e.g. canalised stretches). No signal crayfish were recorded.

The Upper Witham is important at a national level for native crayfish. It yielded "good" numbers of crayfish in comparison with other parts of the UK and meets most of the attributes and targets required to maintain a favourable conservation status for this species. The threat from signal crayfish is minimal, due to the remoteness of the nearest colony in the Witham catchment.

Vigilance is required in order to protect the population from threats such as pollution. The study determined that recovery following a pollution event is very slow, with recolonisation in a downstream direction slower than 200 m a year. The Agency is exploring ways of assisting recovery, through the provision of better habitat.

A mortality event in 2001 prompted investigations by the Environment Agency. It was determined that crayfish plague was not the cause. No direct explanation can be found, but circumstantially it appears to be a natural event, perhaps a less virulent disease linked to moulting stress. The mortality did highlight the need for a more organised response to future crayfish mortalities, and the Environment Agency is currently producing a suitable protocol.

The surveys and mortality investigations also led to the recording of burrows in the banks that are thought to be made by native crayfish. Although apparently a well known phenomena by some, it had not been noticed by Agency staff or consultants previously in Northern Area.

The work on native crayfish in the Upper Witham now needs to shift to a monitoring phase, with a more detailed analysis of the level of porcelain disease in the population. Parallel to monitoring work, the Agency is encouraging habitat improvements, aiming to facilitate awareness workshops for landowners and produce a general leaflet for local people about the crayfish in their local river.

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DISEASES IN SELECTED *AUSTROPOTAMOBIUS PALLIPES* POPULATIONS IN ENGLAND

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ABSTRACT

Tissues from samples of seven English *Austropotamobius pallipes* populations were examined by light microscopy for the presence of diseases.

The first published reference for *Psorospermium haeckeli* in UK crayfish is presented. A photograph of a variety of developmental stages of *Psorospermium haeckeli* is shown. *Psorospermium haeckeli* was present in all populations examined.

Branchiobdella sp. was found in one crayfish population from Yorkshire. This is only the second published reference to *Branchiobdella* sp. in the UK.

Although *Thelohania* sp. was known to be present in all the populations examined, it could not be found in necropsies of samples from four populations undertaken in April 2002, probably because the samples size was too small. Epibionts were present in most populations although the species varied. Nematodes were occasionally present.

The effect of diseases on the individual crayfish, crayfish populations and the European crayfish stock is summarised.

Keywords: crayfish, diseases, England, *Branchiobdella*, *Psorospermium*

INTRODUCTION

The incidence of crayfish diseases in the UK is largely unknown. Scientific publications mainly focus on spread of crayfish plague, e.g. Alderman (1993, 1996), although Alderman & Polgase (1988) provide a review, and Edgerton *et al*. (2000) highlights a wider range of worldwide diseases including viruses, bacteria, rickettsia-like organisms, fungi, protists and metozoans. Using material from recent UK surveys, the present paper aims to document the incidence of selected diseases.

Serious mortalities of crayfish populations are often attributed to crayfish plague or pollution without proof. Less serious mortalities and chronic losses from crayfish populations are often inadequately investigated. This paper aims to show that the crayfish diseases, other than crayfish plague, present in the UK are likely to be having a significant effect on native crayfish stocks.

Crayfish plague issues are not dealt with in the present paper but recent studies can be found in Oidtmann (2000) and Oidtmann *et al*. (2002a, b).

METHODOLOGY

Small numbers (between 3 and 20) of *Austropotamobius pallipes* were collected from sites in England during surveys by hand and trap (Table 1).

Specimens were delivered to the laboratory alive, then euthanised and immediately dissected. Wet preparations of all the major organs were examined microscopically and fixed slides were made where appropriate.

RESULTS

The results are summarised in Table 1.

In those populations where *Thelohania* sp. was found, incidence ranged from 10% to 26%.

Psorospermium haeckeli was found in all populations examined for this parasite (Table 2) and a photograph of a range of developmental stages is shown in Figure 1.

One adult *Branchiobdella* sp. occurred in one crayfish from one population in the UK (River Ouse catchment, Yorkshire), and *Branchiobdella* sp. eggs occurred in a further five specimens from the same location.

Epibionts from the Subclass Peritricha, Suborder Sessilina appeared in six out of the seven samples examined.

In two crayfish specimens from different samples (R. Ouse and Ensors Pool) a nematode was present on the gills.

DISCUSSION AND CONCLUSION

Crayfish plague still constitutes the biggest threat to native European crayfish species but other diseases although less devastating are probably causing decline of some stocks.

The four stocks examined in April 2002 did not show presence of *Thelohania* sp. although from bankside examination at other times of the year it was known to be present in all of these populations, often at high incidence. The numbers examined are too small to draw any firm conclusions but it may indicate a lower incidence of *Thelohania* sp following winter mortalities.

Table 1. Results of necropsies of 71 *A. pallipes* from the UK.

Site	**Date**	**No of crayfish investigated**	***Thelohania* sp.**	***Psorospermium haeckeli***	**Genus *Branchiobdella***	**Epibionts[2]**	**Nematodes**
R. Ouse (Yorks.) SD 996 889	November 1997	19	5/19	Not investigated	6/19	15/19	1/19
Walkmill (Staffs.) SJ 974 083	November 2001	7	2/7	7/7	0/7	7/7	0/7
Walkmill (Staffs.) SJ 974 083	October 2002	10	3/10	3/10	0/10	3/10	0/10
Stowe (Staffs.) SK 101 122	October 2002	20	2/20	3/20	0/20	12/20	0/20
Ensors (Warks.) SP 349 904	April 2002	4	0/4[1]	3/4	0/4	3/4	1/4
Bestwood (Notts.) SK 495 555	April 2002	3	0/3[1]	2/3	0/3	3/3	0/3
Lathkill (Derbys.) SK 214 652	April 2002	5	0/5[1]	3/5	0/5	0/5	0/5
Dove (Derbys.) SK 139 548	April 2002	3	0/3[1]	1/3	0/3	1/3	0/3

Numbers indicate how many crayfish had the pathogen out of the number investigated.
[1]but presence of *Thelohania* sp. known in population.
[2]Epibionts were all from Suborder Sessilina, e.g. *Epistylis* sp.

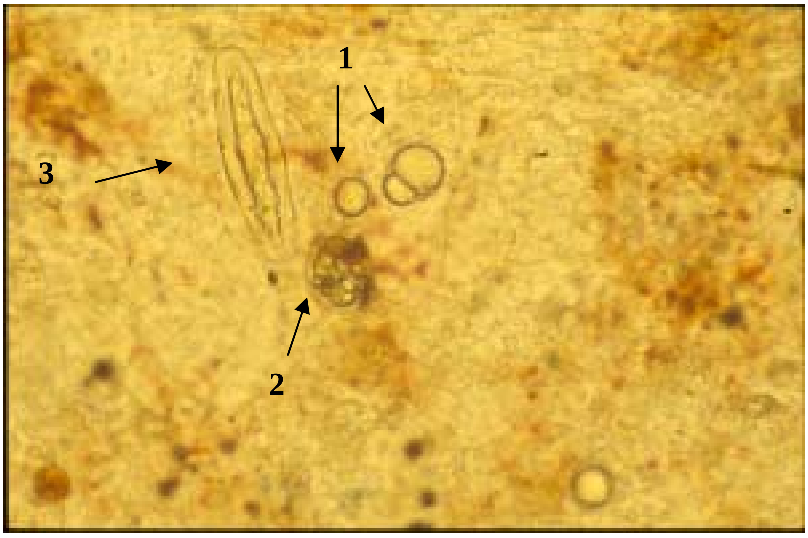

Figure 1. A variety of developmental stages of *Psorospermium haeckeli* in English *A. pallipes.* 1: naked forms, 2: ellipsoid form, 3: mature form.

The *Branchiobdella* sp. found in Yorkshire is only reference to *Branchiobdella* sp. in an existing population of crayfish in the UK. It is the second published reference to *Branchiobdella* sp. in the UK, the first being from populations of *A. pallipes* in the Thames catchment (Leeke & Price, 1965) that no longer exist. Most branchiobdellid species are regarded as epicommensals but some are regarded as parasites. Some cause gill damage (Vogt, 1999) and evoke host reaction: melanisation of gill filaments (Alderman & Polgase, 1988). Others, e.g. *Branchibdella hexadonta,* have been observed feeding on crayfish tissues (Grabda & Wierzbicka, 1969) and others cause detrimental effects to the eggs of ovigerous female crayfish.

Psorospermium haeckeli has not been described in UK crayfish prior to the present publication. The life cycle has been recently described (Vogt & Rug, 1999) but the effect of *P. haeckeli* on crayfish is unclear. The parasite is most often found in connective tissue and it is likely that it forms a host protein coat around itself for disguise, as there is no host tissue response.

In signal crayfish, the presence of *P. haeckeli* is suspected of causing crayfish immunosuppression such that the disease crayfish plague can develop from an *Aphanomyces astaci* infection (Cerenius & Söderhäll, 1992).

Epibiont examples from the Suborder Sessilina observed included *Epistylis* sp., *Vorticella* sp. and *Zoothamnium* sp.; normally one of these species was present in a population rather than a mixture. In general epibiont infestation is regarded as harmless for the crayfish host, it is mainly regarded as an indication of water quality; high epibiont infection often indicates a high organic loading of the water. However in cases of high infestation of the gills, gas exchange across the gill epithelium must be impaired causing stress, which may eventually lead to the crayfish vacating the habitat.

The zebra mussel, *Dreissena polymorpha* (originally from eastern Europe), which may foul any surface in infested waters, occasionally uses the exoskeleton of crayfish as its base for attachment. The infestation on crayfish (as other surfaces) can be very dense and the effect can become very severe both for individual crayfish, impairing moulting, and the population affected. Although the mussel has been observed on UK crayfish (senior author's unpublished studies) it was not found during the present study.

The incidence of nematodes in UK crayfish in the present study was low; in both instances where a nematode was found it was external in the gill chamber. Nematodes have not specifically been reported from UK crayfish before the present study although they have been reported from *A. pallipes* in Europe (Schneider, 1932), they have also been found internally in other species (O'Donoghue *et al*., 1990; Evans *et al*., 1992), but not in UK crayfish. The effect, parasitic or commensal, of nematodes on crayfish is unknown.

The authors' current opinion on the importance of crayfish diseases in European crayfish stocks is summarised in Table 2.

Table 2. Disease importance on European crayfish

	Importance to individual	**Importance to population**	**Importance to European stock**
Crayfish plague	1	1	1
Porcelain disease	1	3	3
Infection with *Psorospermium haeckeli*	3	3	3
Colonisation with epibionts, e.g. Suborder Sessilina	2	2	3
Colonisation with *Dreissena polymorpha*	2	2	3
Branchiobdellosis	2-3[1]	2-3[1]	3
Septicaemia/systematic bacterial infection	2	2	3
Infection of exoskeleton with bacteria (burn spot disease)	2	3	3
Fungal burn spot disease	2	3	3

1 = high, 2 = intermediate, 3 = low
[1]depending on species and preferred location.

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CHEMICAL ECOLOGY: A ROLE IN THE CONTROL OF INVASIVE CRAYFISH?

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ABSTRACT

With the increasing number of invasive aquatic species found in the British Isles, the need for methods to control their spread is becoming more urgent. Control methods are required to have maximum impact on the target species with minimum effect on indigenous species, while also being economically viable. Pheromones have been used as a method for controlling insect pest species for a number of years, and largely fulfil the necessary environmental and economic criteria of an ideal control method. With recent developments in the field of aquatic chemical ecology, the potential application of pheromones as a method of controlling aquatic pests is becoming a reality.

This paper discusses how pheromones have been used in the past to control terrestrial insect pests, and how these established methods could be applied to the control of invasive species. Recent research into the potential use of pheromones in crayfish control is given, along with preliminary results from the first field trials into the use of pheromones as trap bait.

Keywords: crayfish, control, pheromones, laboratory, field

INTRODUCTION

One of the world's most important current conservation issues is that of the impact of invasive species, which is now acknowledged by scientists and governments to be the major threat to native biological diversity (I.U.C.N., 2000). The destructive nature of many invasive species has detrimental impacts on both native habitats and species, often causing economic problems (Walker & Steffen, 1997; Wilcove *et al.*, 1998). The zebra mussel (*Dreissena polymorpha*), for example, is a species native to parts of Russia that was first recorded in the North American Great Lakes in 1988. It was suspected that the planktonic juveniles had been transported there in the ballast water of ships, a common form of dispersal in marine invasive species. *D. polymorpha* is highly prolific and occurs in high densities (up to 1 million m^{-2}) on boats, other animals and water intake pipes (Leung *et al.*, 2002). It has been estimated that the financial cost of such an infestation, which fouls up beaches, boats, and water intakes will cost $5 billion (U.S.) over the next 10 years. It has been estimated that alien species cost the U.S. government $123 billion every year in economic and environmental damage, and subsequent control measures.

Although invasive species are not new (the Romans originally introduced rabbits to Britain when they invaded in 43 A.D.) and not always detrimental (the U.S. food supply comes mainly from introduced species such as rice and cattle), the process of globalisation has rapidly increased the number of accidental and intentional introductions, ensuring that the list of alien species will continue to grow. In the light of the observed significant impacts of established invasive species, methods and guidelines to try and reduce the rate of introductions and to control established species have been proposed. A document produced by I.U.C.N. (The World Conservation Union) concerning the control of invasive species states: "Act rapidly to eradicate or control new alien invasive species, even if there is scientific uncertainty about the long term outcomes of the invasion" (I.U.C.N., 2000). Acting rapidly is critical as the best opportunities for eradicating or containing an invasive species are during the early stages of invasion when populations are small and localised. However, aquatic invaders are often not identified as being present before they have become established, often remaining 'hidden' and spreading for a number of years before being noticed, by which time it is often too late. Many aquatic species have rapid dispersal mechanisms, such as *D. polymorpha*, which has a dispersive larval stage (Howard, 2000), or the Chinese mitten crab (*Eriocheir sinensis*), which can travel up to 1028 km yr^{-1} (Herborg *et. al.*, 2003). Many aquatic invasives, therefore, tend to be well established by the time the impact they are having on the ecosystem is realised.

THE CRAYFISH ISSUE

There are six different species of crayfish that are known to have breeding populations in the U.K., only one of these, *Austopotamobius pallipes*, being indigenous (Holdich, 2002). Of the five invasive species, the North American signal crayfish (*Pacifastacus leniusculus*) is the most widely distributed (Sibley *et al.*, 2002; Sibley, this volume). Since the deliberate introduction of *P. leniusculus*, for aquaculture purposes, into southern Britain during the 1970s, the species has spread significantly throughout British waterways (Holdich *et al.*, 1999; Sibley *et al.*, 2002; Sibley, this volume), with extensive populations now being found as far north as the River Clyde in Scotland (Maitland, 1996). Although there is no documented evidence for *P. leniusculus* being a burrowing species in North America or mainland Europe, in Britain it has been found to burrow extensively causing considerable damage to riparian verges (Holdich, 1999). Due to the high densities at which it can be found, it can have a significant impact on other resident species, often denuding entire river reaches of their native fauna and flora (Guan & Wiles, 1998). *P. leniusculus* also out-competes Britain's native *A. pallipes*, which is listed as a protected species in Annexes 2 and 5 of the European Union Habitats Directive and the Wildlife and Countryside Act of 1981, and a priority species under the U.K. Biodiversity Action Plan. *A. pallipes*, as well as being out competed by the larger, more aggressive and more fecund American species is also highly susceptible to a fungal infection (*Aphanomyces astaci*) which *P. lenuisculus* is a vector of. *P. leniusculus* is also very important in parts of mainland Europe, not only as an invasive pest species, but also as a farmed resource (Holdich, 1999; Ackefors, 1999). Despite various legislation aimed at reducing the spread of alien crayfish in Britain, such as the set up of 'no-go' areas by the

Ministry of Agriculture, Fisheries and Food (M.A.F.F.) in 1996, the illegal and accidental introduction of alien crayfish, has to date proven almost impossible to control (Holdich *et al.*, 1999).

The feasibility of the eradication or control of non-native crayfish populations has been discussed in a number of studies (Holdich *et al.*, 1999; Howard, 2000; Kemp, 2000; Sibley & Nöel, 2002; Hiley, b, this volume; Kozak, this volume). The use of traps, barriers, pesticides and biological control have all been examined and, save for rare circumstances, of the currently available control methods biocides are the only means with potential, although this option does carry a range of adverse side effects that are detrimental to more than just the crayfish (Kemp, 2000; Sibley & Nöel, 2002). The I.U.C.N. guidelines on the choosing of control methods states that: "control methods should be socially, culturally and ethically acceptable, efficient, non-polluting, and should not adversely affect native flora and fauna, human health and well-being, domestic animals or crops." At present there are no methods to control invasive species of crayfish that meet these criteria, but a method that has mentioned by Holdich *et al.*, (1999), Kemp (2000) and Sibley & Nöel, (2002) in their studies was the potential use of pheromones, which from past experiences of their use meet with the I.U.C.N.'s guidelines, but had previously not be examined as a control method for crayfish.

PAST APPLICATIONS OF PHEROMONES

The term 'pheromone' was coined in 1959 by Karlson and Lüscher to describe chemical signals transmitted between members of the same species that elicits a stereotypical response (Agosta, 1992). Animals release pheromones to communicate a variety of messages, from attracting a mate and forming breeding aggregations, to warning conspecifics of the presence of a nearby predator. Many are species-specific, are effective at extremely low concentrations and their often-volatile nature ensures that they work on a scale of many hundred of metres.

Over 3500 pheromones have been isolated from insects (Agosta, 1992), many of them being sex pheromones. In recent years agriculture has exploited these properties to aid the control of insect pests with considerable success. Pheromone-baited traps have been used in 'trap-out' strategies to great success, for example to control the spruce beetle, *Ips typographus*. This species form large pheromone-driven breeding aggregations, once mated the females burrow into trees and lays their eggs. The larvae subsequently hatching to feed on the same tree, often killing it. To control the population 600 000 traps baited with the identified aggregation pheromone were prepared, and over 7000 000 000 individuals were caught in two years. Despite the loss of many trees the decline of the Scandinavian spruce forests was significantly reduced through the use of the pheromone traps (Agosta, 1992).

Pheromones can also be used as breeding disruptors to reduce the number of successful matings in a population. This method has been used in the control of the pink bollworm, *Pectinophora gossypiella*, which attacks cotton plants. Traps baited with female sex pheromones are placed in the cotton field to attract males to prevent them from breeding naturally, thus reducing the number of successful matings and the subsequent numbers of larvae that damage the cotton (http://cetulare.ucdavis.edu/pubveg/tom94.htm).

Principally, pheromones are used as additional methods of direct control used in conjunction with additional methods, but pheromones can also be used as an analytical tool to estimate the population size of a particular species. Traps baited with pheromone are deployed and from the numbers found in the traps after a set period of time the population size can be estimated. This allows for established control methods, to be adjusted according to the size of the population, minimising levels of biocide application and the consequent environmental effects.

THE ROLE OF PHEROMONES IN CRAYFISH BEHAVIOUR

Although there have been a number of contradictory studies concerning the use of pheromones by crayfish, Bechler (1995), in his review, assigned these differences to flawed bioassay techniques. Overall, he concluded that despite the lack of absolute evidence for the use of such pheromones, the evidence supports the contention that pheromones are at least involved in some aspect of sexual behaviour or mate choice in crayfish. Recently, several crayfish species have also been shown to utilise a number of other pheromones in a wide range of activities, such as aggressive interaction, inter- and intra-species recognition, shelter choice and predator avoidance (Blake & Hart, 1995; Chivers *et al.*, 1998; Zulandt Schneider & Moore, 2000; Hazlett, 2000; Bouwma & Hazlett, 2001; Nisikawa *et al.*, 2001; Breithaupt & Eger, 2002; Gherardi, 2002). Few studies, however, have focused on chemical communication in *P. leniusculus*.

LABORATORY-BASED PHEROMONE WORK

Current research into the use of pheromones as a method of controlling *P. leniusculus* has focused on four categories of pheromone: sex, stress, alarm and avoidance pheromones. The sex pheromone under investigation is, in common with many crustacean sex pheromones, a female-released chemical that attracts and stimulates mating behaviour in males during the breeding season (Ameyaw-Akumfi & Hazlett, 1975; Cowan, 1991; Gleeson, 1991; Bamber & Naylor, 1997; Jones & Hartnoll, 1997; Asai *et al.*, 2000; Kamio *et al.*, 2002; Stebbing *et al.*, 2003).

Stress, alarm and avoidance pheromones are all repellents, in extreme cases stimulating escape response; the difference between the categories is their source of release. Stress pheromones are released from stressed but undamaged conspecifics; alarm pheromones are released from a damaged conspecific; while avoidance chemical signals are released directly from a repellent stimulus, i.e. a predatory fish (Zulandt Schneider & Moore, 2000).

The first stage in identifying the use of pheromones is a reliable, unambiguous test, which uses the animal's behavioural response to the pheromone. The basis for any such bioassay is a well-described behavioural response. Crayfish, as is the case with many other species of Crustacea, exhibit a distinct suite of behavioural responses, for example mating/courtship behaviour, and the quite distinctive escape response (Gherardi, 2002). Accurate descriptions of these behaviours are needed prior to the development of bioassays (Stebbing *et al.*, 2003). Careful analysis of the behaviour permits bioassays to be designed that incorporate a specific behaviour stimulated by the pheromone. With the development of reliable bioassays to test for the presence of chemical signals, water samples that are known to be active, i.e. containing the pheromone(s), can be collected (see Stebbing *et al.*, 2003 for further details on bioassay design).

Sexually mature females were shown to release sex pheromone(s) during the breeding season. Water conditioned with mature females attracted and stimulated mating behaviour in mature males, but had no effect on juvenile males or females (Stebbing *et al.*, 2003). Water conditioned by mature females during breeding season was also tested on mature males outside of the breeding season.

The repellent chemicals tested were found to affect all life stages, all year round, with juveniles being particularly sensitive. In most cases, with the introduction of the repellent into the tank, the animal would stop moving and would move away from the source of the repellent. In extreme cases the animal would tail-flip away from the source.

PHEROMONE FIELD TRIALS

Materials & methods

Once that it was established that *P. leniusculus* released pheromone(s) of the nature being studied, methods of translating the lab-based studies to the field were developed. In the field, crayfish traps are normally left out for a minimum time of 24 hours. To test the effect of the pheromone(s) on trapping success a substance that releases the pheromone(s) throughout the trapping period would be required. Several matrixes were tested in the laboratory for release rate and attractiveness to crayfish. Once a gel matrix was found that had suitable characteristics, the pheromone(s) field trials could begin (Henrikson & Pawlik, 1995). The pheromone(s) were field-tested using standard Swedish 'trappy' traps, which were left out for 24 hours. All pheromone(s) tested were freeze-dried samples of active water place into the slow release gel matrix. Traps were baited with either:

a) Sex pheromone water
b) Stress or alarm pheromones with an attractant (food bait) which allowed the testing of the repellents against a known and quantified attractant
c) Food (which was, is most cases approximately 25 g of trout)
d) A blank gel matrix (as a control for the sex pheromones and repellents)

Trapping took place all year round (though sex pheromones were only tested during the breeding season to date) at two field sites, the River Clyde in Scotland and Lartington Ponds in Teesdale, North Yorkshire. These sites were chosen so that both lentic and lotic systems could be tested. Habitat data were collected from the sites in order to help determine whether differences in available habitat influenced number caught. As the data collected so far are only preliminary, the results from the River Clyde and Lartington ponds (Yorkshire) have been pooled (N=12 for each treatment). The number of males and females in each treatment and the total number of animals in each treatment were compared using a Mann-Whitney U-test at the 95% significance level.

Results

<u>Sex pheromone baited traps</u>

Figure 1 shows that the sex pheromone baited traps (SPT) caught significantly more males than females (males vs. females, W 222.0, P 0.000), with on average 10.25 males being found in each trap compared to 0.167 females. There were significantly more animals, in total, in both the stress and alarm traps than in the SPT (sex vs. stress, W 104.5, P 0.0092; sex vs. alarm, W 97, P 0.0024). Significantly more animals were found in the SPT than in the blanks (sex vs. blank, W 222.0, P 0.0000), although no significant difference was seen in the number of animals in the SPT when compared to the food baited traps (sex vs. food, W 117.0, P 0.0598). There were no significant differences, however, in the number of males in the SPT when compared to the stress, alarm or food baited traps, the significant differences in total numbers of animals being caught in the stress and alarm baited traps being due to the number of females).

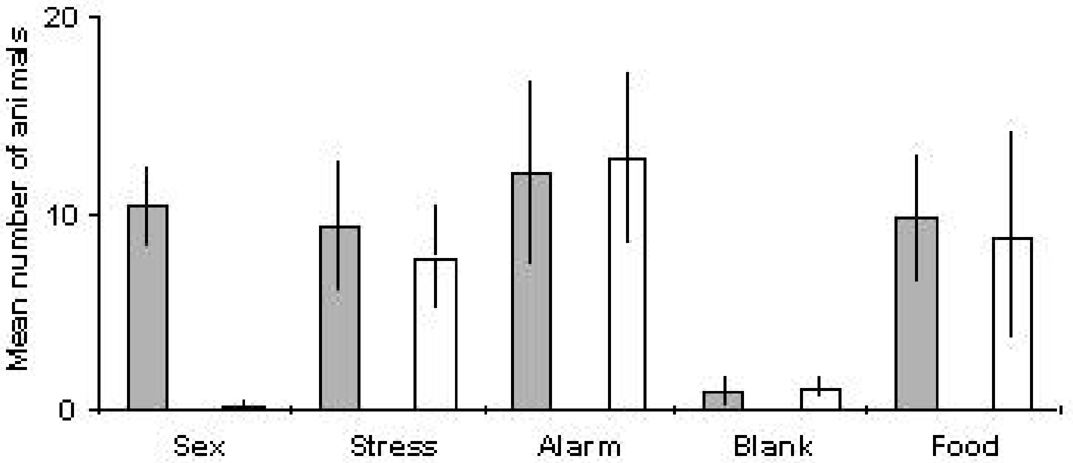

Figure 1. Mean number of male (grey) and female (white) *P. leniusculus* caught in each treatment (N=12), with 95% C.I.

Stress and alarm pheromone baited traps

No significant differences were seen in the number of males compared to females for either the stress or alarm baited traps. There was also no significant difference in the number of total animals found in either of the treatments (stress vs. alarm, W 123.0, P 0.1251). This was also the case when the total number of animals found in the stress or alarm baited traps were compared with the food baited traps (stress vs. food, W 150.5, P 1.0000; alarm vs. food, W 175.5, P 0.1482). Significantly more animals were found in both the stress and alarm pheromone baited traps than in the blank traps.

DISCUSSION

Preliminary results suggest that the sex pheromone baited traps have been demonstrated to be effective at trapping male *P. leniusculus* during the breeding season. Although the sex pheromone traps did not appear to be any more effective than food baited traps, following purification and concentration of the sex pheromone(s) the success rate of the traps may possibly be improved. The only reason for the significant difference in the number of animals caught in the stress and alarm (and almost food) baited traps is due to the fact that they were attracting females and males, whereas the SPT did not attract females. The present design of the traps and level of purification could potentially be used to identify populations of a low density, however field trials to test the pheromones in this capacity have not been undertaken. Improvements could be made on the releasing mechanism once more is known about the nature of the chemical(s) involved which could also increase the effectiveness of the traps.

The lack of success at repelling animals from traps using the stress or alarm pheromones may be due to the design of the field trial experiments rather than the chemical(s) being tested. It is possible that the attractiveness of the food being placed into the traps is a stronger attractant than the repellent is a deterrent, so even though the crayfish may be detecting the repellent pheromone(s) the food over-rides their effect. This is supported by the fact that there was no significant difference between the numbers of animals found in the stress and alarm baited traps and the food baited traps. Field trials are continuing with more repellents in each trap and less food, but also using shelter traps instead of food baited traps the idea being that the shelter is less of an attractant than the food.

It should be noted that the habitat data were not taken into account when analysing the data presented in this paper. With the inclusion of the habitat data into the analyses, a clearer picture could be obtained of the true effectiveness of the pheromones tested.

SUMMARY

Further research will focus on concentrating, purifying, isolating and identifying the pheromones with a view to improving the effectiveness of the traps. The habitat data collected from the sites are being incorporated into a model that will predict the effectiveness of trapping with the control methods as well as where it would be best to place the traps for optimal effect. Heterospecificty trials will also see whether the pheromones in question have any affect on *Austropotamobius pallipes*. With the further development of the sex pheromone traps it is considered likely that they could be used to remove a proportion of the males from a population at the beginning of a breeding season, so that less mating takes place (Holdich *et al.*, 1999). Combining this with standard trapping may provide a means to quickly reduce the size of a population. One concern of Holdich *et al.* (1999) is the fact that male crayfish are able to mate with more than one female; potentially this could mean that even with a few males left in a population then propagation will take place to some extent. However, as is the case in terrestrial pest management, pheromone traps could be used as breeding disruptors, where traps are more attractive than the females. In this manner, the tomato pinworm (*Keiferia lycopersicella*), a pest that destroys tomato and potato crops, was controlled with less than 4% of females being mated with (http://cetulare.ucdavis.edu/pubveg/tom94.htm). Pheromone traps could also be used to estimate population densities, or even to detect their presence at low densities so that early control measures could be taken on a catchment level. An alternative to attracting crayfish to traps could be to repel animals away from certain area, e.g. to protect populations of native species, or to drive animals into areas to make trapping easier (Holdich *et al.*, 1999). Repellent traps could be used to set up physical 'no go areas' to protect native species and to stop the spread of *P. leniusculus*. However, this may prove more difficult than attracting animals to traps.

Pacifastacus leniusculus has now started to become a pest species in other countries such as Japan (Usio *et al.*, 2001), and continues to spread across mainland Europe (Holdich, 2002, this volume). With the increasing threat of *P. leniusculus* to native biota globally, an economic and environmentally friendly control method is in even greater demand. The results from the work carried out to date into the use of pheromones as a control method for *P. leniusculus* are encouraging, and could be used as a model for the control of other established invasive species, which may utilise pheromones, such as the zebra mussel (*Dreissena polymorpha*) and the Chinese mitten crab (*Eriocheir sinensis*). The use of pheromones to control aquatic pests has started to be examined in other species, such as with the sea lamprey

(*Petromyzon marinus*), which has huge detrimental effects on the fisheries industry of the Great Lakes, U.S.A. It has been shown to release bile acids that act as migratory cues for the larvae, and by placing the bile acids into traps it is hoped that larvae can be removed quickly and with no more detrimental effect on the ecosystem (Bjerelius, 2000). Despite extensive work on preventing the introduction of non-native species, there is currently no sign of any decline in the rate of introduction. For example, recent news of the marbled crayfish can clone 20 or more young every six months, and could potentially becoming established in mainland Europe, adds even more urgency to the requirement for an effective method to control such potential pests (Coghlan, 2003; Scholtz, 2003). Despite lagging behind its terrestrial counterparts, lessons are being learnt from recent work examining the use of pheromones to control aquatic species. With continued research, the use of pheromones as a method of controlling aquatic pests could potentially become a widespread and effective tool for the management of these invasive species.

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FIELD APPLICATION OF BIOCIDES FOR SIGNAL CRAYFISH CONTROL

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ABSTRACT

The imported signal crayfish (*Pacifastacus leniusculus*) is highly likely to eliminate all but a minute proportion of the English populations of native crayfish (*Austropotamobius pallipes*) over the next 40-100 years. Once established in a river system, the signal crayfish appears unrestricted by most natural and artificial boundaries and spreads slowly but inexorably to all parts of the river, plus connected canals and stillwaters.

How can a recent colonisation of signal crayfish be prevented from spreading in this way? As few as one signal crayfish per 1000 m^2 of riverbed is sufficient to fuel colonisation – but at this abundance they are virtually undetectable. By the time a new colonisation of signal (or other alien) crayfish is discovered there are likely to be over 1000 individuals spread over 0.5 km or so of the water body, all but one of which must be killed or removed in order to stop the colonisation process.

Application of toxic chemicals appears to be the only way of achieving such a result. Initial results show that several common toxicants, alone or in combination, can provide the required results. All toxicants proposed for this purpose are biodegradable and can be confined to the target areas. Although the environmental damage in the locality is large, it is temporary and the rates of recovery of ecosystems from such incidents are very well known.

This method is unlikely to be used other than in smaller stillwaters (up to 1 ha) and streams which can be dammed then overpumped. It is recommended that, because no other method of stopping signal crayfish is likely to become available, effort should be put into creating and protecting refuge habitats for the native crayfish.

Keywords: signal crayfish, control, toxicants, poisons, refuges

INTRODUCTION

The imported signal crayfish (*Pacifastacus leniusculus*) is highly likely to eliminate all but a minute proportion of the English populations of native crayfish (*Austropotamobius pallipes*) over the next 40-100 years. By the time a new colonisation of signal (or other alien) crayfish is discovered there is likely to be over 1000 individuals spread over 0.5 km or so of river. There is no method currently available of reducing such a colonising population of signal crayfish to below its minimum viable density of around 1 animal 1000 m^{-2} of riverbed other than by the application of chemicals (Hiley, 2000; a, this volume).

The following programme of tests explores the possibilities for the use of chemicals and other environmental manipulations to exterminate signal crayfish that have colonised a moderate sized stillwater (approx 1 ha) or short (<1 km) length of river, these being the typical extents of a colonisation at first discovery. If successful, it is expected that more detailed research and development would take place first in the laboratory then on a small scale in the field, before a working method was attempted in a larger water body.

Since there is no specific toxicant or lethal infective agent against crayfish alone or even against crustaceans, major damage to other aquatic organisms is an inevitable consequence of effective control of signal crayfish using chemicals. Extermination of aquatic life should be expected within the modest and clearly defined area over which control is exercised. Recolonisation of stillwaters and short stretches of river by natural flora and fauna (except in special cases) is a straightforward and well documented matter, e.g. following a pollution incident. If an insecticide was used, damage to the aquatic life might be limited to crustaceans and insects. Unfortunately there are few pesticides available that could be reliably degraded by chemical or physical means within an hour or two of application. Natural pyrethrum, one such pesticide, is difficult to obtain but could form the basis of an effective method. The work described here concentrated on non-specific toxicants in order to ensure that environmental effects could be reliably limited to the target area, using readily available chemicals.

Holdich *et al*. (1999) reviewed various possible methods for control of signal crayfish, finding that there were no toxicants, other than the well-known insecticides, with a history of use against crayfish of any description. There were many references concerning the dangers of pesticides and other toxicants to wild crayfish .A subsequent investigation of the literature confirmed that while several insecticides had been used on occasion to 'control' crayfish in rice fields, the insectides tended to be of the persistant type (e.g fipronil - aapco.ceris.purdue.edu/doc/min2002/attach/02apr29/attachi3.html). Furthermore, several documents and websites state that there are no pesticides approved for crayfish control (e.g. morgan.botany.uga.edu/wayne/messages/555.html). It has been concluded that no trials like those described in this paper have ever been conducted.

The hard choice is between taking effective action when a new colonisation is discovered, for example following an accidental or malicious introduction, or allowing the invasion to continue with consequences on the whole aquatic ecosystem.

The methods investigated here concern the extermination of animals in the water.

METHODS

Toxicants were selected and tested on juvenile signal crayfish in a secure licensed laboratory within a polluted river catchment, to determine which would be effective, at what concentration. Combinations of chemicals were also investigated with a view to encouraging signal crayfish out of their burrows prior to intoxication.

Outline

Potential toxicants were selected from the author's experience. The likely toxic concentrations were determined by consulting data on similar species given in Murphy (1980).

In order to obtain results that would clarify whether or not chemical control in a field situation was feasible, tests on a wide range of dilutions of potential toxicants were undertaken. In addition some methods of bringing deeply burrowed animals out into the open water were investigated, as a preliminary to using a toxicant. A contact-acting toxicant is required for destroying any animals that may crawl out of the water during a control attempt, but this aspect was not tested.

With such a wide range of dilutions, the lowest concentrations acted as controls, having no effects. By performing the tests in sets, duplicating all steps except addition of toxicants, at least four vessels of each set contained controls. By this means the number of animals used per set of tests was reduced. Initial tests were run on one animal per concentration, but as the range of concentrations reduced more animals were tested. Controls were run if animals in most concentrations were likely to be affected.

The symptoms recorded were:
OK = animal sits quiet for most of time, reflex-escapes if container tapped, attacks if probed.
Active = animal is in continual motion, all movements appear normal
Stagger = when animal moves, the motion is abnormal, eyestalk reflex normal, escape reflex present but difficult to induce
Torpid = animal sits quiet, often with very slow movement of limbs, eyestalk reflex difficult to induce, no escape reflex
Dead = no movement or reflexes of any kind can be induced. This is not strictly death, as for example animals narcotised with deoxygenation can remain in such a state for several hours without permanent damage.

All animals were used once only and were destroyed by immersion in boiling water. All remaining animals were also destroyed.

Choice of chemicals

In order for a control method to be seen as practically acceptable, it should employ chemicals which can be degraded after use so that their influence is confined to the target area. The chemicals should be reliably available commercially in quantities and at costs that are not prohibitive, on the scale of operation likely to be considered, e.g. a 1 ha lake.

Ivermectin was among the initial choices because it has been widely used in fish farming; however it was found to be persistent and apparently without a simple denaturing process; if adsorbed onto solids it was not clear if it would remain active. Permethrin certainly remains active when so adsorbed, but a denaturing process appears possible, so this was chosen as one of the test group. If natural pyrethrum is available, this is recommended as it is naturally degraded in sunlight and reported to be readily degraded with chlorination. Testing of natural pyrethrum was not carried out due to the continuing world shortage – around 0.5 l was available at the time. Acids and alkalis, chlorine and ammonia are well known toxicants with a long history of damage to aquatic ecosystems as a result of spillages. Sugar (with bacterial cultures like soil suspension) and sodium sulphite can be used to reduce dissolved oxygen levels. Papain, which digests protein, and potash alum, known to be toxic to fish, were used as speculative controls.

The chemicals used were:
Permethrin, 0.6% solution in commercial formulation
Hydrochloric acid, 10 Molar
Sodium hydroxide, 5% approx W/V
Sucrose, saturated solution

Sodium hypochlorite, household bleach
Soil suspension
Sodium thiosulphate, saturated solution
Sodium sulphite, saturated solution
Ammonium sulphate, saturated solution
Papain/salt powder (meat tenderiser)

pHs and chlorine concentrations achieved were tested with 1-14 pH papers and a chlorine test kit range 0.1-2 mg l^{-1}. The other substances were assumed to be conservative, for the purposes of these initial trials.

All mixing and diluting processes were carried out in glass equipment. The concentrations of saturated solutions were obtained from tables in standard chemistry textbooks. The precision of all concentrations was in accordance with the preliminary nature of the work and final concentrations, except where measured (e.g. pH paper, chlorine test etc.), should be expected to be within 25% of the stated values.

All water used was Bradford tapwater that had been standing for 24 hr in the laboratory in open containers.

Sodium sulphite reacts with oxygen probably as follows: $2(NaSO_3) + O + H_2O= Na_2SO^4 + H_2SO_4$, i.e. there will be a pH reduction as oxygen concentrations are reduced. Two moles of $NaSO_3$ will combine with 1 mole of oxygen. Therefore (126*2)g of $NaSO_3$ will combine with 16 g of O, a ratio of approximately 16 g of sulphite to one of oxygen. Thus a quantity for effective deoxygenation of approx 10 mgl^{-1} oxygen in water is 160 mg l^{-1} sulphite. It is understood that sodium sulphite needs a catalyst to deoxygenate rapidly but no further information was sought since a slow deoxygenation was adequate for these tests. In field use, a catalyst may be required. Sodium sulphite solution is saturated at approximately 150 g l^{-1} at 10 ^oC, i.e. 1 ml of saturated solution should be sufficient to deoxygenate 1litre of water at this temperature.

Ammonium sulphate is saturated at 450 g l^{-1} at 10 ^oC. 1 ml of this in 100 ml of water gives 4500 mg l^{-1}. The molecular weight of ammonium sulphate is 122 therefore 28/122=0.23 correction factor to give results "as N"

The laboratory temperatures averaged 14^oC =/-1 ^oC

Sources of animals

Several sources of small to medium size signal crayfish suited to the experiments were investigated and parts of the upper River Wharfe (Yorkshire) (see Hiley, a, this volume) were found to yield large numbers with relatively little effort. River temperatures during March, when the tests were conducted, were around 8 ^oC that kept the animals relatively inactive and easy to pick up. A total of 290 0+ and 1+ signal crayfish were collected and brought to the laboratory in aerated containers. Three animals were killed due to mechanical damage during this process. No other deaths were recorded at any time during transport and storage although some cannibalism is likely to have taken place. A small number of larger animals were also collected, for confirmatory tests on selected toxicants.

Denaturing of toxicants

In order for a control method to be seen as practically acceptable in the field, all changes of environmental conditions should be reversible so that the original environment can be restored after the alien species has been eliminated. It was assumed that pH changes would be readily reversible by neutralisation with acid or lime, while oxygen deficits however caused would be reversible by aeration and/or oxygen injection. The toxicity of unionised ammonia could be reversed by restoring the pH to neutral, though a significant residual of ammonia would be present for some days until natural bacterial action could convert it to nitrate, perhaps encouraged by aeration. Permethrin is said to be readily denatured in the presence of free chlorine, and this was checked by adding *Daphnia* in a controlled test after chlorine then thiosulphate had been added to denature concentrations of permethrin found to be toxic to the crayfish. Chlorine, used both as a toxicant and as a denaturing agent was removed by the addition of a small excess of sodium thiosulphate and the resulting solution also tested for toxicity to *Daphnia*. *Daphnia obtusa* were used as a substitute for crayfish in these confirmatory tests, being readily available and of broadly similar response characteristics to crayfish and other *Daphnia* species. In a future set of trials it may be appropriate to use the international standard *Daphnia magna*, accepting the substantial additional cost of their culture.

Action of adjuvants

While low oxygen should bring the animals into activity so that they seek the shallows, it is possible that over-rapid deoxygenation will narcotise them. In such a state they may be less susceptible to other toxicants. Survival in a deoxygenated state is very much longer for invertebrates than for vertebrates, in the order of a day for some insect larvae. For these tests, confirmation that a moderate degree of deoxygenation that would bring them into activity seeking the surface was the main objective. Establishing the degree and duration of deoxygenation that would be lethal should be the subject of future research, as it cannot be used for complete destruction of crayfish due to their propensity to climb out of unsuitable water and respire atmospheric oxygen.

Experimental conditions

Collected animals were stored in net bags whilst in the field, which were frequently wetted by dipping in the river. The animals were sorted into size categories and transported either in sealed damp nets or in escape-proof containers of water aerated with a portable pump, within a locked vehicle. No difference in survival during transport, or subsequently, was noticed between these two transportation methods. The air temperatures during collection and transport were between 5 ^{o}C and 10 ^{o}C. These methods may not be so successful at higher temperatures or at temperatures below 0 ^{o}C. The maximum time between collection and installation in the laboratory was 24 hr. The animals were maintained in the laboratory in 150 l aerated tanks in the dark at 13-15 ^{o}C, with an excess of suitable size homes (plastic horticultural plug trays of several sizes) and unfed. Some of the 0+ animals were maintained in 15 l aquaria with black plastic netting as homes. Since they can climb up an airline if it rests against the tank side, care was taken to ensure that air lines were held at some distance from the tank side.

The laboratory was licensed for the keeping of signal crayfish by CEFAS. There were no floor drains or other practical escape routes and the surrounding areas of the basements were dry and of relatively low humidity. Since the site drains via a combined sewer to Esholt WWTW and via tertiary treatment to part of the R Aire that is too polluted to support any sort of crayfish, no special precautions were taken to prevent plague disease transfer. In fact, since all the animals came from a population that has been living upstream of a thriving population of native crayfish for over ten years, it must be assumed that they were plague-free.

Before any animals were introduced to the laboratory, open tanks containing clean tapwater and *Daphnia obtusa*, a species with a high sensitivity to pesticides and toxic metals, were maintained around the laboratory for 14 days to demonstrate the basic cleanliness and freedom from toxicants of the laboratory. These cultures were unfed and had to be replaced every 3-5 days. All the vessels used for the tests were similarly tested. The plastic containers proposed for use were found to be toxic on first filling with water (after 4 days from 16th March), but after draining and refilling, no toxicity to *Daphnia* was found.

1+ and larger crayfish were tested in 2 l of water in plastic containers. It was originally intended that glass tanks of similar size would be used to conduct pesticide tests, since plastic adsorbs pesticides and alters their apparent toxicity. However, due to the availability of small animals, all the pesticide tests were conducted in 200 ml of water in smaller glass vessels, using 0+ animals.

It was found possible to conduct all the tests on 0+ animals as one or two individuals in 200 ml of water. No deaths of controls were recorded in any of the tests and all animals appeared unstressed after 24 hr in such conditions, without homes. It was assumed that the relatively low temperatures (13-15 ^{o}C) and low light levels (one small N-facing window) were contributory factors.

TESTS CONDUCTED

The tests are described here according to the chemical or combination tested.

Chlorine

A cheap domestic bleach with no stated additions of detergents was assumed to be basically water, sodium chloride and sodium hypochlorite.

A 10* series of dilutions was made in 2 l plastic containers with 2+ animals using approximately 100, 10, 1, 0.1 and 0.01 mg l^{-1} as free chlorine. The pH in the strongest was 9, the second 8 and the remainder were between 6.5 and 7.5.

The second test exposed 0+ animals to chlorine concentrations of 200, 100, 10 and 2 mg l^{-1} for 1 hr in glass vessels before placing them in clean water and continuing observations.

Dechlorination

This was carried out using sodium thiosulphate saturated solution, adding just sufficient to obtain a zero reading on the chlorine test.

High pH

Strong sodium hydroxide solution was prepared by adding approximately 10 volumes of water to one volume of commercial solid drain cleaner, stated to be sodium hydroxide pellets.

Solutions were prepared by adding 1 ml, 0.5 ml of sodium hydroxide solution to two flasks containing 200 ml of water, then serially diluting each 1:100 three times. The resulting pHs were taken after 30 min exposure of one 0+ animal in each flask.

The test was repeated contacting the animals for one hour with dilutions of 4, 2, 1 and 0.5 ml in 200 ml, then removing them to clean water

Low pH

Five molar HCL was used as the stock solution. Ten times serial dilutions were made from one flask of 200 ml water and 20 ml stock hydrochloric acid. One 0+ animal was placed in each flask and observed after 1 hr and 24 hr. The pH in each flask was measured after 30 min and again after 24 hr.

Potash alum

A saturated solution of pharmaceutical alum was prepared. To each 1 l of water in plastic vessels was added 10, 5, 1 and 0.1 ml of stock saturated solution, plus a 1+ animal on 22nd March. Since no pH correction was made, the alum should remain in solution as the tapwater was around pH 6.5-7. Alum may be more toxic as it precipitates in higher and lower pHs, but this might be difficult to achieve in the field given the requirements to contact every individual.

Ammonia

A saturated solution of ammonium sulphate was prepared and used to prepare solutions in which ammonia would be the toxic substance. The stock solution was diluted 2, 1, 0.1 and 0.05 ml in 200 ml glass flasks of water to which a 0+ animal was added immediately. After 24 hr of observation 0.1 ml of stock sodium hydroxide solution was added to each vessel to raise the pH to 9 and the observations continued for a further 24 hr. This will convert a high proportion of the ammonia to the unionised form which is much more toxic.

The test was repeated with immediate addition of sodium hydroxide to pH 9, with controls at neutral pH and 10% of these concentrations

Papain/salt

Commercial meat tenderiser was investigated to determine if the enzyme would have a damaging effect on the gills or carapace. Realistic solutions for economic field use were 2 g and 1g l^{-1} and they were tested with two 1+ animals each.

Deoxygenation

In larger water bodies, e.g. ponds and outdoor tanks, the addition of biodegradable organic matter (e.g. sucrose, silage liquor, milk etc.) leads to deoxygenation as the bacteria naturally present consume what for them is a sudden increase in available food. An attempt was made to duplicate the process in the laboratory, without adding unknown amounts of other toxicants such as might be provided with silage liquor. The aerators were removed from five plastic containers each filled with 2 l of water. Saturated sucrose solution was added to each plus 25 ml of soil suspension – sufficient to make the water turbid, visibility approx 25 cm. A 1+ animal was added to each and observed after 1, 2 and 24 hr.

Sodium sulphite reacts with oxygen, removing it from solution and being itself degraded in the process. It may therefore be used to maintain a deoxygenated state in a vessel of water open to the air, for as long as a sufficient concentration of sulphite remains. It is otherwise difficult to ensure an absence of oxygen in water used for prolonged toxicity tests on animals. The addition of a catalyst makes the deoxygenating reaction much faster, with a danger that animals may become intoxicated within their burrows in the field situation.

Sufficient saturated sodium sulphite solution was added to 3 l of water in a glass tank containing a 1+ animal to give a concentration =>500 mg l^{-1} and observed after 2 and 24 hr. Extra sodium sulphite was then added to restore the concentration plus four more 1+ animals and observed continuously for 12 hours. The intoxicated animals were placed in clean aerated water and observed for 1 hr.

Permethrin

A commercial pesticide claiming an active ingredient of 0.6% permethrin was used to prepare a 60 mgl^{-1} stock solution by diluting 1 ml of this in 100 ml of water. The diluted solution degraded after 24 hr, as shown in the results section, so a fresh dilution was made up for the final tests.

In the first test additions of 2.4, 1.2, 0.2 and 0.05 ml of stock (60 mg l^{-1}) solution were made to each of four 200 ml flasks, to which was immediately added an 0+ animal in each. Observations were made after 30 min, 1 hr and 24 hr.

The test was repeated with lower concentrations and removal of the animals to clean water after one hour to check that the effects were not reversible.

Permethrin with denaturing

Using one tenth the concentrations of permethrin that were shown to be toxic in the previous tests three 0+ animals per concentration were exposed then removed after 1 hr. 0.2 ml bleach (giving a measured 5 mg l^{-1} chlorine) was added to each vessel for 1 hr followed by 0.15 ml of thiosulphate. Subsequent tests showed chlorine was absent. At least 10 *Daphnia* were added to each vessel and observed over 24 hr.

The process was repeated with the original permethrin concentrations, made up from freshly prepared stock and using four 0+animals per concentration (i.e. 16 animals in total). The denaturing process was carried out on separately prepared but identical vessels at the same time, allowing 30 min of contact with bleach then 10 min with thiosulphate before adding four 0+ animals and >10 *Daphnia* to each resulting solution.

The test was repeated with two animals in each of four flasks containing 0.1 ml of stock permethrin in 200 ml of water as controls and the same concentration detoxified with 1 hr contact with chlorine then 15 min with thiosulphate.

RESULTS

Chlorine

First test:

mg l^{-1}chlorine	100	10	1	0.1	0.001
pH	9	8	7.5	7	6.5
Result after 4 hr	OK	OK	OK	OK	OK
Result after 24 hr	dead	torpid	OK	OK	OK

Second test:

mg l^{-1} chlorine	200	100	10	2
Result after 1 hr	OK	OK	OK	OK
Result after 3 hr	Torpid	OK	OK	OK
Result after 24 hr	Dead	Dead	OK	OK

In summary, a concentration between 10 and 100 mg l^{-1} of chlorine is likely to kill signal crayfish within 24 hr of 1 h exposure. A delay in response of over an hour was observed, which may not have been noted previously for this species. If lower concentrations of chlorine are used the risk of degradation due to reaction with sediments and dissolved organic matter would increase. Chlorine is likely to be most effective in clean situations and its action may be enhanced by the addition of mineral acid. Chlorine is easily denatured as mentioned above.

Denaturing of chlorine

The results of this work are given in section below.

High pH

First test:

pH	12	12	9	7	7	6	6	6
Result after 2 hr	torpid	OK	OK	OK	OK	OK	OK	OK
Result after 24 hr	dead	dead	OK	OK	OK	OK	OK	OK

Second test:

pH	14	14	12	12	7
Result after 1 hr	Torpid	OK	OK	OK	OK
Result after 24 hr*	dead	dead	dead	OK	OK

*in clean conditions after 1hrs contact

The effects of high pH appear to be partly cumulative. At high pH the likelihood of creating foaming agents (soaps) is high, therefore aeration and cascading actions, e.g. in a river are likely to create foams at least until the water is neutralised. After exposure of, e.g. 24 hr using (e.g.) quicklime, the water should be neutralised with acid before being aerated or released downriver.

Low pH

First test:

pH after 30 min	0.5	1	1	1
Result after 1 hr	torpid	OK	OK	OK
pH after 24 hr	1	1.5	2	n/a
Result after 24 hr	dead	dead	OK	OK

While such low pHs may be achievable in acidic and poorly buffered waters, crayfish tend to prefer more alkaline and well buffered waters. Obtaining a pH below 1.5 may be difficult in such waters especially if the bed materials include limestone, chalk or other base-rich rocks. The pH in burrows is likely to remain above the lethal level.

Potash alum

First test:

Potash alum mg l^{-1}	n/a	n/a	n/a	n/a
Result after 24 hr	OK	OK	OK	OK

Although alum is cheap, it is difficult to deal with in large quantities. It is very toxic to fish so would have to be precipitated then removed. The above concentrations were the highest that might give a practical field method, and they were clearly too low to have any effect.

Ammonia

First test:

Ammonium sulphate mgl^{-1}	4500	2250	225	112
Ammonia "as N"	1033	500	50	25
Result after 2 hr	OK	OK	OK	OK

Since ammonia has a rapid action with fish, it was concluded that intoxication with ammonia at neutral pH was impractical due to the high concentrations required.

Following immediately from the first test, the pH was raised in each vessel (except control):

pH	9	9	9	9.	7
Result after 30 min	dead	dead	OK	OK	OK
Result after 24 hr	dead	dead	dead	dead	OK

After 24 hr all the test animals were dead and all the controls were OK. Thus unionised ammonia is very much more toxic than the ionic form, which is as expected. The actual concentration of unionised ammonia has not been calculated. It is a function of pH, temperature and ammonia concentration principally. In the tests on high pH on its own, effects were not observed at pH 9.

Second test:

Ammonium sulphate mg l^{-1}	4500	2250	225	112
Ammonia "as N"	1033	500	50	25
Sodium hydroxide (strong) ml	0.1	0.1	0.1	0.1
pH	9	9	9	9
Result after 24 hr	dead	dead	dead	dead

Ammonium sulphate mg l^{-1}	450	225	22.5	11.2
Ammonia "as N"	103	50	5	2.5
pH	7	7	7	7
Result after 24 hr	OK	OK	OK	OK

A concentration of around 100 mg l^{-1} ammonia (as N) at pH 9 is likely to provide 100% kill after 1 hr. This is too strong to be realistically allowed to travel down a watercourse. However, at a still higher pH substantially less ammonia would be required – perhaps below 25 mg l^{-1} as N, at which concentration the correction of pH and some dilution may yield a non-toxic water for release. With longer exposure times, yet lower concentrations could be used.

Papain/salt

First test:

Papain/salt solution, g l^{-1}	2	1
Result after 24 hr	OK	OK

There is no point in examining this substance further.

Deoxygenation

First test:

Sucrose solution (ml l^{-1})	50	25	10	10	5
Result after 24 hr	OK	OK	OK	OK	OK

In these cool conditions with small volumes bacterial deoxygenation is difficult to achieve. This is not true in larger volumes and at field scale, so the method has high potential for field use.

Second test:

Sodium sulphite, mg l^{-1}	>500
Result after 2 hr	OK
Result after 24 hr	dead

Third test:

Sodium sulphite, mg l^{-1}	>500	0
Result after 10 min	Active	OK
Result after 15 min	Rapid ventilation	OK
Result after 1 hr	active/climb out	OK
Result after 12 hr	torpid	OK

Aerated water (recovery)	
Result after 1 hr	partial activity

After 10 min activity increased, then after 15 min all four put their heads into their homes and left their tails out with pleopods fanning rapidly. Subsequently behaviour alternated between moving around actively and being still with pleopods fanning. Sometimes one or two animals came to the surface and partially crawled out. All these behaviours were not observed in the adjacent control tank, therefore they were concluded to be due either to low oxygen or the sulphite itself.

The use of deoxygenation does appear to hold some hope of drawing animals out of their burrows and, if carried out over perhaps 24 hr, bringing them to the sides of the waterbody where they can be more effectively intoxicated with another substance. Further tests are required to determine the lethal time under deoxygenated conditions – it is likely to be 24 hr or more. Sodium sulphite with the catalyst could be used to achieve a similar effect in a river, over a shorter time span.

Permethrin

First test:

Permethrin mg l^{-1}	0.72	0.36	0.06	0.015	0
Result after 30 min	torpid	torpid	OK	OK	OK

Animals from highest two concentrations were placed in clean water:

Result after 1 hr	torpid	torpid	active	active	OK
Result after 24 hr	dead	dead	dead	dead	OK

A delayed action was apparent, with animals first becoming continuously active, then torpid for several hours before dying. Recovery is not apparent after removal to clean water and apparently healthy animals die later, having therefore received a toxic dose. A delay of several hours in response is therefore found. Low doses could be used to stimulate the animals into activity so that a second toxicant could be used more effectively.

Second test:

Permethrin	0.06	0.03	0.015	0.006	0
Result after 1 hr	dead	torpid	slow	OK	OK
Result after 24 hr	dead	torpid	dead	dead	OK

It is possible that the stock was already degrading, having been made up for over 24 hr. This is the first test in which the effects were not in sequence. The repeats (see later) were run with more animals.

Permethrin with denaturing

<u>First test</u>:

Permethrin mg l^{-1}	0.06	0.03	0.015	0.006	0
Result after 1 hr	OK	OK	OK	OK	OK

Animals removed:

Result after 24 hr	OK	OK	OK	OK	OK

5ml bleach added, 1 hr later 0.15 ml thio added to all but the last (control) vessel and *Daphnia* added:

Result after 24 hr	OK	OK	OK	OK	OK

From this test it was concluded that the denaturing stages were not of themselves toxic, although the stock solution of permethrin was degraded.

<u>Second test</u> (with freshly prepared stock solution):

Permethrin mg l^{-1}	0.06	0.03	0.015	0.006	0
Result after 1 hr	torpid	torpid	torpid	torpid	OK

Animals removed to clean water:

Result after 8 hr	dead	dead	dead	dead	OK

To separate vessels containing permethrin as above:

5ml bleach added, 30 min later 0.15 ml thio added to all but control, *Daphnia* and crayfish added:

Result after 8 hr	dead	dead	dead	dead	OK

It was concluded that 30 min was too short a contact time for the chlorine to denature the permethrin. This also confirmed that the original stock solution had degraded.

Third <u>test</u>:

Permethrin mg l^{-1}	0.06	0.03	0.015	0.006	0
Result after 1 hr	torpid	torpid	torpid	torpid	OK

Animals removed:

Result after 8 hr	dead	dead	tor/dd	dead	OK

To separate vessels containing permethrin as above: 5 ml bleach added, 30 min later 0.15 ml thio added to all but control, *Daphnia* and crayfish added:

Result after 8 hr	tor/dd	dead	dead	dead	OK

The claim in Crowther & Smith (1982) that permethrin is chemically degraded by any chlorine residual was shown to be not applicable in the time frame of the current work. It may be that they considered permethrin to be similar chemically to natural pyrethrum, which was used for control of animals in water mains prior to the development of permethrin, and which was “known” to be degraded by chlorine. However, permethrin is considerably more stable than natural pyrethrum. If denaturing of permethrin cannot be accomplished in the field, then it may be advisable to look to natural pyrethrum for use in such cases. It is understood that once a supply of natural pyrethrum, e.g. 10 l or so of concentrate, is obtained, this could be stored without degradation for many years.

In the tests reported in paragraph above the controls were blank, whereas they should have had bleach and thio added.

DISCUSSION

This rapid appraisal enabled the selection of some promising methods for the control of signal crayfish in the field. Further work on concentrations and conditions would be advisable prior to field tests to ensure that the desired effects were achieved without risks of environmental damage outside the target waterbody.

The delay between contact with a toxicant and any apparent response was considerable, with deaths sometimes taking up to 24 hr to occur after a 1-hour contact. This may give problems in the field application as it would be usual to expect to observe effects within an hour or so, for example if working with freshwater fish. Suspicions of underdosing based on such observations could lead to serious overdosing.

Problems of incidental damage may have restrained the search for effective control measures for signal crayfish. By accepting and dealing with such damage in order that no long term harm is caused, several potential control methods were established.

CONCLUSIONS

There are four possible methods each of which could be used on its own to exterminate signal crayfish: pH 12+, 10-100mg l^{-1}- chlorine, 10µg l^{-1} permethrin/natural pyrethrum, and zero oxygen created by sodium sulphite or organic addition. There are three methods in which toxicant and adjuvant could be combined with advantages over these four: ammonia with high pH, acid with chlorine, and deoxygenation as a precursor to any method. In all methods there will be some animals that leave the water. These may survive and recolonise over the succeeding few days after control, rendering the work ineffective. Spraying of the margins with a pesticide like permethrin is a potential (but untested) means of completing the extermination with minimal environmental effects.

High pH on its own is attractive because of the simplicity both in creating and denaturing such a condition. However, encouraging the animals into movement with deoxygenation using sodium sulphite then adding a mixture of ammonium and caustic might involve less overall addition of chemicals since the neutralising stage could also render the residual ammonia non-toxic. Chlorine is only suited to clean situations because of its affinity for organic matter. If it were to be used after deoxygenation, it would be important to ensure that all the sulphite had oxidised first, otherwise it would denature the chlorine. The failure of the tests to denature permethrin was unexpected and puts this synthetic pyrethroid lower in the priority for use, because of the risk of environmental damage outside the target area. However, the use of natural pyrethrum remains a possibility with a distinct advantage that only crustaceans and insects would be damaged, leaving the remainder of the fauna and all the flora intact.

All the exposures here were nominally one hour, to check if control in an isolated stretch (e.g. dammed and over-pumped) of a small river would be feasible. This was found to be true. Very much lower concentrations of toxicant would be needed for 24 hr exposures in any situation.

The 0+ signal crayfish has been found to be amenable to laboratory investigations of this kind, being easy to capture and handle at this time of year; requiring no aeration in standard beakers or half-filled flasks at 13-15 ^{o}C; yielding consistent results. Furthermore there was little sign of cannibalism in the stock tanks, in which the animals were kept in size-classes. Abundant habitat material in the form of horticultural plug trays was no doubt also helpful in preventing aggression. Over the two-week storage period no feeding appeared to be necessary.

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PRACTICAL ELIMINATION OF SIGNAL CRAYFISH, *PACIFASTACUS LENIUSCULUS* (DANA), FROM A POND

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ABSTRACT

Signal crayfish (*Pacifastacus leniusculus*) was imported to the Czech Republic in 1980. Its culture in the RIFCH USB at Vodňany was established in 1995. In 1997, 500 signal crayfish specimens were stocked into a 0.16 ha experimental pond to provide a source of crayfish for various experimental purposes. A decision to eliminate the signal crayfish from the RIFCH USB was taken in 2001 and several experiments were performed in order to find the most effective method of suppression of this species. More than 700 crayfish specimens were present in the pond (4300 crayfish ha^{-1}) and only 340 of them were bigger than 80 mm. Trapping was of limited effectiveness, catching only a proportion of crayfish bigger than 80 mm. In a subsequent experiment pond water was drawn off several times (3x) and all individuals were removed after each draw down. 614, 103 and 24 crayfish specimens of all age classes were removed during the first, second and the third harvest, respectively. However, the crayfish population was not destroyed completely. Estimation of population density was computed from the above data according to Petersen, Schnabel and Leslie and Davis. Consecutively, the pond was disinfected with chlorinated lime ($CaO.CaCl(OCL)H_2O$ – with active chlorine content more than 30%) using 125 kg (780 kg ha^{-1}) on the water surface at full water. Although the dose was several times higher than recommended for disinfection of a pond on water surface, there was a lethal effect on control fish stock in a cage only. No any visible effect was found for the crayfish. Pond overwintering was used as the next approach. No crayfish were found in spring 2002 but their occurrence could not be excluded completely.

Keywords: signal crayfish, elimination, population density, trapping, overwintering

INTRODUCTION

Five species of the crayfish occur in open waters of the Czech Republic (see Holdich, this volume). The noble crayfish, *Astacus astacus,* and the stone crayfish, *Austropotamobius torrentium,* are two species native in the Czech Republic. The noble crayfish is the most abundant species occurring in brooks, small rivers and ponds. The stone crayfish is highly endangered in the Czech Republic and occurs probably at four localities only. The narrow clawed crayfish, *Astacus leptodactylus* (an European species alien in the Czech Republic), occurs mainly in quarry pits in Southern and Eastern Bohemia. The North American spiny-cheek crayfish, *Orconectes limosus,* is expanding in the Elbe and Vltava rivers and in some of their tributaries. The occurrence of signal crayfish, *Pacifastacus leniusculus,* is restricted to several sites only (Kozak *et al*., 2002).

The signal crayfish was imported to the Czech Republic in 1980. Czech Fisheries Community imported 1000 juveniles of between 12 and 15 mm total body length. Juveniles were stocked to the following four localities: Spustík pond (15 km from Velké Meziříčí), pond near to Čáslavice village, Skříňka pond (2 km from Velká Bíteš city), and to an unknown locality near Ivančice village. Occurrence of signal crayfish in Czech open waters was checked out in Spustík pond from which it was stocked to the Stržek pond in Kozlov village. From this pond the crayfish expanded to pond Nad trait, several metres away. Several signal crayfish were stocked to a reservoir close to Lubná village near Kroměříž city in 1988 and to a small pond in Lomy village. At present, there is high-density of the signal crayfish. The next locality with a signal crayfish population is the experimental area of RIFCH USB in Vodňany (Policar & Kozák, 2000). The uncontrolled spread of signals is a very big risk for native crayfish not only in Czech Republic but throughout Europe (Holdich, 2002). A review of possible methods for controlling nuisance populations of alien crayfish was presented by Holdich *et al*. (1999). They divided the control methods to the five broad categories:

1. Legislative – local and national regulations,
2. Mechanical – control by hand or with traps,
3. Biological – parasites, disease and predators,
4. Physical – temperature, environmental manipulation,
5. Chemical – biocides, attractants, repelling agents.

Bills & Marking (1988) trapped a nuisance population of *Orconectes rusticus* continuously for six weeks with catches declining from 6500 crayfish to 206 over the trial period. Males dominated the catches. Small-sized crayfish did not enter the traps. They suggested that trapping on its own might suppress the crayfish population but would be unlikely to control it. Roqueplo *et al*. (1995) used standard cylindrical traps and also a trap shaped like a tambourine with funnels in the sides, to trap a nuisance population of *Procambarus clarkii* from a pond. They found that regular use of traps substantially reduced the population, but did not eliminate it. When a population of *P. leniusculus* in England was heavily trapped from carp ponds using Swedish trappies the population was estimated to have been reduced from 4000 to 1500 over the equivalent of 900 trap nights (Holdich *et al*., 1999). They suggested if regular trapping of large individuals had been continued then fish predation on the smaller individuals that might eventually have eliminated the population.

Westman (1991) reviewed the wide variety of traps used in Finland. Westman *et al*. (1979) stated that crayfish are very skilful at escaping from standard traps and as a consequence developed the "Evo-trap", which has narrow slit-like apertures, that made it much more difficult for crayfish to escape. In contrast Holdich *et al*. (1999) has shown that the Swedish traps commonly used in Britain are not very effective at retaining crayfish once captured and that traps needed to be emptied frequently. Edsman & Söderbäck (1999) recommended for the standardised sampling methodology setting the traps just before dusk and their lifting at around 0600 h. Romaire & Pfister (1983) recorded a maximum catch of crayfish per trap after 6-12 h with no visible effect on catches with an increase in time. Conversely catches decreased when traps were deployed for less than 6 h.

The common method of crayfish population density estimation is using the multiple-recapture method with capturing, marking, releasing and resampling of crayfish and computation according to Petersen (Ricker, 1975) and Schnabel (Schnabel, 1938) (Abrahamsson, 1966, 1973; Elser *et al*., 1994; Westman *et al*., 1999). Population density by these methods is usually underestimated (Brown & Brawis, 1979; Shimizu & Goldman, 1983; Hogger, 1986). The other approach to population density estimation is a method according to Leslie and Davis (Cowx, 1983), based on removing the majority of population without releasing them.

MATERIAL and METHODS

Signal crayfish culture in the RIFCH USB at Vodňany was established in 1995. In 1997, 500 signal crayfish specimens were stocked into a 0.16 ha experimental pond. The pond was harvested every spring and crayfish (mainly females) were used for experiments. A decision to eliminate the signal crayfish from the area of RIFCH USB was taken in 2001. Several experiments were performed in order to find the most effective method of suppression of this species. The authors examined the following four methods:

Trapping

"Evo traps" were used for trapping. Altogether, 70 crayfish were caught in eight traps during five nights. More than 700 crayfish specimens occurred into the pond (4300 crayfish ha^{-1}) and only 340 of them were bigger than 80 mm. Estimation of population density was performed from the recapture experiment data (with the use of trapping) and computation according to Petersen and Schnabel.

Petersen: $N = M * C / R$
Schnabel: $N_i = \Sigma \{C_i * M_i\} / \Sigma R_i$
Where:
N = estimated abundance
M = No. of marked crayfish in pond
C = No. of captured crayfish
R = No. of marked captured crayfish

Crayfish escaping from "Evo traps" was evaluated after 24 h in another experiment. Ten adult signal crayfish (five males and five females) were stocked per trap without any bait and altogether seven traps during five days were set to the experimental pond. The number of crayfish that stayed in traps were counted daily and escaping crayfish were compensated. The values of mean body length, mean carapace length and mean body wet weight were 108.3 ± 11.88 mm (80-144 mm), 54.4 ± 6.24 mm (40-78 mm) and 49.43 ± 17.846 g (19-141 g) respectively. Size of escaping and/or non-escaping crayfish was statistically evaluated by the non-parametric Mann-Whitney U test.

Hand removal following draw-down

In a separate experiment, pond water was drawn off three times (April 6, 9 and 10) and all individuals removed from the pond on each occasion. All individuals were measured and weighed. Estimation of population density and number of remaining crayfish in the pond was computed according to Leslie and Davis.

Disinfection with chlorinated lime

Subsequently, the pond was disinfected with chlorinated lime ($CaO.CaCl(OCl)H_2O$ – with an active chlorine content of more than 30% using 125 kg (780 kg ha^{-1}) on the water surface of un-drained ponds. The temperature, oxygen content, pH value and chlorine content were monitored before and after application. Control fish (rudd *Scardinius erythrophthalmus*, roach *Rutilus rutilus* and tench *Tinca tinca*) and crayfish stocks were situated in cages throughout the pond.

Pond overwintering

A further experiment was conducted involving draining the pond and allowing it to remain empty over winter. The pond was emptied in September 2001 and filled up in April 2002. The minimum winter temperature was about minus 20 °C.

RESULTS

Trapping

Catching with traps was not found to be very effective, catching only a part of the crayfish population bigger than 80 mm (Figs 1 and 2). Small-sized crayfish did not enter the traps. Trapping may have suppressed the crayfish population, but did not eliminate it.
A population density estimation according to Petersen gave an estimate, i.e. 225.3 specimens as a mean. Based on the same data, the population density estimation according to Schnabel revealed 225.2 specimens. Crayfish bigger than 80 mm were trapped only. The results of three harvests showed that there were 343 such individuals in the pond. Hence, the estimated population density was somewhat lower than the actual density.

Figure 1. Length-weight relationship of crayfish in the experimental pond.

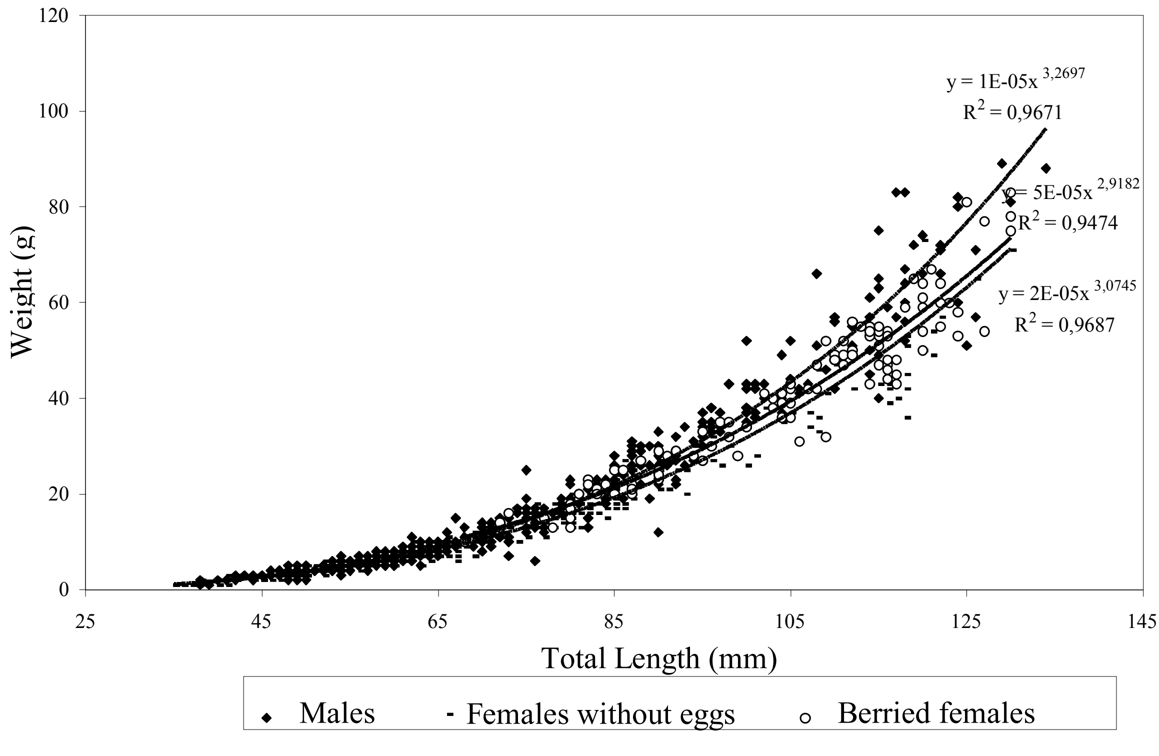


Figure 2. Length-weight relationship of crayfish trapped for the purpose of population density estimation by means of Petersen and Schnabel method.

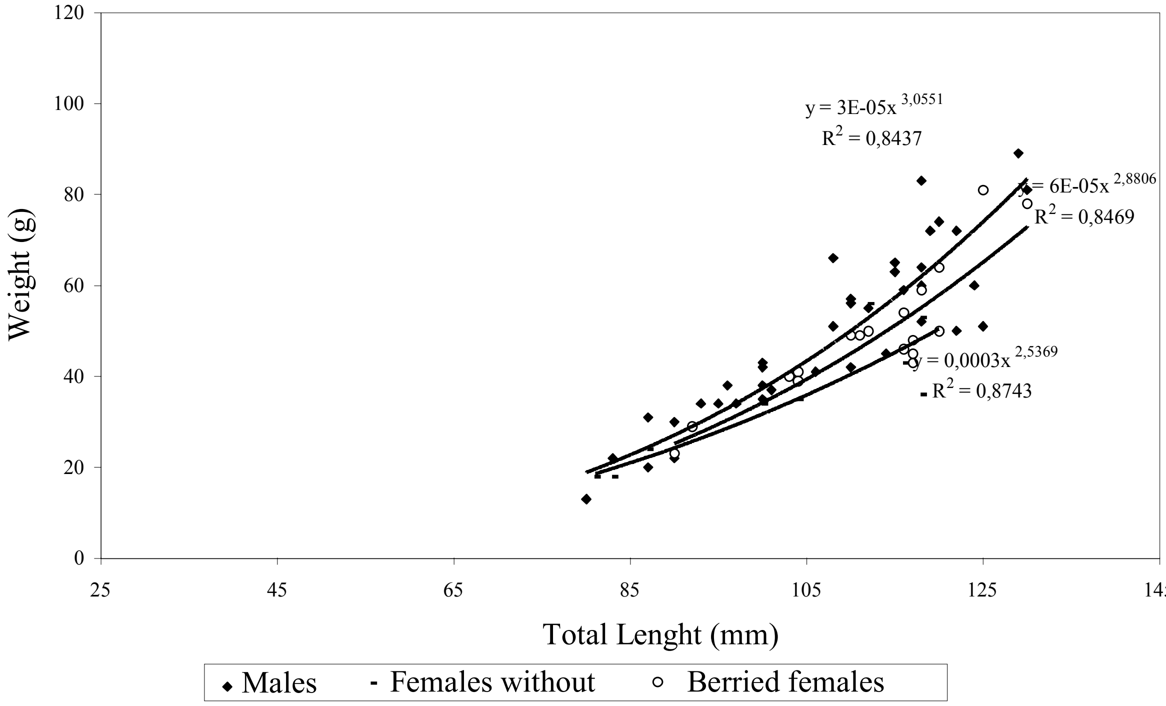
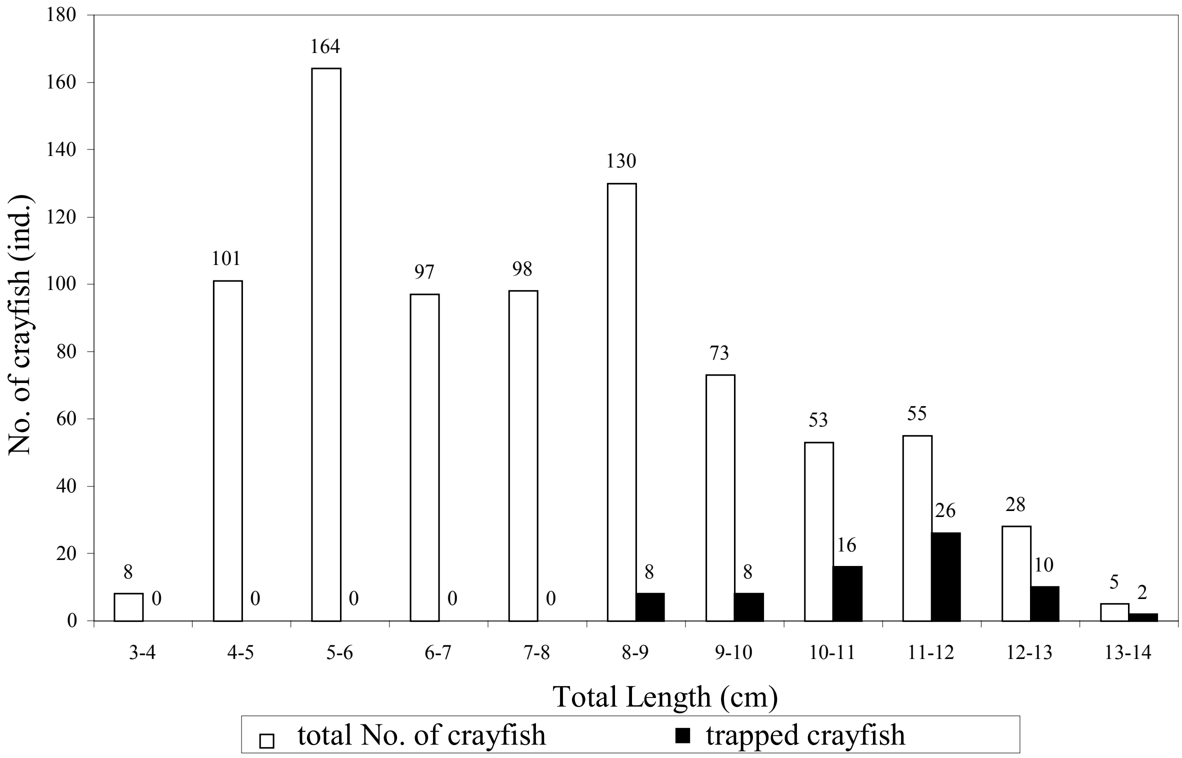


Figure 3. Signal crayfish size structure caught by means of traps and by pond drainage.



Size distribution of crayfish in the pond, as well as that of the trapped crayfish is evident from Fig. 3.

In order to determine the extent to which crayfish escaped from "Evo traps" a further experiment was run. It was found that an unexpectedly high (39.7 ± 29.03 %) frequency of crayfish escaped from the traps with 90% maximum and 0% minimum (Table 1). Crayfish in the test were of a mean body length of 108.3 ± 11.88 mm (80-104 mm), mean carapace length of 54.4 ± 6.24 mm (40-78 mm), and mean body wet of 49.43 ± 17.846 g (19-141 g). No significant difference in size or weight was found between crayfish that stayed and escaped from traps. No effect of sex or trap was found.

Table 1. Crayfish escapes (%) from traps

Trap No.	Day of trapping 1	2	3	4	5	6	7	Average	Min	Max	STD
1	80	90	90	30	20	20	20	50.00	20	90	32.071
2	60	40	30	80	90	0	70	52.86	0	90	29.137
3	10	10	0	60	80	30	70	37.14	0	80	30.102
4	50	20	50	40	20	70	50	42.86	20	70	16.660
5	0	0	0	20	40	10	40	15.71	0	40	16.782
Average	40	32	34	46	50	26	50				
Min	0	0	0	20	20	0	20				
Max	80	90	90	80	90	70	70				
STD	30.33	31.87	33.82	21.54	29.66	24.17	18.97				

Hand removal following draw-down

Subsequently, pond water was drawn off three times and all individuals were removed from the pond on each occasion. Firstly, 614 crayfish specimens were collected, while 103 and 24 crayfish specimens of all age classes were found during the second and the third harvest, respectively. However, the crayfish population was not destroyed completely.

According to the computation of estimation of population density according to Leslie and Davis, the line of linear relationship intersects the x-axis at value 742.7 (Fig. 4). If the number of crayfish caught already (741 specimens) from this value, a value of 1.7 is derived. This means that the pond would be theoretically harvested completely and only a few specimens could remain. According to the low number of samples it was a relatively precise, although somewhat underestimated value.

Disinfection with chlorinated lime

Although the dose used was several times higher than recommended for disinfection of a pond at the water surface, there was a lethal effect on control fish stock in a cage only. Rudd and roach died after 4 h and tench died after 24 h after application. No visible effect was found for the 20 adult crayfish placed around the dyke in cages. Chlorine content and pH values are shown in Table 2.

Table 2. Chlorine content in pond after application of chlorinated lime (temperature 8.6 °C, 11.6 mg l^{-1} O^2)

Time	Cl_2 (mg l^{-1})	pH
before application – outlet	0.01	7.11
directly after application - inlet	0.75	8.64
directly after application - outlet	0.01	8.10
30 min. after application - outlet	0.10	8.39
5 hours after application - outlet	0.75	8.88
24 hours after applications - outlet	0.25	9.30
30 hours after applications – outlet (pond drainage)	0.20	9.30

It is presumed that the active chlorine was bound to the sediment because the theoretical value of chlorine should have been more than 15 mg l^{-1}.

Pond overwintering

Pond overwintering was used as the next approach (from 2001/02). No crayfish were found in Spring 2002 but their occurrence could not be excluded completely. Pond water was drawn off again on August 2002 and 40 signal crayfish (27-111 mm total length) were caught. Crayfish survived the 3 months of the winter season with a minimum temperature of about minus 20°C in their shelters.

DISCUSSION and CONCLUSIONS

Literature data differ in the minimum size of crayfish that can be caught in traps, stating sizes from 40 to 75 mm (Abrahamsson, 1966; Edsman & Söderbäck, 1999; Holdich *et al*., 1999; Westman *et al*., 1999). The smallest size of crayfish caught into our traps was 80 mm. After triple draining of the pond, 343 specimens of this size were registered in the population. Upon trapping, the population density estimation according to Petersen and Schnabel revealed a computed population of 225 crayfish specimens. In accordance with other authors (e.g. Brown & Brewis, 1979; Shimizu & Goldman, 1983; Hogger, 1986) it was clear that the population density computed by these methods was largely underestimated. Moreover, younger age classes that represented the majority of the population were not included in the estimate. The population size in the pond was at least 741 crayfish specimens, however, an even bigger population was likely due to difficulties with harvesting the crayfish and especially the youngest age classes. Population size underestimation is also affected by the time of the year in which the estimation is performed. Crayfish activity was low during this period due to water temperature and duration of the daylight period. Gravidity of females during this period also accounts for their low activity. These factors led to low numbers of crayfish in catches, as well as its size composition. In order to obtain a more precise estimate by means of these methods, catches should be performed in August when the activity of males and females would be the highest. These methods are more applicable for the determination of density of crayfish in reservoirs.

From the estimate of population density performed according to Leslie and Davis, it can be seen how difficult it is to harvest the entire crayfish population from a pond. It is likely that if the pond had been drained off and harvested once more, more specimens would have been harvested than determined by the population density estimate by this method (ca. two specimens). To harvest the majority of crayfish population from a reservoir, the reservoir must be harvested repeatedly. On the other hand, the method gave relatively precise data on the pond population density after the second harvest.

It was found that crayfish had a relatively high tendency to escape from traps of the given type, i.e. 39. 7 ± 29.03 % (0-90%). This completely agrees with the data of Holdich *et al*. (1999) who recommended checking the traps and picking up the catch more frequently due to the low ability of traps to retain the crayfish caught. Results of escapes from individual traps and in individual days fluctuated so far that there surely was a whole series of other factors affecting the escapes than the type of the trap. These might include social behaviour among individuals, duration of starvation period, weather, hydrochemical parameters, etc. Ease of operation and storage, as well as catch effectiveness of this type of trap account for its popularity in Sweden and in other countries (Westman, 1991). However, to use it most effectively, several principles must be fulfilled and if not, the catch is decreased to certain extent by crayfish escapes. Traps should be set before dusk and harvested in early morning (Edsman & Söderbäck, 1999), or at least 6 h after setting them up, as stated by Romaire & Pfister (1983).

Elimination of signal crayfish from ponds is very difficult in the long-term but not impossible. Multiple approaches are needed for each situation to control a signal crayfish population. Repeated drying of a pond and picking up the crayfish, along with overwintering and/or oversummering appears to be the most effective mechanical method of elimination of signal crayfish from a pond. Some chemical methods (e.g. liming) could also be used effectively. Better efficiency of chlorinated lime should be achieved by application on the pond bottom, followed by slight filling the pond with water, with maximum utilisation of increasing pH. Quick kills could be achieved with known chemicals but these methods are not friendly to the environment (Holdich *et al*., 1999; Hiley, this volume).

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Short communication

DISPERSAL AND MOVEMENT OF SIGNAL CRAYFISH IN UPLAND RIVERS

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Within Great Britain, upland rivers in North Yorkshire continue to hold good populations of native white-clawed crayfish, *Austropotamobius pallipes*, although there are several expanding populations of introduced signal crayfish, *Pacifastacus leniusculus* (Peay & Rogers, 1999). Knowledge of the range expansion of signal crayfish populations is important in understanding the threat that they pose to native crayfish populations and the wider ecosystem. In addition an understanding of the movements, dispersal and spatial behaviour of crayfish is required if future control of populations is to be attempted. The upstream dispersal of signal crayfish is likely to be principally determined by adult crayfish, capable of substantial movements against flow, while downstream dispersal is likely to be a combination of juvenile and adult movement. Radio telemetry was used to provide fine scale information (+/- 1 m) on movement and dispersal of adult signal crayfish (Bubb *et al.,* 2002a, b).

Fieldwork was carried out on the rivers Wharfe and Ure, both of which have substantial populations of native crayfish, but also expanding signal crayfish populations. On both rivers signal crayfish were introduced into fishing lakes in the early 1980s and have subsequently escaped into the main rivers. The population of signal crayfish in the Wharfe is well established and fieldwork in 2002 recorded individuals 22.9 km downstream and 3.8 km upstream from the site of introduction into the main river. This represents downstream colonisation of 1.5 km yr^{-1} and upstream colonisation of 0.25 km yr^{-1} and an upstream to downstream ratio of expansion of 1:6. The population of signal crayfish at West Tanfield in the River Ure is less well established. Signal crayfish were first recorded in the River Ure in 1997, and have subsequently been recorded (2002) 184 m upstream and 824 m downstream from the site of introduction. This represents an upstream to downstream ratio of expansion of 1:4.5.

Adult signal crayfish (carapace length >37mm, weight >18.3g) were radio tagged at sites on the rivers Ure and Wharfe. Crayfish were tracked over four periods i) Wharfe, October 2000-February 2001; ii) Ure, August – September 2001; iii) Wharfe, June – August 2002; iv) Ure, June-August 2002. A total of 64 crayfish were tagged with lightweight (1.6 g) radio transmitters and their movements recorded over periods of up to 3 months.

The positions of crayfish were recorded during daylight hours every other day and so their recorded positions represent daytime refuge locations. There was a large variation in the amount of movement recorded between individual crayfish, from a maximum movement of

780 m in 74 days to a minimum movement of 2 m in 32 days. The movements of crayfish were generally sporadic with stationary phases interrupted by periods of movement.

There was no significant difference in the amount of movement recorded between females and males, or any significant correlation between distance traveled and crayfish size. Several high flow events occurred during the study, but these did not cause any mortality or apparent displacement of crayfish downstream.

The maximum amount of movement was recorded in June to August in both the River Ure and Wharfe, with no significant difference in the amount of movement recorded between the two rivers when tracking was carried out concurrently. A lower level of movement was recorded between August and September and this reduced even further in the tracking period October to February. There was a significant difference between the maximum distance traveled upstream and the maximum distance traveled downstream, with greater distances moved downstream. The differences in distances moved upstream and downstream were especially marked when distances greater than 100 m and 200 m were considered, with 66% and 86% of values respectively in a downstream direction. This difference may contribute to the observed directional bias in the expansion of crayfish populations in the Wharfe and Ure. It is the few individuals that make long distance movements that contribute most strongly to the rate of expansion of populations. However, the impact of young age classes on the expansion of signal crayfish populations is unknown, although through passive transport there is the potential for these age classes to be an important component of downstream dispersal.

Bubb, D. H., Lucas, M. C. & Thom, T. J. (2002a). Winter movements and activity of signal crayfish *Pacifastacus leniusculus* in an upland river, determined by radio telemetry. *Hydrobiologia,* **483**, 111-119.

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Peay, S. & Rogers, D. (1999) The peristaltic spread of signal crayfish (*Pacifastacus leniusculus*) in the River Wharfe, Yorkshire, England. *Freshwater Crayfish*, **12**, 665-676.

Keywords: *Pacifastacus leniusculus*, home range, overwintering, telemetry, behaviour, invasive species

Short communication

THE POTENTIAL USE OF PIT TELEMETRY AS A METHOD FOR IDENTIFYING AND TRACKING CRAYFISH IN THE NATURAL ENVIRONMENT

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A method for tracking crayfish and other benthic animals in rivers and streams, based on passive integrated transponder (PIT) technology, using a portable detector was investigated. The reader unit consists of a coil antenna, mounted on a pole to facilitate searching of the stream bed, connected to a decoding electronics module. The decoding electronics are mounted in a compact lightweight plastic enclosure with shoulder strap attachment. The total weight of the system is 2700 g. It is powered by an integral battery that provides approximately 7 hours of continuous use. The maximum detection range of PIT tags by the system was 15 cm. An assessment was made of the ability of the reader unit to detect and locate tags that were within the detection range in the field. Within a stream, 135 tags were hidden in a variety of microhabitats and burrows and the area blind searched. More than 80% of tags were identified and located. In a laboratory study, 30 signal crayfish *Pacifastacus leniusculus* (> 33.7 mm carapace length) were internally implanted with PIT tags and 30 crayfish matched for size and sex were kept as controls and maintained for 6 months. Tagging had no significant effect on survival, moulting or growth of crayfish, and during the experiment tag retention was 100%.

Bubb, D.H., Lucas, M.C., Thom, T.J. & Rycroft, P. (2002). The potential use of PIT telemetry for identifying and tracking crayfish in their natural environment. *Hydrobiologia*, **483**, 225-230.

Keywords: passive integrated transponder, telemetry, marking, tagging, *Pacifastacus leniusculus*

Short communication

BURROWING BEHAVIOUR AND MOVEMENTS OF THE SIGNAL CRAYFISH *PACIFASTACUS LENIUSCULUS* (DANA) IN THE U.K. MIDLANDS

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The signal crayfish, *Pacifastacus leniusculus*, is North American in origin and was brought to the U.K. for aquaculture purposes. It subsequently escaped or was introduced into a variety of waterbodies. One interesting feature of its biology not recorded for its native environment is its ability to burrow (Holdich *et al*., 1995). In some rivers burrowing is so extensive as to cause collapse of the riverbank (Sibley, 2000).

Three of the main burrowing features of this crayfish are: a) digging - using the chelae and pereopods (See Fig. 1), b) ‘pleopod venting’ – pleopod movement causing water circulation and the removal of fine sediment, and c) tail scooping – reversing into the burrow and utilizing the tail to scoop out sediment.

Figure 1. A signal crayfish, digging with chelae and pereopods. Note the animal frequently inverts itself to enlarge the upper part of the burrow.

Burrow morphologies examined using an optic cable video camera showed the majority to have single openings with depths of up to 0.79 m. Analysis of stream bank substrate showed that *P. leniusculus* selected those with higher clay contents where available for burrow construction (correlations between % clay and burrow density = n=78, W=3081, $P<0.001$). However, in-lab substrate selection experiments indicated a significant preference for simulated 'natural refuges' over burrowing in clay. In the field *P. leniusculus* uses both when available. Measurements of burrow O_2, CO_2, ammonia and pH showed slightly hypoxic conditions and elevated levels of ammonia suggesting high rates of burrow irrigation. Experimental determination of water turnover in artificial burrows showed that the average rate was 0.63 L h^{-1} for adults (mass range = 30-101.3g).

Signal crayfish are known to move both upstream and downstream and this has implications for management. Crayfish movements have been monitored in the UK Midlands by means of radio tracking (see also Hiley, a, this volume; Bubb *et al*., a, b, this volume). Results indicate that activity is greatest during and immediately following dusk. Most individuals maintained themselves in the same burrow/shelter for the duration of radio-tracking, but some animals travelled to and occupied between one to four different shelters or pre-existing burrows. The maximum distance recorded by any individual for movement in one night was 106.5 m and all movements that occurred were in an upstream direction. Crayfish activity was significantly lower in winter than in summer, and during two flood events, all animals maintained their pre-flood positions.

The usefulness of this information for control and management are: 1) forecasts on preferred sites for population expansion can be deduced from substrate preferences; 2) identification of sites vulnerable to bank damage can be made; 3) information on burrow construction and irrigation may be relevant in the event of any attempts at biocide application for population control; 4) knowledge of crayfish movement and activity is important for predicting time scale of spread and occupation of new sites.

Holdich, D.M., Rogers, W. D. & Reader, J.P. (1995). *Crayfish conservation*. Project Record 378/10/N&Y. National Rivers Authority, Bristol. 278 pp.

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Keywords: signal crayfish, burrows, activity, behaviour

SECTION 4. MISCELLANEOUS

Keep up to date with what is going on in the world of crayfish by joining the I.A.A.

The International Association of Astacology (I.A.A.), founded in Austria in 1972, is dedicated to the study, conservation, and wise utilisation of freshwater crayfish. Any individual or firm interested in furthering the study of astacology is eligible for membership.

Services to members include a quarterly newsletter, membership directory, bi-annual international symposia, free symposium proceedings, miscellaneous publications, discounts on books, and publication of the journal *Freshwater Crayfish*.

Any individual wishing to join can pay the membership fee (£28) (bona fide students get a 50% reduction), which covers a two-year period, by credit card to the Head Office in the U.S.A (includes a surcharge), or by cheque to 'I.A.A. England' – details can be obtained from David Holdich (david.holdich@ntlworld.com). The rate for firms is twice that of the individual rate. The next membership period will cover 2004 and 2005, but anybody joining between now and December 31st 2003 will get **free membership** for the rest of 2003.

There have been 14 international symposia so far and the 15th is planned for London in 2004 – details are given on the next page. The 14th symposium was in Mexico (2002) and the 16th may be in Queensland (2006). The proceedings for the 12th (Germany, 1998) and 13th (Perth, Australia, 2000) symposia can be obtained via David. *Freshwater Crayfish* 13 costs £40 (including a CD and p+p from Australia).

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