

# **Eradication of alien crayfish populations**

R&D Technical Report W1-037/TR1

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This project was jointly funded by the Environment Agency and English Nature in order to inform policy decisions on alien Crayfish control.

## **Key words**

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## FOREWORD

The Environment Agency and English Nature require research to be undertaken to establish the feasibility of eradicating non-native crayfish populations from the wild where they threaten sensitive sites or important populations of native crayfish. So far, no proven method of eradication has been found. The following report on the field and laboratory trials conducted up to the autumn of 2000, sets out the current position regarding the possibilities for effective control methods.

## Acknowledgements

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# EXECUTIVE SUMMARY

## Background

The unauthorised or accidental introduction of alien species of crayfish, especially signal crayfish, to stillwaters and watercourses poses a severe threat to the remaining English and Welsh populations of the native white-clawed crayfish (*Austropotamobius pallipes*), which are apparently lost as the alien species colonise.

The crayfish plague *Aphanomyces astaci*, has a mortality rate of almost 100% in native crayfish populations. However, recovery may occur by a process of recolonisation. The complete replacement of native crayfish by competing, apparently disease free, alien species seems to be permanent. The Environment Agency and English Nature jointly commissioned this project, to investigate the potential for the eradication of unwanted populations of alien crayfish in the UK.

Phases I (literature review, Rogers, 1998) and II (field and laboratory work) of the Research & Development Project are reported here.

## Main objectives

- Produce a protocol for determining the best method of control or eradication in different situations.
- Protect remaining native crayfish populations and release habitat presently occupied by alien crayfish for recolonisation by native crayfish on the long term.
- Carry out the trials and monitoring specified in the Final Report of Phase I.
- Evaluate the efficiency of each technique or combination of eradication techniques used in a series of case studies.

## Results

The methodologies used or considered are detailed in the main text. From the range of techniques considered, a variety of harvesting and collection methods were attempted in the field. Several biocides were investigated in two separate laboratory trials. The use of predators was not pursued as it was considered to be unsuitable for eradication of crayfish populations.

None of the methodologies tested in the field fulfilled the R & D project objectives of eradicating or controlling signal crayfish. Most collection or harvesting methods used were shown to be sustainable, i.e. they failed to reduce the numbers captured in subsequent samples.

No technique trialed was successful in controlling the spread of signal crayfish. Populations continued to expand, in both range and numbers of individuals, even when population density was low. In order to prevent the spread of signal crayfish it seems to be essential to destroy all individuals. Current sampling techniques are incapable of detecting low-density populations, and even if a control method with potential to eradicate this species could be developed, it would not be possible to ascertain whether or not eradication had been successful.

Chemical control, which was investigated by laboratory trial only, revealed some chemicals and combinations of chemicals, which appeared competent to achieve the objective of eradicating signal crayfish. Since there are no biocides specific to signal crayfish, substantial but temporary damage to the local ecosystem appears to be inevitable. Recolonisation by the natural fauna would occur in weeks to years. Chemical control is likely to be acceptable for use only in confined stillwaters. It may also be suitable for canal populations, where individual pounds can be isolated during treatment. No protocol for the application of suitable methodologies has been produced.

## **Conclusions**

None of the methods attempted in the field showed any realistic potential of achieving the objective of this R & D project, to eradicate or control signal crayfish populations.

Control with biocides was found to be the only eradication method with this potential. This technique carries a range of adverse side effects.

A sampling method which is capable of detecting signal crayfish at population densities that threaten native crayfish (less than 1 adult per 500 m<sup>2</sup> of riverbed, see section 1.2) is required.

Research into control methods with no potential for reducing crayfish population density below the minimum viable population density (MVPD) (Section 1.2), should be discontinued.

It is anticipated that all white-clawed crayfish resident in catchments also containing signal crayfish will be lost, unless a very substantial upstream barrier such as a large dam restricts upstream migration. Current legislation will not protect white-clawed crayfish in native-only catchments from either accidental destruction or future introductions of signal crayfish.

Conservation effort should focus on the use of poisons when necessary to protect native-only catchments, and the establishment of isolated 'refuge sites' for white-clawed crayfish.

A discussion should be conducted on the relative environmental consequences of allowing signal crayfish to expand their range, or of eradicating selected populations with biocides. The output of this discussion would guide future efforts at controlling alien crayfish. Nonetheless, the finding of this study is that in very many catchments alien crayfish populations are already too well established for there to be any realistic prospect of eradication or control.



# 1. PROJECT DESCRIPTION

## 1.1 Introduction

There is concern in the UK and Europe regarding the decline of the white-clawed crayfish, (*Austropotamobius pallipes*), which is decreasing throughout its range and is now a protected species in the UK.

This Research and Development project was jointly commissioned by the Environment Agency and English Nature, in order to assess potential techniques for the eradication of unwanted populations of alien crayfish in the UK. The unauthorised or accidental introduction of alien crayfish species is a severe threat to remaining populations of the white-clawed crayfish, which are apparently lost as the alien species colonise (Lowery, 1988). It is thought that competition and introduction of disease are jointly and separately responsible.

This report provides a discussion of the issues and the potential for eradication of alien crayfish. It draws together the work that has been carried out over phases I (literature review and identification of case studies) and II (field and laboratory work) of the Eradication project during the past three years. Phase I was carried out as a separate contract (Holdich and Rogers, 1998). The appendices give more detail of the individual case studies that have been carried out.

The Phase I report set out:

- 1 an overview of the status of crayfish species in Britain;
- 2 the threat of alien species to the native species;
- 3 a description of the case studies and methods proposed;

### 1.1.1 Objectives of Phase II

The white-clawed crayfish is a target species in the UK Biodiversity Action Plan, which aims to maintain the present distribution of this species by:

- limiting the spread of crayfish plague;
- limiting the spread of alien species; and
- maintaining appropriate habitat conditions (Palmer, 1994).

The long-term aim of this alien eradication project is to support these targets. Phase II involved overseeing a number of projects, undertaken by staff of the Environment Agency and others, trialing potential methods for eradication of alien (signal) crayfish, reporting upon their results and producing a protocol for the application of suitable methods in given situations. The specific objectives were as follows:

- To ensure the uptake of the trials and monitoring specified in the Final Report of Phase I, the literature survey. To ensure that the actions noted by Environment Agency and English Nature staff are implemented at each site.
- To ensure the trials and monitoring are undertaken with a level of quality compatible with inclusion in the R&D project.

- To evaluate the efficiency of each technique or combination of eradication techniques.
- Produce a protocol for determining the best method of control or eradication in different situations.
- Negotiate for the inclusion of alternative sites or methods if any of those proposed are not suitable for the purposes of the project.
- Produce an R&D Technical Report.

## 1.2 Crayfish Status in Britain

### 1.2.1 Status and distribution of crayfish species recorded in the UK

There is only one species of freshwater crayfish which is considered to be native in Britain, the white-clawed crayfish *Austropotamobius pallipes*. Several other species have been introduced since the 1970s'. Five crayfish species can be found in Britain's rivers and ponds. These are described briefly here.

### 1.2.2 White-clawed Crayfish

The white-clawed crayfish (*Austropotamobius pallipes*) is the only British representative of the group of freshwater crayfish (Astacidae), which contains many species that are found in countries with temperate to tropical climates. *A. pallipes* is a cold water crayfish, which tends to be confined to smaller upland, and clean lowland, base-rich watercourses. In England and Wales it can also be found in some base poor waters, larger rivers, canals and stillwaters and crayfish abundance in these atypical habitats can vary enormously from year to year, due to unknown but apparently natural causes. The species does not occur naturally in Scotland. There are also catchments in the far southwest of England and parts of west Wales where it has not been recorded. This may be due to natural conditions on the catchments, such as the prevalence of fairly acidic and base-poor water and high flows. It may simply be that these areas were too isolated to have been colonised naturally. The distribution of white-clawed crayfish is shown in Figure 1.1.

White-clawed crayfish typically produce 80 – 100 eggs per female crayfish per year.

The decline of the white-clawed crayfish is attributable to a variety of factors which, both independently and in combination, pose a very real threat to the continued survival of the species. Factors identified as contributing to this decline include:

- loss of suitable habitat due to drainage, flood defence and other changes in river channels (Holdich et al, 1971, Jay and Holdich, 1981);
- changes in water chemistry, such as nutrient enrichment from fertiliser runoff or pollution incidents including, but not limited to sheep dip pollution;
- infection with crayfish plague, cause by the fungus *Aphanomyces astaci* (Alderman, 1993);
- competition for resources such as habitat from invasive alien crayfish species, particularly the signal crayfish *Pacifastacus leniusculus* (Holdich et al, 1995).

This R & D project addresses the two most major threats to the white-clawed crayfish, namely direct competition with signal crayfish, and infection with crayfish plague carried by this species.

### **Signal crayfish**

By far the most prolific of the alien crayfish species established in Britain, the North American signal crayfish, *Pacifastacus leniusculus* is larger and faster growing than the white-clawed crayfish. It was introduced to Britain in the 1970's, being farmed throughout the 1970's and 1980's as a sideline to fish farming. Signal crayfish were usually released into ponds, but escapes were common, leading to colonisation of the river system. In a few cases, such as the River Gwash (Appendix 4), it has been alleged that signal crayfish were introduced directly to a watercourse. Since the advent of commercial signal crayfish production, farming of this species has become substantially less profitable. The gross annual turnover of crayfish farming in the UK is very small (around £100,000 in 1996) compared to trout farming (£27.4M) (Rogers, 1996). This is partly due to the increasing wildcatch of signal crayfish following their successful colonisation of many English river catchments, but also reflects the limited popularity of freshwater crayfish in UK markets.

The signal crayfish is more fertile than the white-clawed crayfish, with a single pair producing between 100 and 200 eggs per year. It is an invasive species, extremely aggressive and can act as a carrier of the crayfish plague fungus. It has spread rapidly through Britain since its introduction, and can now be found in all but a handful of English river catchments (Figure 1.1). This is likely to be an under-representation of locations of crayfish. Wild populations extend their range annually and chance or illegal introductions continue.

### **Narrow-clawed crayfish**

Originating in Asia and Eastern Europe, the narrow-clawed or Turkish crayfish *Astacus leptodactylus*, has been imported into Britain for the restaurant trade since the early 1970s. Escapes and deliberate introductions have led to the establishment of this species at over 20 known locations, mainly in and around London, although records also exist in the Manifold Valley (Staffordshire) and there are unconfirmed reports of a population of narrow-clawed crayfish in the Huddersfield Broad Canal (John Spicer, University of Sheffield, 1998, pers. comm). This species is particularly unsusceptible to trapping and therefore difficult to detect, so its distribution may be considerably wider than population records suggest.

The narrow-clawed crayfish can grow to twice the size of the native species, and is much more fecund, producing over 200 eggs per year. However it is a comparatively unaggressive species, and is vulnerable to crayfish plague, and therefore is not thought to pose as great a threat to the white-clawed crayfish as the signal crayfish. The effects of competition from the narrow-clawed crayfish on native populations are not known.

### **Other crayfish species found in Britain**

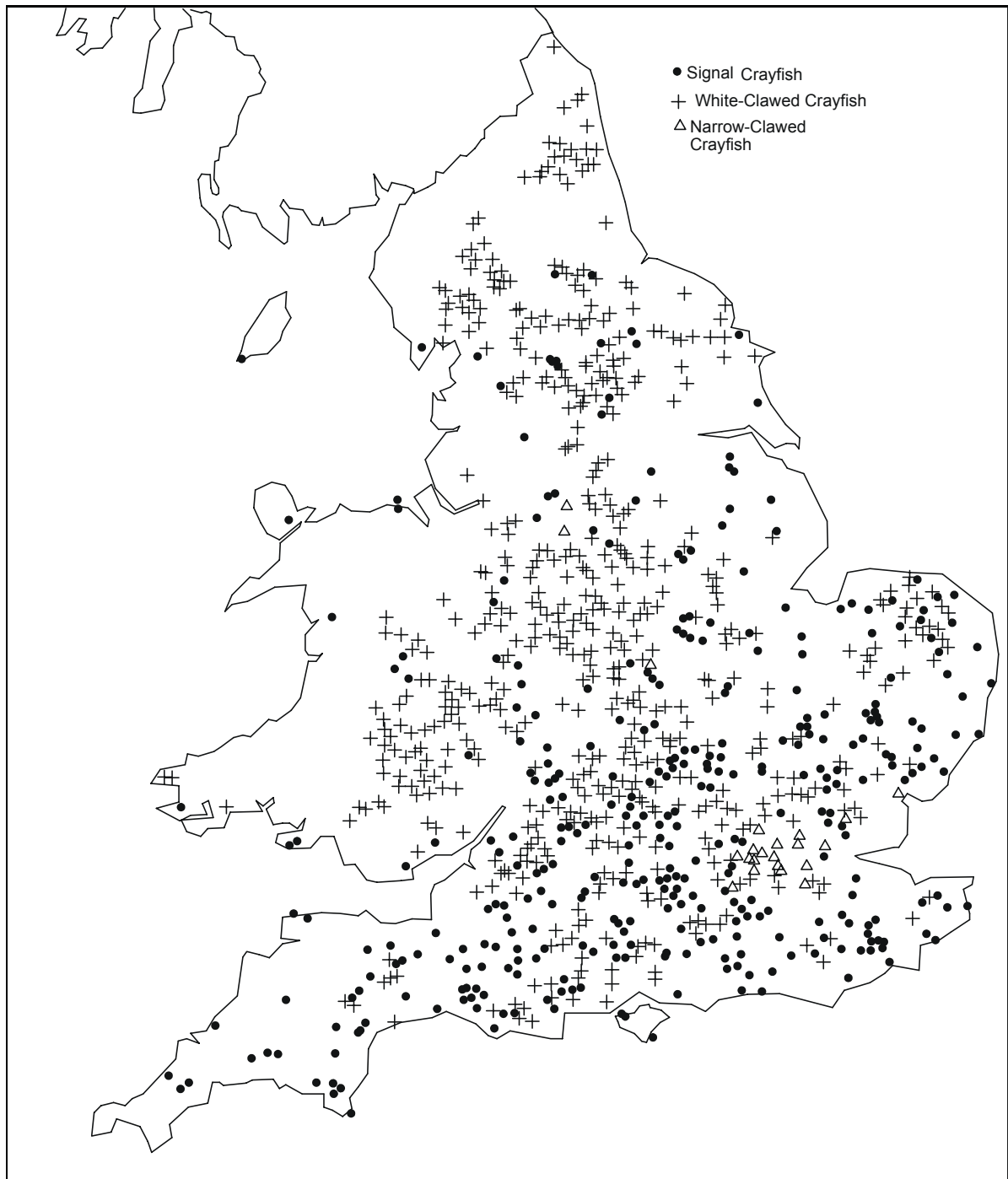
Three other crayfish species can also be found in British waters. These are the noble *Astacus astacus*, red swamp *Procambarus clarkii* and spiny-cheek crayfish *Orconectes limosus*. These species have a more limited known distribution than those previously mentioned. The noble crayfish is vulnerable to plague, but is considerably larger and more fecund than the white-clawed crayfish. It breeds readily in Britain, and has flourished in several enclosed sites. It is also known to have escaped in one (Chew Valley, Somerset).

The red swamp crayfish is known to exist in very few sites in Britain, but is the most widely introduced crayfish worldwide. It can act as a carrier of crayfish plague, is highly aggressive and very fertile, producing more than 500 eggs per year. It burrows extensively and has caused problems in most countries into which it has been introduced. As it is normally a warm water species, it has not been considered as posing a substantial threat to white-clawed crayfish until recently, when records from Switzerland (Mickasch, 1999) showed it to be highly adaptable, and capable of breeding in much colder water than was previously thought and to have a higher tolerance of pollution. Should it become established and begin to spread in Britain it could pose as serious a threat. Juvenile red swamp crayfish have recently been found in a pond in Hampstead Heath, confirming for the first time that this species is now breeding in Britain (Richter and Wiles, 2000).

Unconfirmed reports (Mickasch, 1999) of the introduction of the spiny-cheek or striped crayfish to Britain are also cause for concern. It is fast-growing and very fertile, producing more than 300 eggs per year, and can act as a carrier of crayfish plague. It has spread rapidly in Continent Europe and could be expected to do the same in Britain should it become established here.

Figure 1.1 shows the known distribution of white-clawed, signal and narrow-clawed crayfish populations in Britain, based on all Environment Agency records up to the year 1998, which is the last year for which data are available. Records of white-clawed crayfish populations, which are known to have been lost, have been omitted from this map. However given the rapid expansion of signal crayfish populations, and the difficulties of effective sampling of either species, these records can provide only an indication of crayfish distribution. It is certain that additional white-clawed crayfish populations have been lost, and that actual populations of signal crayfish are more extensive than indicated on the map.

In Section 1.2.5, the issue of colonisation by signal crayfish is discussed in more detail. The key point to note is that Figure 1.1 shows a widespread distribution of records of white-clawed crayfish. It does not provide a good indication of the threat to the native population posed by the very widespread and extensive distribution of signal crayfish in almost all parts of the geographic range of the white-clawed crayfish.



**Fig.1.1** Distribution of crayfish species in Britain based on all known records, where white-clawed populations are not known to have been lost (Provided by Jonathan Brickland, Environment Agency)

### 1.2.3 Crayfish and Legislation

The white-clawed crayfish is scheduled under the Wildlife and Countryside Act (1981), as amended. It is listed under Annex II and V of the EC Species Habitats Directive 1991, which requires designation of Special Areas of Conservation for the species, and the UK Conservation (Natural Habitats etc.), Regulations 1994 which enact the EC Directive. It is protected under Annex II of the Bern Convention. It also appears on the IUCN Red Data List, and is a target species on the UK Biodiversity Action Plan (BAP). Before achieving protected

status, the native crayfish was occasionally used for 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 other crayfish species.

In order to try to control the spread of alien species, *Pacifastacus leniusculus* was included under part I, Schedule 9 of The Wildlife and Countryside Act from 1992, along with all other alien crayfish species, with the exception of the tropical crayfish *Cherax quadricarinatus*. This makes it an offence to release any alien crayfish into the wild even if it is already resident in the country. In 1996 a ban was placed on the keeping of non-native crayfish in specific 'no go' areas, by means of an Order under the Import of Live Fish (England and Wales) Act 1980, the Prohibition of Keeping of Live Fish (Crayfish) (Amendment) Order 1996, and the parallel Act for Scotland. The Regulations mean that in the geographic areas identified in the Act, a licence is required to keep alien crayfish. This will not be granted unless the applicant can demonstrate that the crayfish can be kept in fully secure conditions. The Regulations do not apply to some areas of the country, mainly those where alien crayfish are already well established in the wild. In addition, the Regulations only apply to new holdings so even in areas where the Regulations apply they do not prevent existing owners of crayfish from continuing to keep them.

#### **1.2.4 Crayfish Plague**

Crayfish plague, caused by the oomycete fungus *Aphanomyces astaci*, is endemic in signal crayfish. This disease, to which white clawed crayfish are relatively immune, causes virtually 100% mortality (Alderman, 1996). Signal crayfish carrying plague often remain asymptomatic until weakened by age or other illness (Svärdson *et al*, 1991), whilst remaining infective to white-clawed crayfish. Since the first recorded occurrence of plague in Britain (1981), there have been sporadic outbreaks of the disease in many English rivers, resulting in the loss of the native species from the affected areas.

Many population depletions have been attributed to crayfish plague. Although there have been several authenticated cases of this lethal fungal disease in the last 30 years (Holdich *et al*, 1995), some cases of apparent disappearance of white-clawed crayfish have been attributed to the disease without supporting evidence (Hiley, pers. comm.). It is possible that some of these may have been due to other causes. Crayfish are difficult to sample, and most British native crayfish records are qualitative. Due to the paucity of information available, it is difficult to quantify the impacts of pollution, alien introductions and plague disease on this species. Other diseases that afflict white-clawed crayfish may give rise to large fluctuations in population density, including the protozoan *Thelohania* and the gill worm *Branchiobdella*. Boom and bust fluctuations involving a host and disease or parasite are characteristic of populations of a range of invertebrate species.

White-clawed crayfish become infected with crayfish plague after contact with the waterborne spores of *A. astaci*. These spores germinate within a few days of infection and symptoms of disease include loss of coordination and distension of the abdomen (Smith & Söderhäll, 1986). If a watercourse containing white-clawed crayfish becomes infected with plague spores, then all individuals downstream of the point of introduction can be expected to die (Alderman, 1996). Furthermore there is potential for upstream infection, where white-clawed crayfish are relatively abundant upstream. Infected crayfish may walk upstream, spreading the disease to others. A major mechanism for infection is thought to be scavenging of dead crayfish by previously uninfected individuals.

Both farmed signal crayfish and the transport of plague spores on angler's fishing nets (Reynolds, 1988) have been held responsible for plague outbreaks, which continue periodically to this day. An outbreak of crayfish plague was confirmed to be spreading through the river Ribble in Lancashire in 2000. (P. Bradley, Malham Tarn Field Centre, pers. comm.). The suspected source of infection is either trout from a fish farm with signal crayfish or contaminated angling gear.

### **1.2.5 The impact of competition by signal crayfish on the white-clawed crayfish**

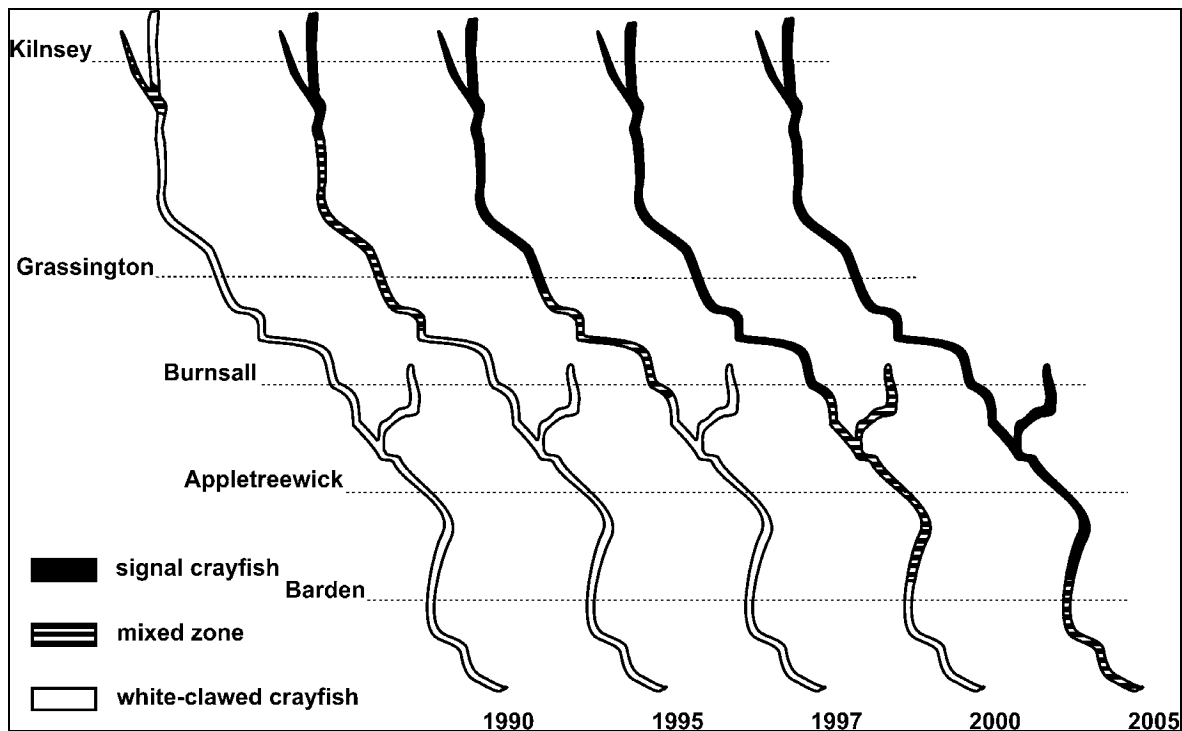
There is evidence that competition from signal crayfish is a major contributing factor in the decline of white-clawed crayfish in Britain. The mechanism by which this occurs is not fully known, but is thought to be multi-factorial, with contributing factors including the higher reproduction and growth rates of signal crayfish, competition for refuges, predation and reproductive interference (Holdich *et al*, 1995).

### **1.2.6 Colonisation by signal crayfish**

Previous research suggests that when signal crayfish colonise, they replace white-clawed crayfish completely (Peay & Rogers, 1999). The natural habitats of the two species are similar, although it appears that the signal crayfish may have a wider range than the native species. Therefore it is likely that any habitats in which the white-clawed crayfish can occur can be colonised by signal crayfish.

The spread of the signal crayfish appears to have no boundaries other than those of the river system. Once it becomes established in a catchment, the species can be expected to colonise all parts of the system at a rate of approximately 1 km per year in each direction (Peay & Rogers, 1999). This figure assumes one original population, with no subsequent introductions within the catchment. There is nothing presently known that would prevent the consequent loss of the white-clawed crayfish. Unless signal crayfish can be absolutely reliably confined, the risk of colonisation of an adjacent watercourse remains real.

Figure 1.2 is an example of the progressive spread of signal crayfish. The schematic diagram shows approximately 20 km of the River Wharfe in Yorkshire. The distributions for 1990, 1995 and 1997 are best approximations based on field surveys. Sufficiently intensive survey was carried out in 1997 to be confident that white-clawed crayfish had been eliminated at Grassington, whilst there was an extensive mixed zone with both species, over some 5 km of the river downstream. The distributions shown for 2000 and 2005 were estimates. In practice Peay found that signal crayfish had reached Barden by 1998, and numbers had increased in 1999, earlier than the prediction of 2000. This indicates the difficulty in detecting the downstream extent of an invading population. It may also show the variation in the rate of spread, depending on how favourable the habitat is in the reach being colonised.

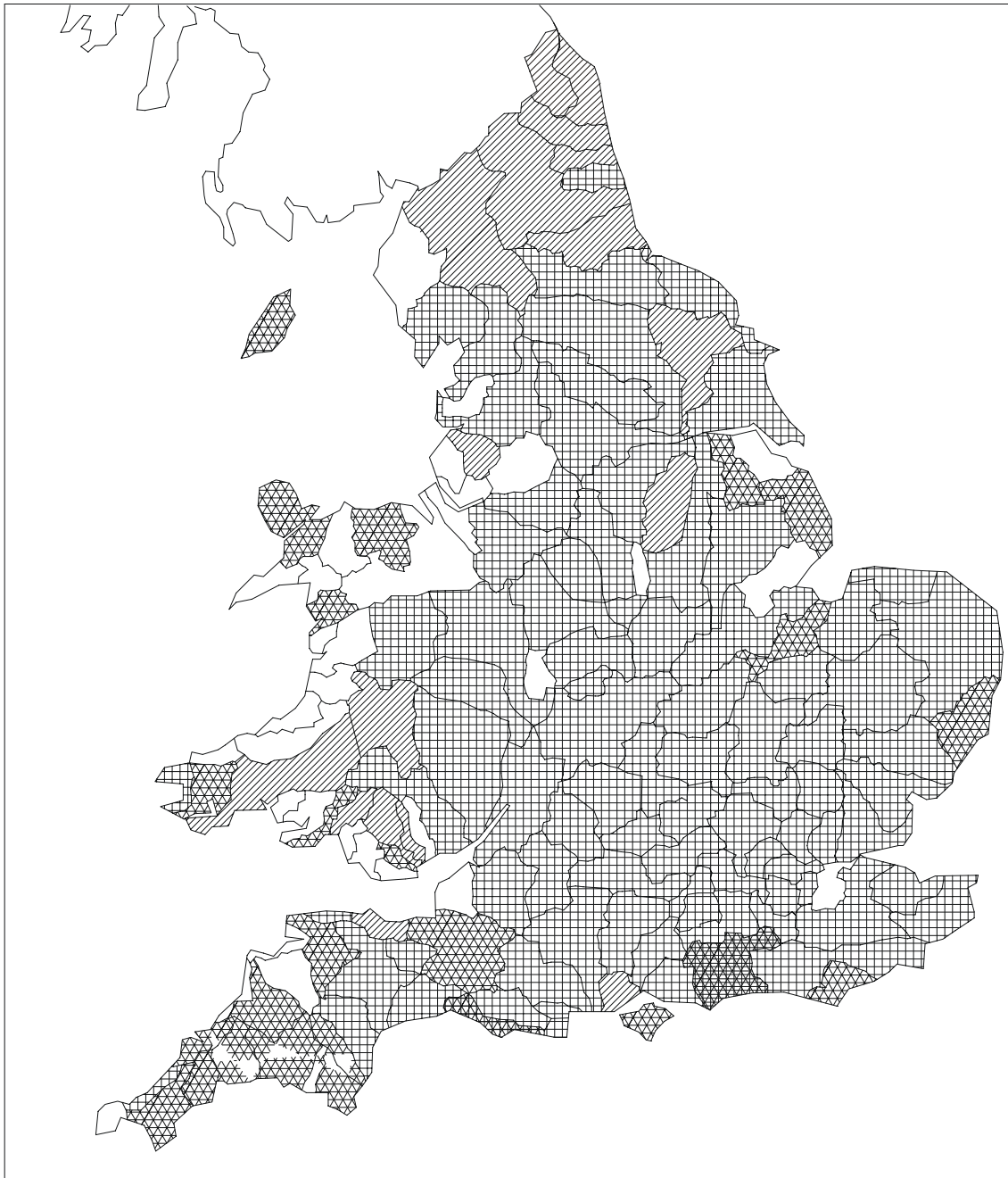


**Figure 1.2** The progressive spread of signal crayfish in the River Wharfe (Peay and Rogers, 1999).

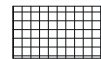
Of the 156 river catchments in the UK, 109 contain records of native crayfish populations since the 1900's, only 14 of these contain no record of signal crayfish. The distribution of those catchments, thought to be 'safe' on the basis of current data can be seen on Figure 1.2. It must be noted, however, that national crayfish records are certainly incomplete, and even the most recent data is not necessarily up to date.

It is possible that a few of the signal crayfish records may be for aquarium populations as the individual records have not been checked here, although this is unlikely to affect the distribution of mixed catchments. Even an aquarium population may represent a very high future risk to a catchment with native crayfish. Yorkshire was also a stronghold for white-clawed crayfish, but there are now unenclosed populations of signal crayfish, in all the major river catchments in most cases. Even the Yorkshire Derwent now has a population of signal crayfish, although it appears to be contained at least temporarily in a wholly enclosed pond (Sue Pacey, Environment Agency pers. comm.).





Catchments with records of both  
White-Clawed & Signal Crayfish Species



Catchments with records of only  
White-Clawed Crayfish



Catchments containing Signal Crayfish  
population but with no records of  
White-Clawed Crayfish



**Figure 1.3 Distribution of catchments with signal and white-clawed crayfish populations**

Signal crayfish can survive for up to three months out of water, as long as humidity levels are high (Holdich *et al* 1995). They are regularly found walking on land at night both for food and to escape unsuitable or overcrowded conditions. There are reports of signal crayfish leaving an overcrowded fishing pond and escaping into the streets of Glossop (Andy Goodwin, Environment Agency, Northwest Region, pers. comm.). At West Tanfield Fishery (Appendix 1) the fishery operator has frequently observed signal crayfish out of water, feeding on vegetation beside the stream.

Few, if any, fish farms are fenced sufficiently securely to prevent crayfish escape, (West Tanfield fishery: R Ure Appendix 1;). Crayfish are usually kept in outdoor ponds as a by-product of fish rearing. The ponds have a through flow of water and, whilst there may be a mesh to discourage adult crayfish from leaving the pond, this is not fine enough to prevent passage of fertile eggs, newly released young, or juveniles. Mesh of 1 mm would be effective, but would be very prone to clogging with algae in outside ponds. Even ponds with no obvious outflow may flood surface ditches during periods of high rainfall, allowing crayfish access to streams or rivers and crayfish are also able to walk many tens of metres or more over land. In principle, a pond or stream connected to a heavily polluted watercourse may effectively be isolated because all escaping crayfish would be killed before they could access clean water. Nonetheless, it is the objective of the Environment Agency to continue the improvement of all watercourses of 'poor' and 'bad' quality, so any such barrier of poor quality water is likely to be reduced over time.

Many species of freshwater organism drift passively in the water at some stage in their life cycle, but no evidence has been found for signal crayfish colonising other than by walking, even where the watercourse is polluted. The downstream advance at approximately 1 km a year (Peay & Rogers 1999, Holdich *et al* 1995a, Sibley 2000) supports the hypothesis that crayfish do not drift. It is unlikely that escaping signal crayfish would use the current to move rapidly through a polluted watercourse, though they may bypass polluted water by travelling on land. Crayfish, both native and alien, are adversely affected by very large floods. Crayfish washed out of refuges are likely to be crushed, but there is some possibility of survival and recolonisation downstream.

In conclusion, there is no such thing as a confined population of signal crayfish in a river catchment. Efforts to remove signal crayfish from affected rivers may be thwarted by repeated colonisation from adjacent populations. This process is likely to be at work in the River Ure at West Tanfield (Appendix 1) and the River Wensum at Reepham Fishery (Appendix 2). This mechanism may also be responsible for the colonisation of the River Manifold (Appendix 7.2), where the source of signal crayfish has not yet been found.

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. There are a number of anecdotal reports of fishery owners with crayfish giving them to other owners of ponds or angling lakes. This was sometimes in the belief that the crayfish would control aquatic plants. In practice, in some lakes crayfish subsequently reached such high density that they interfered with angling amenity, e.g. at Boxmoor (Holdich *et al* 1995), and Reepham Fishery (Appendix 2).

### **1.2.7 Impacts of signal crayfish on river ecosystems.**

Signal crayfish can have radical impacts on the entire river ecosystem because of their key positions as burrowers and omnivores, affecting macroinvertebrates (Guan and Wiles, 1997), macrophytes, fish (Lang and Wylde, 2000) and riverbed characteristics (Holdich *et al*, 1995). Signal crayfish appear to be able to attain a much greater population density than white-clawed crayfish in similar habitats in the River Wharfe. S. Peay and P. Hiley discovered population densities of up to 20 signal crayfish per m<sup>2</sup> by systematic manual searching in favourable habitats at the margins of the River Wharfe at Grassington in 1999. This was highly variable however, depending on the micro-habitat within the channel, where fewer refuges were available and detectable density was less than 2 per m<sup>2</sup>. Average densities of 2.9 white-clawed crayfish per m<sup>2</sup> were found in similar conditions several miles downstream at Barden (Peay, 1997).

Signal crayfish growth rates are faster than those of white-clawed crayfish (see 1.2.2) and they appear to be able to attain higher population densities in habitats previously occupied by white-clawed crayfish. Their food requirement is therefore likely to be greater, further increasing their impacts on their environment. High densities of signal crayfish burrows have been recorded, for example on the Buckinghamshire Great Ouse (Guan and Wiles, 1996), and in Gaddesby Brook (Sibley, 2000). Even when an abundance of suitable refugia are available, signal crayfish burrow into the sediment of the bed. A major increase in sand and gravel displacement caused by signal crayfish burrowing was observed on the River Wharfe at Grassington in the period 1997-1999 (Peay, pers. comm.). This coincided with a major increase in population density. The burrowing activity of signal crayfish causes substantial habitat change for other organisms when the signal crayfish colonise a river. White-clawed crayfish rarely burrow, although burrows have been observed during night viewing in the Yorkshire River Derwent, at West Ayton (Hiley & Peay pers. comm.) and in streams in the Thames region (Julie Bywater, pers. comm.).

### **1.2.8 Potential impacts of other alien crayfish**

The key issues relating to alien crayfish in Britain are:

- White-clawed crayfish, the only native species, was widely distributed in much of England and Wales until the introduction of alien crayfish.
- Introduction of alien crayfish and the crayfish plague are the biggest threats to the survival of the white-clawed crayfish in Britain, and the rest of its European range.
- White-clawed and signal crayfish cannot co-exist. The white-clawed is always lost over time.
- The white-clawed crayfish is a protected species, and new legislation protects against further deliberate introductions of alien species in Britain.
- There are now so many populations of signal crayfish established in the wild throughout England and Wales that almost all catchments with white-clawed crayfish are under severe threats from alien invasion.
- Signal crayfish are not only a severe threat to native crayfish, but also have impacts on habitats and other species.

### **1.3 Potential for Eradication of Crayfish**

Whether or not it is feasible to eradicate, or even control signal crayfish depends on a number of inter-related factors:

- Is there any method of determining whether or not a control method has been effective?
- Is there a method which will kill/ remove all the alien crayfish in a target area, or sufficient to prevent the population from spreading?
- Is any method specific to alien crayfish and if not, is its use acceptable?

The order of these questions may seem surprising, but unless the endpoint is known there is a risk of very large expenditure of resources without achieving eradication, or even control. Understanding is needed about crayfish populations in order to assess the potential for eradication.

#### **1.3.1 The Problem of Detecting a Population**

The fundamental problem of any attempt to eradicate alien crayfish, or indeed any other species, is the difficulty of achieving and detecting ‘zero’ population. In order for any methodology for the eradication of alien crayfish species to be deemed successful, it must fulfil two essential criteria:

- The methodology must be capable of removing sufficient crayfish to ensure the extinction of the population.
- This loss of the population must be demonstrable.

A density threshold exists for all animal populations, below which the population will cease to be self sustaining, and will be lost. This is not an absolute density, but is more likely to be a reflection of the increased probability of extinction by chance in small isolated populations. Even large populations may become extinct due to rare catastrophic events, but this is much less likely than extinction of small populations. The likelihood of extinction is dependent on variables such as location of a suitable mate, mortality rate of juveniles and genetic variation within the population, and thus differ widely between both species and populations. Any methodology with the potential for achieving eradication or control must reduce the population density to below a threshold level, the Minimum Viable Population Density (MVPD) below which extinction can be expected.

In principle, the minimum of crayfish needed to start/ sustain a population is one adult male and one adult female, or a single female carrying eggs. Small populations of any species are more likely to die out due to chance, due to natural factors of failure to breed and random losses caused by disease, predators or environmental conditions. There is therefore a theoretical Minimum Viable Population Density (MVPD) for the likely long term survival of an isolated population. Any population which exceeds this density is likely to continue to increase both in density and extent until it is limited by some biotic or environmental factor. This may be the maximum carrying capacity of the population in a particular set of conditions, or a chance catastrophe may cause a sudden reduction. Even very low rates of dispersal and recolonisation in fragmented populations markedly increase the likelihood of survival of the overall population.

### **Minimum Viable Population Density: A Theoretical Example.**

A limiting factor in the MVPD of adult crayfish may be the finding of a mate. Males actively seek females, using a combination of sight, and possibly other stimuli, such as pheromones and sound. If, on average, receptive female cannot find a male, then the potential production from that female will be lost for the next year.

Information is limited as to the normal wandering range of crayfish during the breeding season, or at other times of year. Individual animals can vary markedly in the distance they travel, as evidenced by Armitage (2000) and Lucas & Thorn at Durham University (1998) using radio-tracking techniques. In signal crayfish, individuals have been observed to range to 10's – 100's metres in a night within a week in the River Wharfe (Peay, pers. comm.) Suppose a male crayfish makes a nocturnal walk of 100 m. If a female is able to attract a male that comes within 1 m of herself, then the random walk of a male can be translated into an area of riverbed 'searched' by a male each night. In this case there would need to be just one fertile female per 100 m<sup>2</sup> per night in order for mating to be successful. (The actual area of influence would be teardrop shaped in a river if only chemical attraction was used). If the attractant were effective over 10 m, a viable population would consist of one fertile adult crayfish of each sex per 1000 m<sup>2</sup> in one 24 hour period.

During the course of a two-month breeding season one crayfish could theoretically cover 2.4 hectares using the assumptions above. However, at least some crayfish appear to be territorial, often returning to the same refuge every day for a period of time. There could therefore be a limited 'home range' available to an individual. A crayfish with a constant refuge could be assumed to cover all the local area over a succession of days and nights, and the total area covered in one season will be limited by territory size. The size of crayfish territories remains unknown, and may vary depending on factors such as habitat availability, population density or hierarchical position of an individual.

Some individuals will move more than 1 km within a short time period (Armitage, 2000), and will be able to detect the presence of other crayfish over a much wider area of river than crayfish with a fixed refuge.

These factors demonstrate the impracticality of arriving at a realistic figure for the MVPD of crayfish. Using assumptions given here it is likely to lie somewhere between 2 per 200 m<sup>2</sup> and 2 per 4.5 hectares. Based on these assumptions, colonisation could potentially result following the release of as few as 11 individuals into 1 km<sup>2</sup> of water.

### **Box 1.1 Minimum viable population density: a theoretical example**

To be successful, artificial control of a population will have to reduce the density to less than the MVPD and keep it there. Any method that does not achieve this will allow the population to continue to expand in both density and range.

In order to either identify the need for control, or assess its effectiveness, low density populations have to be detectable. The lower the efficiency of any method for sampling the population, the greater the likelihood of a population being able to survive undetected and extend its range, similarly undetected. In addition, the lower the population density, the greater the effort and/or resources required to detect it.

It is possible that even intensive field sampling may fail to detect low-density populations of signal crayfish, which are above the MVPD, and are expanding their range. Current survey techniques do not have sufficient sensitivity to detect these populations, meaning they are effectively "invisible". It is therefore probably not possible to detect the "leading edge" of a colonising population. This has severe implications for the safety of white-clawed crayfish in supposedly 'signal-free' catchments or isolated refuges. Delays of several years can occur between signal crayfish introduction and subsequent detection of the population (Hiley 2000).

### Theoretical model of population growth and detection rates of signal crayfish

A manual survey (e.g. 15 minute stone turning covering an area of 5 m<sup>2</sup>) may detect densities of approximately 1 per 5 m<sup>2</sup> of 1 year old crayfish or older in favourable conditions for a survey. In a 1 hectare site, the introduction of 2000 adult animals would be necessary to enable immediate detection, by this method, if the whole population was evenly dispersed. The random dispersal of the population and variation in micro-habitat would lead to a more clumped distribution. Smaller introductions may cause a lag of several years to occur before the population is detected, by which time breeding will have led to a substantial population increase.

Signal crayfish can breed at 2 or 3 years old depending on growth rate, producing around 100 young per mated female. The three-year survival rate of juveniles is estimated at around 14 % (Guan & Wiles, 1996). Following the escape of one adult pair, first generation juveniles would reach sufficient size for detection by manual survey 3 years after the introduction. Thus, following colonisation by the adult pair of a 1 hectare waterbody, it may take up to 12 years for the detectable population density to rise above the threshold level of one per 5 m<sup>2</sup> (See Chart).

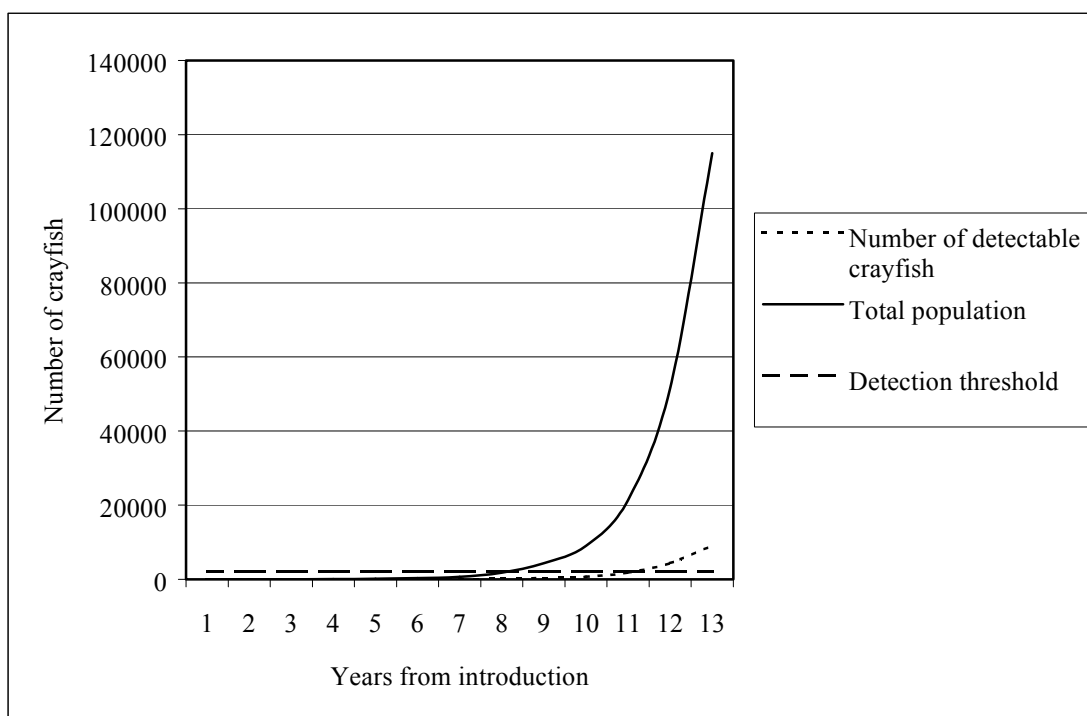


Figure 1.2.1 Crayfish detection threshold for manual survey

### Box 1.2 Theoretical model of population growth and detection rates of signal crayfish.

Box 1.2 shows an example of how expanding populations can potentially remain undetected for several years.

Unless a signal crayfish population can be reduced to virtually zero, then the population will continue to expand. As the lowest density reliably identified by any known survey method lies in the region of 1 per 5 m<sup>2</sup>, using manual surveys in favourable conditions for survey, the only way to determine whether an eradication methodology has been successful is to carry out intensive surveys for many years, at least twelve years after treatment based on the assumptions in Box 1.2.

Although a small number of signal crayfish may escape from a rearing pond at any time, the pressure to migrate is likely to increase as the population density reaches a level at which food and shelter resources are limiting. The potential delay between the escape of small numbers of signal crayfish and the subsequent detection of the population may create the impression that a population is contained, when it is already established in an adjacent watercourse.

On the basis of the estimates here, the minimum detectable density of a signal crayfish population could be one to two orders of magnitude above the minimum viable population density.

### **1.3.2 The Problem of Achieving any control of population**

The problem of determining how far signal crayfish have spread is outlined above. This makes it difficult to decide on the area in which crayfish need to be eradicated. Attempting to control the population in less than its full extent will allow recolonisation to occur. If crayfish have already escaped from a pond to a nearby watercourse, signal crayfish will recolonise the pond from the watercourse, even if eradication in the pond has been completely successful.

## 2. METHODS TESTED OR CONSIDERED

### 2.1 Potential Control Methods

Control has been perceived as involving removal or destruction *in situ* of signal crayfish, with the aim of reducing population density sufficiently to prevent the colonisation of new territory.

Phase I of the research project (Rogers and Holdich, 1998) outlined potential methods for achieving this:

- manual removal
- habitat destruction
- barriers
- predators
- disease
- biocides
- use of pheromones

Phase II set out to investigate the comparative efficiency of these methods. Case studies are presented on projects carried out involving manual removal, habitat destruction, barriers and biocides. Use of pheromones was outside the scope of this project (Rogers and Holdich, 1998), and is the subject of a separately commissioned R & D Project, recently initiated at Newcastle University (David Fraser, English Nature, pers. comm.). Removal methods used in this project included trapping, netting and hand capture, all of which depend for their success on local conditions being suitable. All signal crayfish captured must be disposed of in a suitable manner. Freezing is the method of killing alien crayfish recommended by the Environment Agency.

In order to realistically evaluate potential control methods, the potential impacts of each method must also be considered.

### 2.2 Case Studies

A series of case studies was identified in Phase I, which were either being undertaken at the time or were proposed. These were intended to be used to investigate the effectiveness of the potential methods for eradication. The case studies have been monitored during Phase II and advice has been provided on their implementation where appropriate. All the studies carried out have been organised and undertaken by local “champions”, mainly individuals within the Environment Agency regions. In some cases the objectives of the projects have changed over time. In others, projects were not progressed for various reasons. Additional projects have also been followed during the R&D project and findings are reported and discussed. All of the methods are discussed, whether or not they were implemented in the case studies.

Details of the case studies are given in the Appendices, but a brief summary is given here in Table 2.1. Studies involving only native crayfish are included where they contribute to an understanding of the effectiveness of potential methods of eradication. The methods considered or used are summarised in Table 2.2.



**Table 2.1 Case Study Sites.**

Site	Site Description and History	Work
West Tanfield Fishery: River Ure SE 259 776 Northumbria and Yorkshire Regions Appendix 1	A 3 ha fishing lake adjacent to the River Ure, connected by an underground outlet pipe, which runs into a small outlet stream. The lake supports a strong population of signal crayfish, which were found to have spread to the river in 1997.	Manual removal in stream and fish farm. Design and installation of barrier outfall for lake.
Reepham Fishery: River Wensum TG 106 220 Anglia Region Appendix 2	The site comprises a spring-fed fishing lake containing signal crayfish, plus adjacent ponds. The lake drains into Reepham Stream and then to the River Wensum.	Manual removal by trapping; mark-recapture in lake only, three sessions.
Durford Bridge: River Rother SU 782 231 Southern Region Appendix 3	Durford Bridge is thought to be the downstream limit of a population of white-clawed crayfish. A signal crayfish population exists downstream of the bridge. The populations were thought to be separated by two small weirs near the bridge.	Monitoring, surveys.
Gunthorpe Bridge: River Gwash SK 868 051 Anglia Region Appendix 4	Signal crayfish were introduced upstream of the bridge in 1997. They were thought to extend 500 m upstream and 700 m downstream of the bridge. This section contains areas of favourable habitat. i.e. stones, emergent vegetation etc. The population was thought to be being limited by areas with little available habitat at both ends.	Intensive manual removal from 1300 m stream, five sessions.
Wixoe: River Stour TL 708 431 Anglia Region Appendix 5	A 9.2 km section of the Upper River Stour from Little Thurlow to Wixoe. Signal crayfish were first recorded at a single site at Great Thurlow in 1991, but in 1997 were found to have colonised the entire section.	Continuous monitoring and manual removal.
Ullesthorpe Pond: Leicestershire SK 516 868 Severn Trent Region Appendix 6.1	A clay-lined 0.2 hectare pond, situated between the headwaters of the R. Soar and R. Swift catchments. It contains high density fish stocks, and a large population of signal crayfish.	Monitoring and mark-recapture by trapping.
Llanfihangel Pond: River Vyrnwy SO 088 164 Severn Trent Region Appendix 6.2	A 0.5 ha pond in peaty ground at the headwaters of the River Vyrnwy, with a dense population of signal crayfish in both the pond and outfall stream	Habitat destruction by excavation in pond only.
Tetford Pond: River Lymn TF 332 747 Anglia Region Appendix 6.3	A 0.3 ha pond, stocked with signal crayfish, immediately adjacent to the River Lymn	No action. Desk study for possible use of biocides.

**Table 2.2 Summary of Methods and Projects reported.**

Project	Manual Removal	Habitat Destruction	Barriers	Poisons	Predators
West Tanfield	Field Trial	--	Field Trial	--	--
Reepham Fishery	Field Trial	--	--	--	--
Durford Bridge	Considered	--	Observed	--	--
River Gwash	Field Trial	--	--	--	Considered
Wixoe	Field Trial	--	--	--	--
Ullesthorpe Pond	Field Trial	--	--	Considered	--
Llanfihangel Pond	--	Field Trial	--	--	--
Tetford Pond	--	--	--	Considered	--
Bradford University	--	--	--	Laboratory	--
Nottingham University	--	--	--	Laboratory	--
Gaddesby Brook	Field Trial	--	--	--	--
River Hamps	Field Trial	--	--	Observed	--
Huddersfield Canal <sup>n</sup>	Field Trial	--	--	Observed	--
River Yare	Field Trial	--	--	--	--
River Derwent <sup>n</sup>	Field Trial	--	--	--	--
Catton Park Lake	Considered	--	--	--	--

<sup>n</sup> work on white-clawed crayfish

The methodologies tested are summarised below, with detailed descriptions of works undertaken at each site provided in the Appendices.

## 2.3 Removal of Live Crayfish

The majority of projects shown in Table 2.2 used one or more forms of manual removal to attempt to eradicate or control signal crayfish populations. Techniques used at sites where removal was undertaken are summarised in Table 2.3.

**Table 2.3 Techniques used for removal of live crayfish**

Site	Standard Traps	Small Mesh Traps	Refuge Traps	Hand Removal	Modified Kick-sample	Dewatering
West Tanfield	--	--	--	yes	--	--
Reepham <sup>1</sup>	yes	yes	--	--	--	--
River Gwash	--	--	--	yes	yes	--
Wixoe	yes	yes	--	--	--	--
Gaddesby Brook <sup>1</sup>	--	modified trappies	--	yes	yes	--
Ullesthorpe Pond <sup>1</sup>	yes	--	--	--	--	--
Huddersfield Narrow Canal <sup>1</sup>	yes	yes	yes	yes	--	yes
River Hamps	yes	--	--	yes	--	--
Catton Park Lake <sup>2</sup>	yes	--	--	--	--	--

<sup>1</sup> Included a mark-recapture study

<sup>2</sup> Primarily monitoring or population study

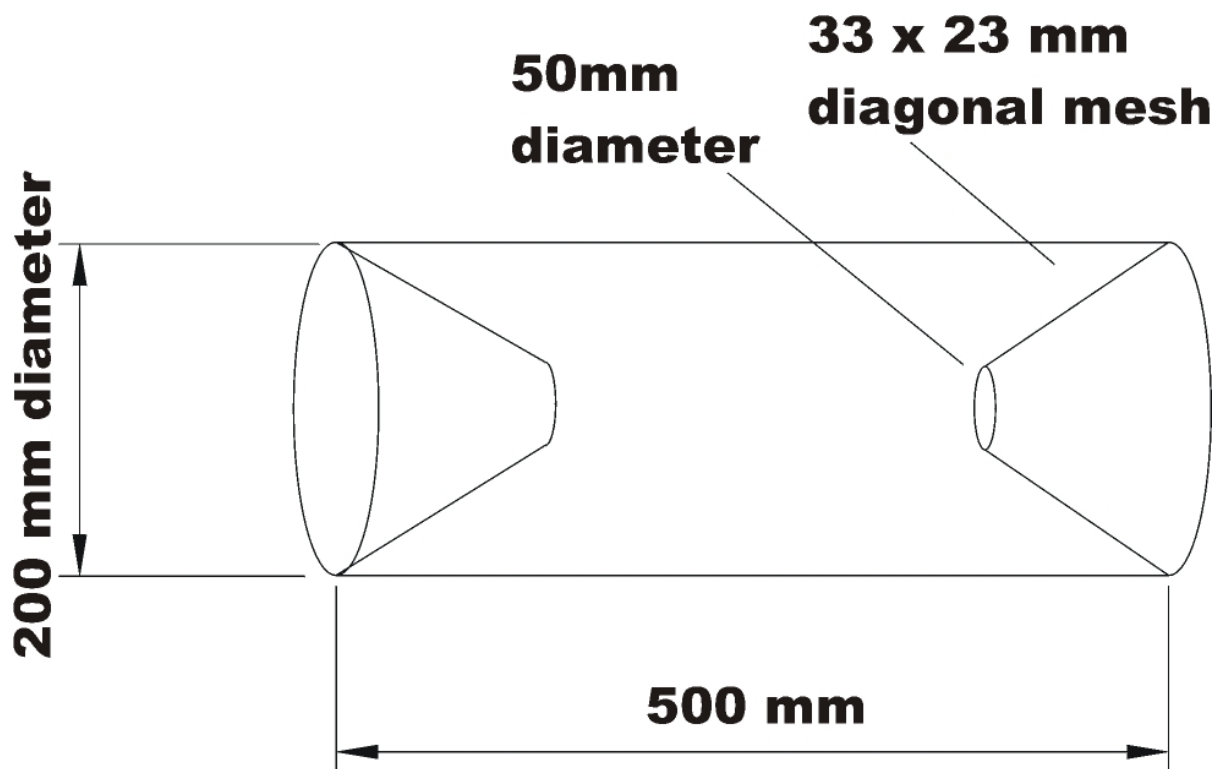
In addition, 5 sites carried out mark-recapture studies with the aim of testing trapping efficiency (see section 2.1.2).

### 2.3.1 Traps

#### Standard traps

Trapping using standard Swedish Trappies was carried out at five sites. These are cylindrical traps with conical entrance funnels of 5 cm diameter. Traps are constructed from rigid yellow plastic with a diamond mesh 33 mm by 23 mm (Figure 2.1). Trappies are baited, lowered into the water and left for a minimum of one night. Traps can either be tied to the bank, or a line can be attached with a float. The traps can then be retrieved using a standard grapnel.

Factors such as spatial density of traps, duration of trapping period and bait used were not standardised throughout the various projects. For example, at Reepham Fishery traps were placed at 2-3 m intervals along the banks. Each session of trapping lasted for 3 nights, with traps being checked daily and checked daily (Reepham Fishery, Appendix 2), whereas at Wixoe (Appendix 5) trapping occurred throughout the duration of the project and traps were checked weekly. Bait used in different studies included cat food and kippers.

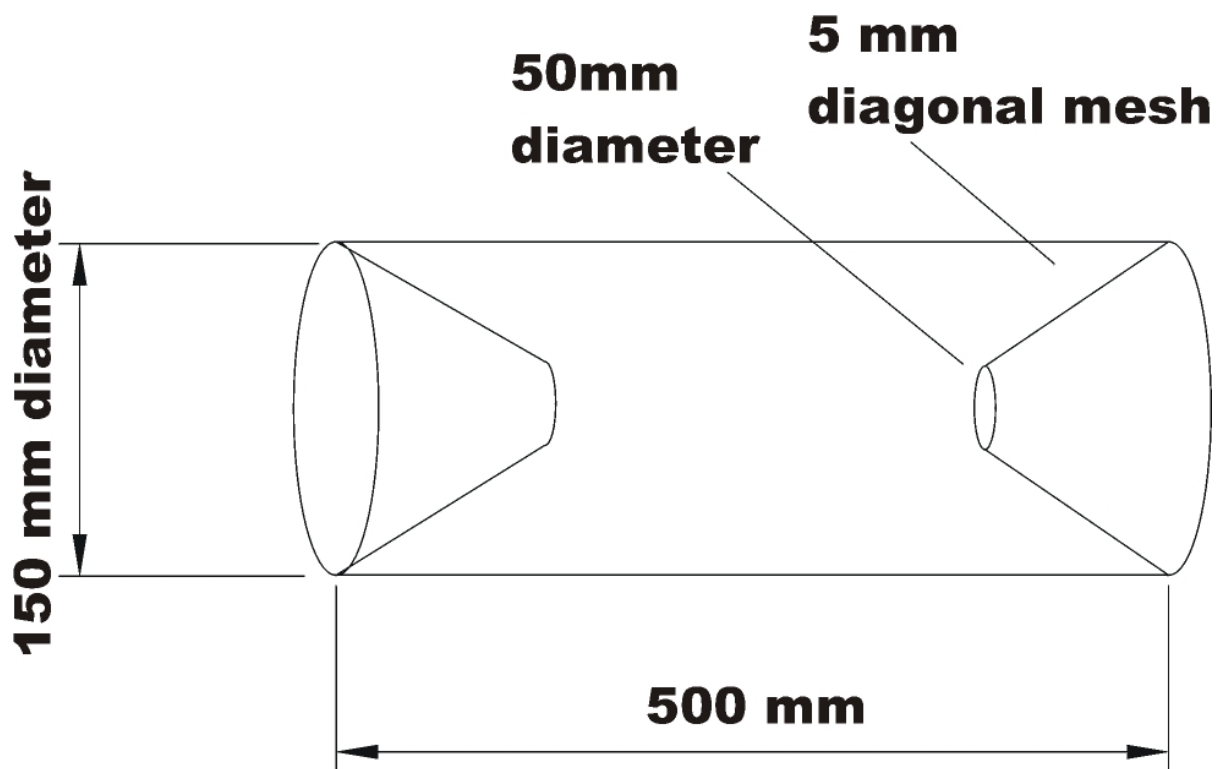


**Figure 2.1: Schematic diagram of commercial Swedish Trappy**

### **Small Mesh Traps**

Trapping using small mesh traps was carried out at four sites. As these traps are non-standard, the exact design varied slightly between sites. The small mesh traps used at Wixoe and Reepham Fishery were designed by Steven Lane (EA Anglian Region). The Gaddesby Brook study used Trappies modified by wrapping in fine mesh and by constriction of the apertures. The Huddersfield Narrow Canal project purchased dark green 5 mm mesh traps from GB Nets (Figure 2.2). These traps are flat-packed and assembled with cable-ties.

Trapping procedures for these small mesh traps are the same as for Swedish Trappies, but very lightweight traps, such as those available from GB Nets, may require weighting with stones or fishing weights.

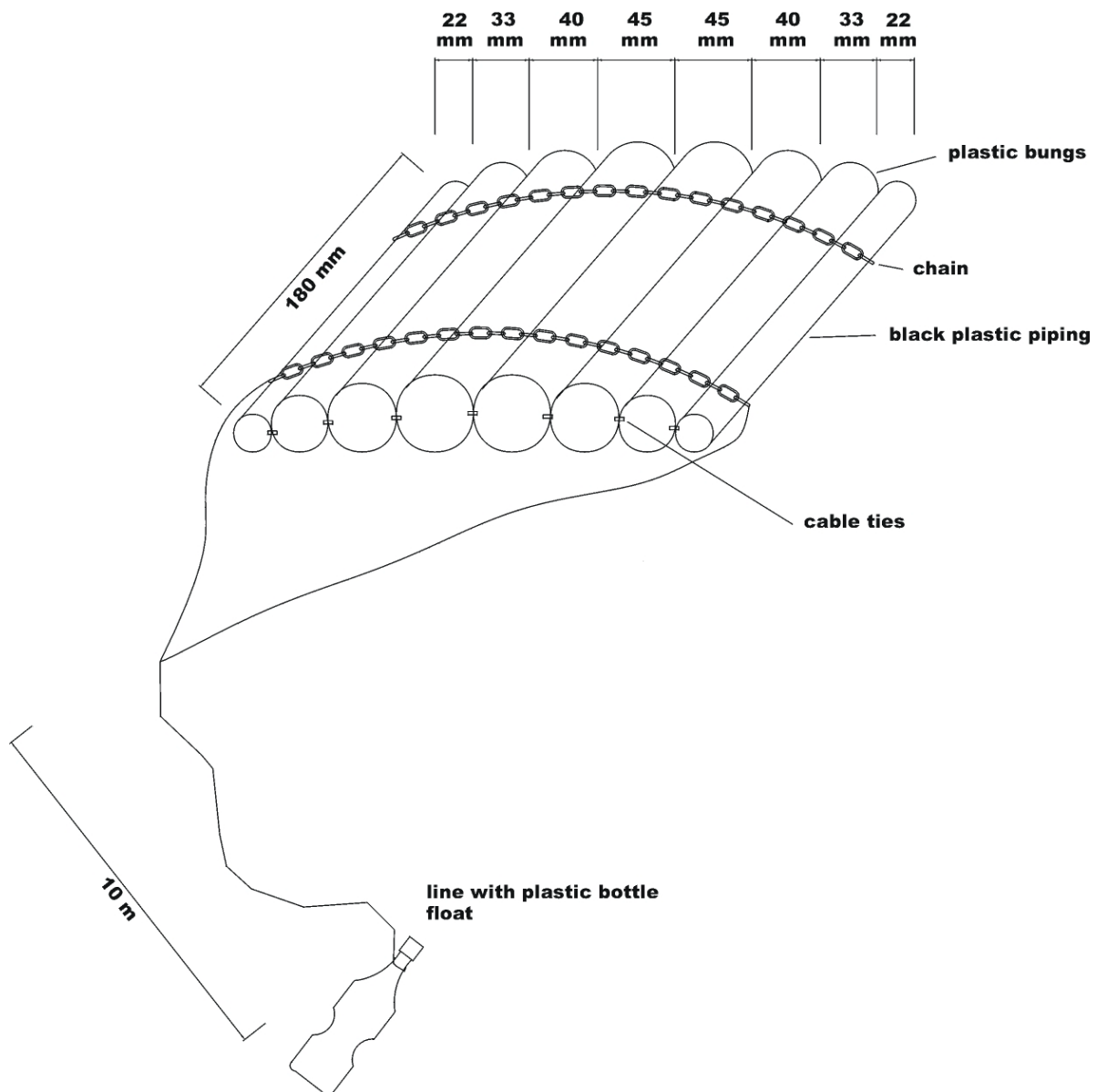


**Figure 2.2: Schematic of small mesh trap**

### **Refuge Traps**

Refuge traps differ from both Trappies and small mesh traps in that crayfish can enter and leave the traps at will. This removes the need for baiting and reduces the frequency with which traps must be checked. Refuge traps are not intended to capture active crayfish, but rather to provide preferential habitat for resting animals.

There is no known commercial manufacturer of refuge traps for crayfish. The refuge trap pictured (Figure 2.3) is currently being trialed on the Huddersfield Narrow Canal. Black plastic pipes of different diameters are used to provide habitat for a wide range of size classes. One end of each tube is blocked with plastic bungs, with holes drilled in to allow draining of water, and the trap is weighted with a steel chain. The traps can either be attached to a line and float, or pegged to the pond or riverbed through the chain. Other designs of refuge traps have been developed by Martin Frayling and Adrian Hutchings at Sparsholt College. These also consist of tubes of different diameters, but tubes are mounted on a perspex back board, and weighted with iron strips.



**Fig 2.3 Example of a Refuge Trap**

### 2.3.2 Mark-Recapture Studies.

Mark-recapture studies were carried out at Wixoe, Ullesthorpe Pond, Gaddesby Brook, Huddersfield Narrow Canal and the River Wharfe. Marking techniques included uropod clipping; painting with solvent-based correction fluid or permanent marker pen, and gluing numbered disks to the carapace. Crayfish captured were marked and released. The percentage of marked crayfish recaptured in subsequent trapping studies was then used to give an estimate of the trappable population. Where trapping was followed by intensive manual removal, comparison of animals marked and those recaptured in the final removal gave an indication of either the efficiency of manual removal or the combined effects of efficiency, migration and mortality.

At Gaddesby Brook only large male crayfish were marked and released after capture. This was intended to regulate population growth by increasing predation pressure on juvenile size classes and suppressing their daily activity.

### **2.3.3 Hand Searching**

Hand searching techniques also differed slightly between sites, particularly with respect to percentage of watercourse searched. This difference was largely unavoidable as, whilst manual removal by stone-turning is suited to sites such as the small stream at West Tanfield Fishery and in parts of the River Hamps, it becomes more difficult or impossible in deep or silty water. At West Tanfield there was some use of artificial refuges (roof tile and clay drainage pipes) to provide foci, as the crayfish were more easily caught there than under the banks.

Most sessions of manual removal involved searching exhaustively, turning every stone until no more crayfish could be found. The 'area searched' and 'time taken' were usually recorded to allow future conversion of results to catch per unit effort.

At the River Gwash there was some partial excavation of crayfish burrows to allow animals to be pulled out. This is a localised form of habitat destruction.

### **2.3.4 Modified kick-sampling**

Both on the River Gwash and in Gaddesby Brook, a form of modified kick-sampling was used to capture signal crayfish. This involved drag netting, with a line of large nets of the type used by the Environment Agency fisheries staff for surveying. Each net was staggered about a foot behind the next. The nets were overlapping to maximize the catch. Teams of four or five people worked upstream within each marked section. Some sections were trawled many times in succession until no more crayfish were caught. Overhanging banks were searched by pushing a net under the overhang and dragging up the bank and along the roof of the overhang.

### **2.3.5 De-watering**

Following an intensive trapping regime, a section of the Huddersfield Narrow Canal was de-watered to allow rescue of white-clawed crayfish to be carried out prior to engineering works on an aqueduct. The wash walls in this section of canal are unpointed and provide ideal crayfish habitat. Water was drawn down to the bottom of the wash walls and any crayfish emerging were captured and recorded before being translocated to a safe site. Crayfish started to emerge about 10 minutes after exposure, and individuals continued to crawl out of the wash walls for up to two days afterwards. This technique has been used in a number of other projects prior to engineering works (e.g. Peay, 1998; Scott Wilson Resource Consultants 1998).

## **2.4 Habitat Destruction**

Habitat destruction is intended to clear out all crayfish by removing every potential refuge and associated crayfish. It was carried out at Llanfihangel Pond (Appendix 6.2). The pond was partly drained and enlarged and the spoil was removed. The aim was to destroy all crayfish and crayfish burrows.

## 2.5 Use of Barriers

### 2.5.1 Weirs

The potential of barriers to limit the spread of signal crayfish was investigated at Durford Bridge and West Tanfield Fishery. At Durford Bridge a population of signal crayfish was believed to be separated from an upstream population of white-clawed crayfish by two small weirs. The downstream weir is slightly higher than the upstream weir, but both are under 1 m high. The upstream limit of the signal population was monitored to investigate the ability of low barriers to prevent the spread of signal crayfish populations.

### 2.5.2 Catchpits

At West Tanfield Fishery a catchpit system was installed in Summer 2000, to try to prevent escapes from the lake into the trout farm (Appendix 1). This consists of a bellmouth outlet pipe running from the lake to a chamber with a vertical bellmouth outlet. The specifications of both the original catchpit design and the installed catchpit are described in section A1.4. Figure 2.4 illustrates the proposed catchpit, as designed by Scott Wilson staff. The intention was to ensure that no crayfish could, by swimming, walking or passive carriage, pass through the chamber and colonise downstream watercourses.

The main features of the design are:

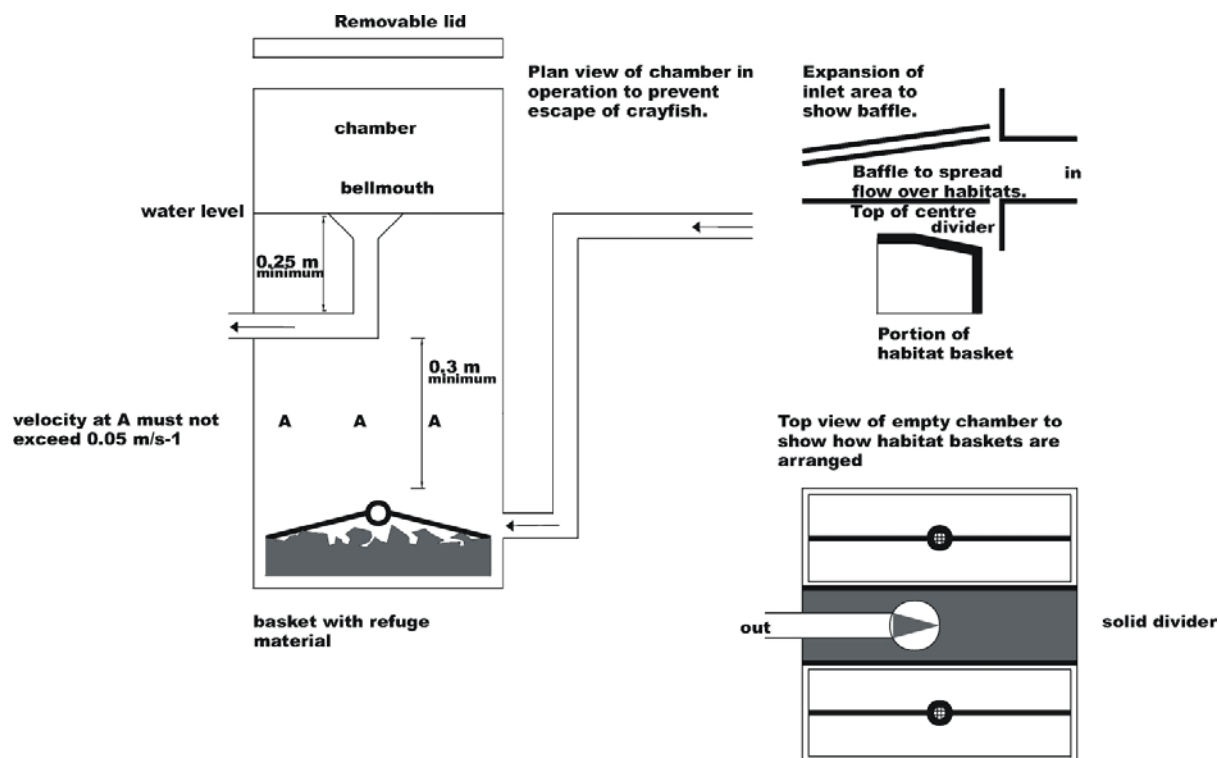
- smooth plastic interior to prevent climbing;
- a vertical bellmouth with a sufficiently long vertical arm to prevent a crayfish reaching up to the lip;
- a tank size designed for the on site flow, maximum internal velocity  $0.05\text{ms}^{-1}$ ;
- baffle to reduce velocity at the inlet;
- removable baskets with material suitable for crayfish, refugees, to be lifted and emptied of crayfish regularly.

The estimated maximum velocity of  $5\text{cms}^{-1}$  was derived from a simple empirical test in which small crayfish were dropped in water and the time taken to reach the bottom by drift or swimming was recorded (Elaine Axford, Environment Agency). At higher velocity there is the possibility of a crayfish being washed up into bellmouth before it can settle in the refuge material at the bottom on the tank.

A fine mesh was initially considered as an extra barrier in the bellmouth, but concerns about possible blockage with algae led to this being dropped from the design. In practice in the constructed catchpit a coarse mesh was added.

As signal crayfish are known to have already escaped into the Ure it was recognised that the catchpit will not stop the spread of these crayfish in the Ure catchment. Nonetheless, the site was considered to be suitable because of the length of the existing culvert and the presence of an existing inspection chamber, which could be monitored for crayfish. If successful, the catchpit may have potential to prevent the escape of signal crayfish populations in similar situations specifically where a water body is well-removed from the nearest open water course.





**Figure 2.4 Proposed design of catchpit at West Tanfield Fishery**

### 2.5.3 Fencing

Fencing or other barriers have been considered as methods of preventing signal crayfish from escaping from a wholly enclosed pond. A smooth faced vertical concrete or tiled wall 1m high or more might be sufficient deterrent, but would be expensive to construct. All fences require maintenance. In addition, a fence with a mesh fine enough to prevent crayfish passing through it would be dense enough for signal crayfish to climb.

No fencing methods have been trialled. A short-term barrier could be used to enclose a crayfish population during the use of biocides in an enclosed waterbody. Temporary drift fencing is regularly used to contain populations of amphibians. It consists of heavy duty polythene sheeting stretched between posts 1m apart, which are set at a 45° angle forming a one-way barrier. The lower edge of the sheeting is buried below turf.

## 2.6 Use of Predators

At the outset of Phase II, it was intended to stock a section of the River Gwash very heavily with eels and chub. The aim was to increase the predation pressure especially on juvenile crayfish. This proposal was later abandoned for various reasons. Retaining the eels within the chosen reach was thought to be a major difficulty. In addition, the burrowing habits of signal crayfish make them potentially one of the most resistant species to intensive fish predation. It was felt that this introduction might also have short-term impacts on populations of fish and other invertebrates.

## 2.7 Use of Biocides

At the outset of phase II, there was concern that none of the removal methods proposed would be effective in eliminating signal crayfish populations. Investigations were also begun into alternative methods that would destroy the crayfish *in situ*. No crayfish-specific biocides were known, which implied that other aquatic life would be damaged by the use of chemicals to control signal crayfish. The use of biocides would therefore be more difficult to justify and it would not be reasonable to begin field trials of them until it had been confirmed that less damaging methods could not achieve the objectives. The planned field trials of biocides were therefore not progressed. Two independent laboratory trials of biocides were conducted and are reported here.

The proposal to use rotenone in Ullesthorpe Pond (Appendix 6.1) was abandoned when it became clear during laboratory trials (Holdich, pers comm.) that this substance was ineffective against crayfish. Rotenone has been in use for removing nuisance fish species (e.g. pike and perch) from trout fisheries in the UK for at least 40 years. It leaves the invertebrate trout food more or less intact and stocking can take place soon after this natural and biodegradable substance has been applied (Lord Richard Percy, Newcastle University, pers. comm.).

Environment Agency concerns over the effectiveness and political acceptability of using chemicals led to the project at Tetford Pond being abandoned (Appendix 6.3).

Due to the obvious lack of any effective non-chemical control method, together with no prospect of a successful eradication method by any other means, trials of poisoning with common chemicals were carried out early in 2000 (Appendix 8). Essentially the method was to:

- use an adjuvant to stimulate crayfish to leave their refuges;
- then use a toxicant to kill the crayfish;
- then neutralise or denature the toxicant.

Chemicals tested included:

- chlorine (sodium hypochlorite);
- high pH (sodium hydroxide);
- low pH (hydrochloric acid);
- potash alum;
- ammonium sulphate/ sodium hydroxide;
- papain (enzyme in meat tenderiser);
- deoxygenation with sucrose/ soil suspension;
- deoxygenation with sodium sulphite;
- permethrin (Homebase all-in-one insecticide).

Some of these were used in various combinations.

### **3. RESULTS AND OBSERVATIONS**

The findings of the main projects are briefly reported with reference to fuller information contained in the appendices. Information from the other studies, also included in the appendices, is included where relevant.

#### **3.1 Removal of live crayfish**

##### **3.1.1 Trapping**

No data have been obtained on the efficacy of refuge traps, although early indications are that the size range available for trapping is greater than that of either standard or small mesh traps (Erica Kemp, Adrian Hutching pers. comm.).

##### **Reepham fishery: River Wensum**

The three-night intensive trapping in phases I and II of the work at Reepham fishery captured totals of 2419 and 2179 crayfish. Zippin population estimates for the two phases place the trappable population at 3624 and 7899 respectively. This would imply a theoretical trapping efficiency of 66 % during phase I and 27.6 % during phase II. In practise the trappable population constitutes such a small proportion of the total, that these figure are severe under estimations of the true population.

Small mesh traps used during phase III did not capture significantly more crayfish than standard traps, however they were effective over a broader size range.

Total numbers of crayfish caught decreased by 80 % between phases I (2419) and III (498). However as the phases took place at different times of year (phase I: October, phase III: April) this is not indicative of an 80% decrease in the trappable population. It reflects the differences in crayfish activity, as evidenced by the trapping monitoring at Wixoe on the River Stour (Appendix 5). Crayfish activity is usually low in April at the end of the winter period. Females are especially trap-shy when berried.

Signal crayfish have been reported in the Wensum. The colonisation may have occurred from a site further upstream rather than from Reepham fishery, although it is highly likely that a population is well established in Reepham Stream.

##### **Wixoe: River Stour.**

Weekly trapping in this part of the Upper Stour has been sustained for two years. The main function of this work is intensive monitoring rather than attempted eradication. The numbers caught at Wixoe are increasing annually, indicating the population is increasing due to immigration from upstream. The total catch at Wixoe is now in excess of 2000 per year, which strongly suggests that trapping will not affect the downstream rate of colonisation, even with continuous weekly removal of crayfish.

Small mesh traps, used from April 2000 caught crayfish across a broader size range (19-72 mm) than Trappies (38-76 mm). The modal size for small mesh traps was 30 mm CL, (carapace length) with most of the catch in the range 20-40 mm CL. By contrast Trappies

caught hardly any crayfish less than 40 mm CL, and the highest frequency of catch was in the size range 45-60 mm CL.

## **Other Projects**

Intensive trapping of signal crayfish in Gaddesby Brook has been in progress since 1995, and the species has been commercially harvested for a longer period. Surveys confirmed the continued expansion in the range of the population (Sibley, 2000). Trapping was recognised as having too low efficiency to have any effect (Appendix 7.1). Fine mesh Trappies were found to capture a wider size range and more individuals than the commercial variety, as reported in other studies (Appendix 5). Intensive trapping appeared to reduce the trappable population by two thirds between 1995 and 1998, but only the very largest crayfish were affected. Despite this, the signal crayfish extended their range downstream by 3 km in this 3-year period. With a change of method to modified kick-sampling, a larger number of crayfish were captured. Using 96 man-days effort in late 1999, 6507 signals were removed. Not all stretches of the brook were netted in each survey, only sample sites. Using mark-recapture of male signal crayfish, the present population is estimated at 20 000 or more, and even this is likely to be an underestimate of the smaller size classes.

On a 3.5 km stretch of the River Hamps, 40 man-days hand search plus 70 traps retrieved 1500 signal crayfish over a weekend in May. A follow-up survey the day after a session of intensive removal recorded around 3-4 crayfish per m<sup>2</sup>, in a sample of the area that had been intensively covered in the manual removal exercise. Large animals were selectively removed both by trap and by hand. Less experienced operators tended to catch fewer small adults and juveniles. These results confirm the difficulty in using such methods to eradicate signal crayfish.

A trapping and removal study of signal crayfish in Catton Park Lake, adjacent to the River Trent, yielded 1236 animals over a 17-week period. From mark-recapture results from other sites (section 3.1.1), it can be assumed that this figure represents perhaps 10-20 % of the total trappable population and only a few percent of the total population. Colonisation of the River Trent is highly likely, as the lake is periodically flooded, allowing crayfish access to the river.

### **3.1.2 Mark-Recapture**

Mark-recapture results using trapping in Ullesthorpe Pond, Gaddesby Brook and Huddersfield Narrow Canal achieved apparent recapture rates of between 10 % and 33 % of the trappable population. Most methodologies for estimating population size from mark-recapture techniques assume equal catchability. This assumption is not valid with respect to crayfish, as there is a sex bias towards males, and a size bias. Work done on night-viewing Meanwood Beck, Leeds, (Peay, pers. comm.) and radio tracking (Lucas *et al* 2000, Armitage 2000) suggests both territoriality (which would artificially increase recapture rates) and response to capture (which causes some individuals to flee the area, reducing recapture) may influence recapture rates. This is in addition to the biases due to the methods themselves.

## **3.2 Manual Removal**

### **3.2.1 West Tanfield Fishery: River Ure**

No depletion of numbers in this very small outlet stream was noted over the five repeats of the intensive collection exercise. This may be partially due to continual escapes from the fishery lake, but also reflects the difficulty of removing crayfish from refuges in the stream banks. Intensive removal in the river itself yielded similar results, with numbers increasing markedly in the last two surveys (July and August) due to juveniles becoming large enough to catch, and lower flows making more of the channel accessible.

As the catchpit system was only installed at West Tanfield fishery in summer 2000, no results on the success of this system are available as yet.

### **3.2.2 Gunthorpe Bridge: River Gwash**

Five repeats of 100 man-days searching approximately 1.3 km have been carried out in two years on this river which feeds Rutland Water. The original intention was to prevent colonisation of the reservoir. The first three sets of results were 2227, 1227 and 2550 animals, indicating that no depletion was apparent. The lower capture obtained during the second session is a reflection of the time of year surveying occurred (February in Session 2 and October in Sessions 1 and 3) and the lower number of man-days effort put into this exercise (60). When adjusted for catch per unit effort, the three sessions caught 22.3, 20.1 and 25.5 crayfish per man-day's work.

Total capture results from capture periods four and five were 1008 and 1009 respectively. This decrease of approximately 50 % compared with the previous years' data is probably due to a change in survey methodology in these sessions. More people carried out the work over a shorter time period to achieve the same number of man-day's effort, some of whom were less experienced than the original surveyors. In addition, in the earlier sessions there may have been some recolonisation of in-channel refuges by animals from bankside refuges in adjacent sections, which were recovered when sections were re-worked.

Apparent changes in modal size of the crayfish between these exercises were found to be due to recruitment rather than the effects of the removal exercises. Modal sizes were 17-18 mm in the autumn sessions, and 15 mm in both spring sessions. The variability of data indicates the level of caution required in interpreting survey results. Given the predicted migration rate of signal crayfish populations (Section 1.2.3), there can be no reasonable doubt that this species has now colonised Rutland Water, as it is less than 1 km downstream of the known limit of the population, and more than 10 years have passed since the initial introduction.

## **3.3 De-watering**

Intensive trapping of white-clawed crayfish on Huddersfield Narrow Canal showed an apparent recapture rate of 30% in a short section of canal, approximately 25 m in length. This gave an estimated population (Peterson Population Estimate) of 24 trappable white-clawed crayfish. The section was de-watered within two weeks of this estimation, and 252 crayfish were rescued in one afternoon, 51 of which fell within the trappable size class. This indicates that at least 50% of the trappable size classes are not susceptible to trapping. It assumes that all individuals were recovered during drawdown. Work took place in the winter, some

animals were undoubtedly not retrieved, as they would have been sheltering in the wash walls which are unpointed in this section. Trapping efficiency is therefore likely to be significantly lower.

During repeated drawdowns carried out at a similar section at the same time the previous year, crayfish emerged from the walls up to two days after the initial drawdown.

The population estimate obtained by trapping gave less than 10 % of the population found at drawdown. The actual population size may well increase by a similar factor. In another 25 m section of the Huddersfield Narrow Canal very intensive trapping produced 51 marked animals. 17 % of these were recovered later, out of a total of 534 crayfish captured from three drawdowns and during works. About 20 % of the total were caught during engineering works i.e. after de-watering twice.

In a 1 km stretch of the River Derwent in Yorkshire, during a river restoration project, only 10 % of the population of native crayfish rescued was found during intensive day and night hand-searches. What was assumed to be the remaining 90 % (approximately 850 animals) was rescued during the excavation phase of the project, by inspecting the vegetation spoil as it was hauled from the river in this reach with a high proportion of silty reaches and abundant aquatic plants. Here too, not all crayfish will have been retrieved, and juveniles were under represented.

Results from all projects refer to the ‘trappable population’ rather than the total population. Although different eradication techniques are capable of capturing different percentages of the total population, none are capable of capturing anywhere near an entire population.

This work has shown that manual removal is much less effective than was expected. None of the studies reported any sustained reduction in numbers or size ratios that could be clearly ascribed to the removal process. The variability of the sampling methods and the limitations of all methods of estimating population size have also hampered the appreciation of the relative efficiency of the various methods. The fact that numbers taken by any method in a removal exercise tend to remain similar from year to year is a strong indication that the method would need to be applied at many times the maximum intensity used in any of these studies to generate an appreciable effect.

### **3.4 Habitat destruction**

The concept of clearing out all crayfish by gaining access to every potential refuge is sound, but difficult to put into practice. Signal crayfish are well known for surviving several months out of water, in damp places. The efforts of draining, and excavation of bankside refuges at Llanfihangel Pond in 1997 (Appendix 6.2) were thwarted by the existence of escaped signals in the outlet stream. Despite a partial removal in the outlet while the pond itself was partially drained and dredged, recolonisation could readily occur. Signal crayfish were found to have re-established when the pond was monitored in 1999 as well as in the stream. It was accepted that the River Vyrnywy would be colonised from this pond, and signal crayfish presence was confirmed in the river in 1999.

In the River Gwash (Appendix 4), large numbers of burrows were found in the clay and rocky areas. To remove the crayfish from these would require extensive mechanical excavation and even then, this would not eliminate the species – merely reduce numbers to a lower level.

Furthermore, excavation would probably create a whole new set of good quality habitats for the few remaining crayfish.

The River Ure (Appendix 1) contains so much high quality habitat, that it would be practically impossible to remove all the rocks especially from the tree-lined banks. The River Ure is more than 25m wide in this area and more than 1m deep in many places. It is also a river of high value for nature conservation and trout-angling which would make any large scale habitat destruction unacceptable. Complete removal may have been possible in the small tributary, but concerns of the fish farmer about siltation meant that permission was refused for full excavation of the stream banks. In addition, many signal crayfish were still present in the waterlogged ground in the adjacent wood. They were also subsequently found in the pipe from the lake.

Following the lining of the outlet stream with corrugated iron by the fish farm operator, signal crayfish were observed to be living in the bank behind the corrugations. The intention is that these areas should be backfilled and compacted, although this will not necessarily remove all the refuges.

### **3.5 Escape/migration prevention**

#### **Durford Bridge, River Rother**

Ongoing monitoring has shown that detected limits of the signal crayfish population now extend beyond the upper weir. Both weirs have been no more than a temporary barrier at most. A mixed population now exists above the weirs, and eventual loss of the white-clawed population is inevitable (Appendix 3).

#### **West Tanfield: River Ure,**

A catchpit system has been installed at the outlet of West Tanfield Lake to attempt to prevent further escapes. The specifications of the original design have not been met in full, but is similar. The main differences are that the vertical arm of the bellmouth is shorter and a coarse mesh tray has been placed over the bellmouth. Full details are provided in Appendix 1.4. It is not yet known whether or not the catchpit is successfully containing the signal crayfish population, although initial indications are favourable.

### **3.6 Crayfish eradication using biocides**

Initial laboratory trials of poisoning with common chemicals were carried out early in 2000 (Appendix 8). Results of the chemical trials showed four possible methods, each of which could be used on its own to kill crayfish:

- pH 12 or higher (sodium hydroxide);
- 10-100 mg l<sup>-1</sup> chlorine (sodium hypochlorite bleach);
- 10 µg l<sup>-1</sup> permethrin;
- zero oxygen, from sodium sulphite or organic addition (sucrose).

Improved results could be obtained from combinations of:

- ammonia (ammonium sulphate) with high pH (sodium hydroxide);
- mineral acid with chlorine, and

- deoxygenation as a precursor to other treatments.

Use of chlorine is not suitable in sites with abundant organic matter, as it is readily denatured. Permethrin was found to be more resistant to denaturing than expected, which may make its use unacceptable. Natural pyrethrum would be highly preferable, if obtainable because it breaks down more readily. It is, however, in short supply. Excluding permethrin, the best combination for potential use in the field appeared to be the following steps:

- 1 deoxygenation with sodium sulphite.
- 2 ammonium sulphate and sodium hydroxide mix.
- 3 neutralise with acid.
- 4 aerate.

There is a risk of creating soaps or foams at high pH, so this method would not be suitable for running water. It will also require laboratory trial of the full process, prior to any field use, including the post trial toxicology testing to ensure the water is no longer toxic to non-target organisations.

Low pH, potash alum and papain were not effective under conditions likely to be found in the field.



## 4. ANALYSIS AND DISCUSSION

### 4.1 Populations of Signal Crayfish and Removal Efficiency

Most of the manual removal methods did not have any detectable effect on population size of signal crayfish. In most cases there was:

- no reduction in numbers captured in subsequent surveys (which could not be attributed to other factors such as season or method);
- no reduction in population size by independent survey, and
- no significant alteration of the size distribution of the remaining crayfish.

The effort that would be required to effect a substantial reduction in the population size can therefore be concluded to be many times larger in every case.

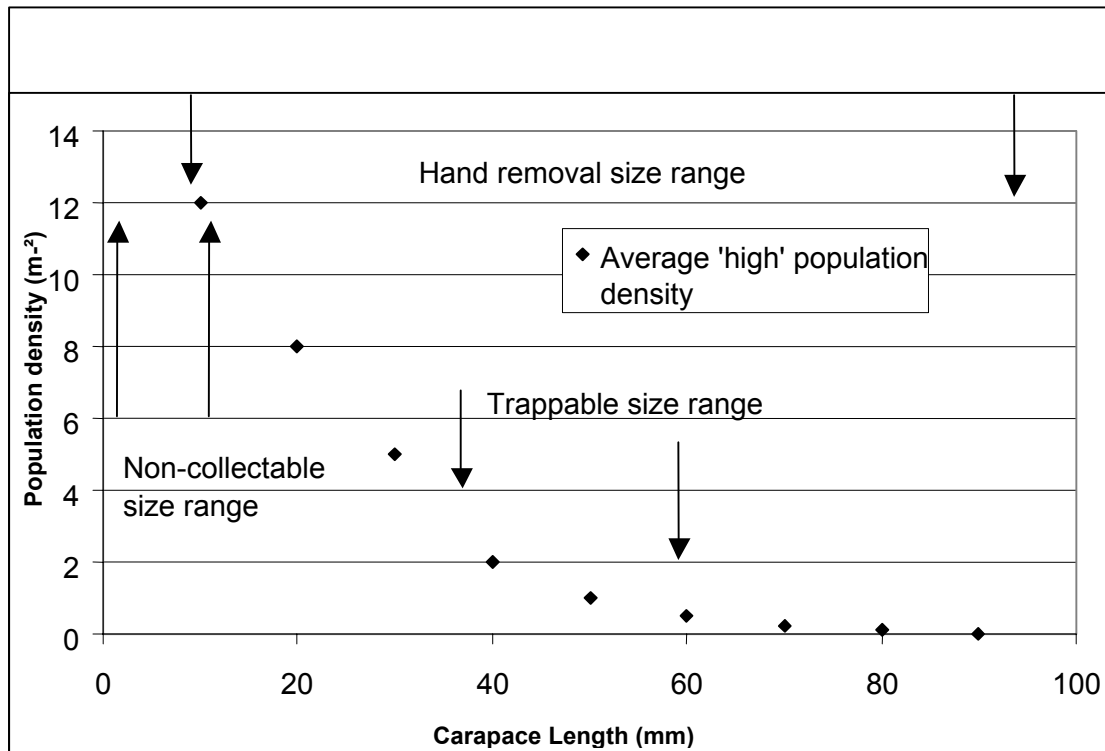
Taking up to 2,500 animals four times in two years from 1.3 km of the River Gwash appears to be sustainable. An established population of signal crayfish may average 10 individuals  $m^{-2}$ , which would equate to 56,000 individuals in the 4 m wide River Gwash. Many more than 5,000 individuals would need to be removed each year to have any detectable effect on the population – and that would be far from eradication.

Where removal methods were applied to less than the complete range of a population, immigration from outside the treatment area has contributed to the difficulties experienced in reducing population sizes (West Tanfield Fishery, Appendix 1 also Gaddesby Brook, River Gwash, and Llanfihangel Pond).

All trapping programs had little or no effect on population size, and are applicable only to ‘the trappable population’. The size range taken in traps lies between 30 mm and 70 mm carapace length, although some smaller individuals are taken, mainly in small mesh traps. The bell-curve distribution of a population sampled by trapping clearly shows the reduced efficiency of capture of size classes below 45mm. Animals of less than 30 mm carapace length will make up the majority of the animals in a population of signal crayfish, (i.e. juveniles).

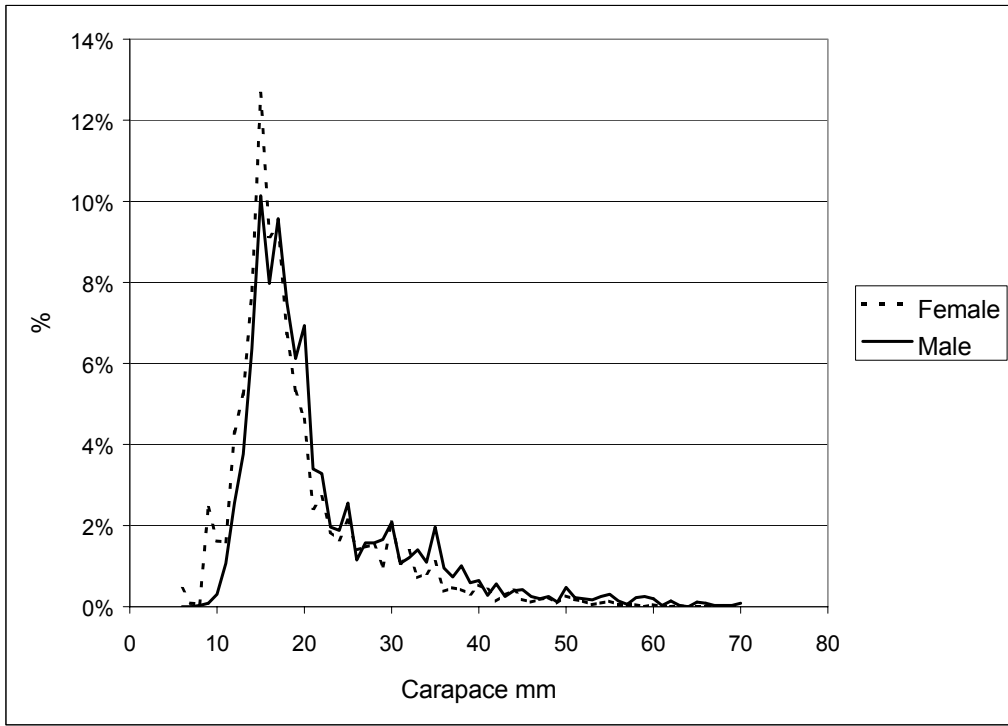
Population estimates obtained from trapping assume equal catchability of individuals. This is demonstrably false, as shown by comparative population estimates from mark-recapture and drawdown schemes on the Huddersfield Narrow Canal (Appendix 7.3). Comparisons of the size distribution from the Gwash, or other projects involving hand searching, with any of the trapping studies show the limitations. Figure 4.1 shows a theoretical example of the relationship between size and population density in signal crayfish. Population density is estimated, based on results from a range of surveys. Table 4.1 shows some examples of recorded population density at various sites by different methods. All of these under-estimate juvenile crayfish, especially young of the year (0+).

Traps would have to be able to remove 100 % of the sexually mature signal crayfish in a population in order to approach the Objectives of the Eradication study.

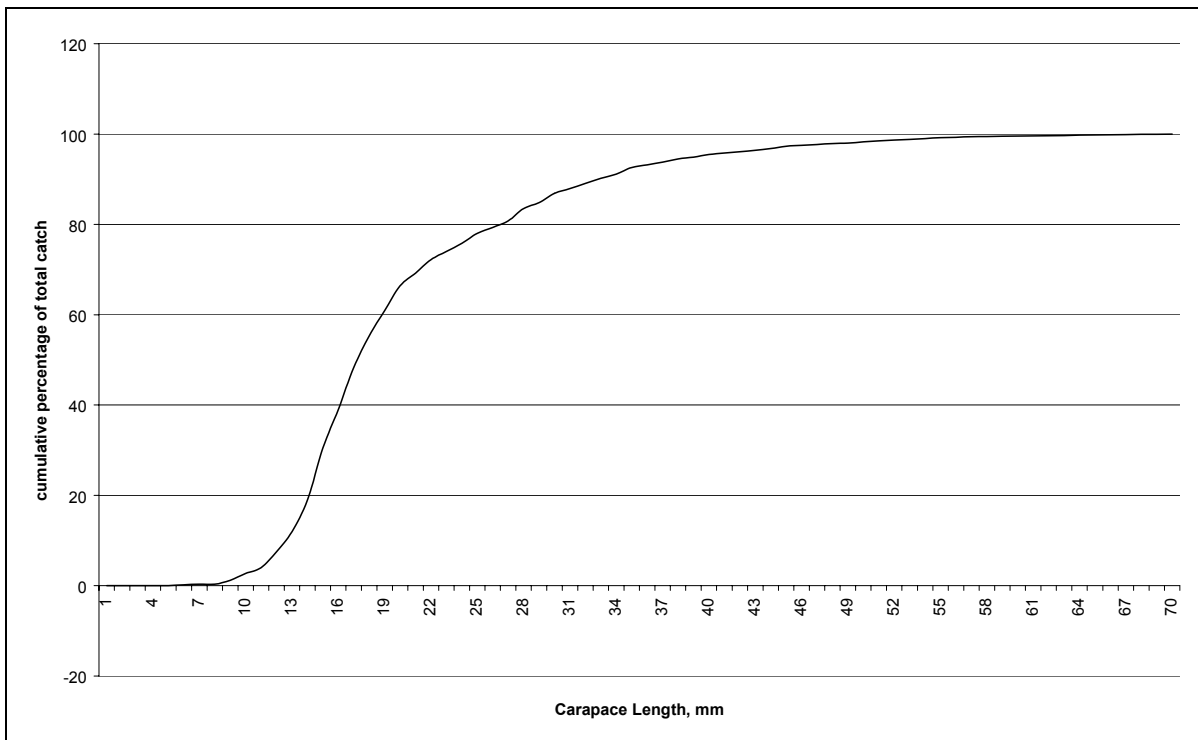


**Figure 4.1 Theoretical diagram of selectivity of removal methods.**

Figure 4.2 shows the data from the River Gwash, with different sizes shown relative to the total catch. It can be seen that the majority of crayfish captured fell below the minimum trappable size of 30-40 mm. Figure 4.3 shows the cumulative percentage of the total catch made up by the different size classes caught. It shows crayfish of more than 30 mm CL as 15% of the total and those above 40 mm CL as 4%. The 0+ individuals, below 14 mm CL, are under represented, and the 1+ individuals, 16 –20 mm CL (Holdich and Lowery, 1988, Kirjavainen and Westman, 1995), are also likely to be only a proportion of those present in the total population.



**Figure 4.2 River Gwash – Percentage total catch by size of Crayfish**



**Figure 4.3: Percentage of crayfish in the trappable size classes (Gwash data)**

An estimate of efficiency of manual removal can be made using the Gwash project. The project covered a section of watercourse 1300m long and averaging about 4 m wide, i.e. in the order of 5000 m<sup>2</sup>. This makes no allowance for increased bed area due to depth, but most of the stream is less than 0.5 m deep, with only a few pools of 1 m or more. The Gwash results

show the major effects of micro-habitat on crayfish density and “catchability”, with more than tenfold differences in catches between some sections. Nonetheless, most of it is suitable to highly favourable habitat for crayfish.

Peay (1997) recorded signal crayfish density at 2 m<sup>-2</sup> using semi-quantitative manual survey in the River Wharfe, a large, stony upland river. Further survey showed an increase to an average of 9 m<sup>-2</sup> two years later (Peay, pers. comm.). Guan (2000) carried out intensive surveys in the Great Ouse in Buckinghamshire and calculated annual average densities of 2.2 m<sup>-2</sup> for crayfish above 23 mm CL in a pool and 6.1 m<sup>-2</sup> for crayfish of all sizes in a riffle. Recorded densities were 4m<sup>-2</sup> and 15 m<sup>-2</sup> in these habitats respectively in summer.

In the River Gwash catches per 100 man-days effort were in the range 1000-2500. The removal efficiency depends on the population density. Using an estimate of an average density of 2 m<sup>-2</sup> in the River Gwash would yield a population of 10,000 crayfish and a removal efficiency of 10-25 %. A density of 6 m<sup>-2</sup> would represent 3-8 %, a density of 10m<sup>-2</sup> would mean an efficiency of 2-5 % and 15 m<sup>-2</sup> would be 1-3 %. This is no more than densities recorded in surveys and far less than farmed densities which can exceed 25 m<sup>-2</sup>. Table 4.1 shows some examples of density estimates by various authors, using a range of methods.

The results from the manual removal in the River Gwash show that the catch per manday averaged 22, 20, 26, 10 and 10 in sessions 1, 2, 3, 4 and 5 respectively. This is a relatively low yield for what is likely to be a fairly dense population. It is likely to reflect the considerable difficulties of finding crayfish in a small, lowland river. The Gwash has sections which have stone of sufficient size to provide refuges overlying a clean gravel bed. There are many sections with soft substrates, even though the largely shaded conditions mean there is relatively little growth of submerged or emergent aquatic plants. Areas with soft banks have several to 10's crayfish burrows per linear metre of bank.

By contrast, in an upland limestone river, the River Wharfe, there are some areas with very favourable conditions for manual searching. The substrate is a layer of large cobble over gravel, in shallow water with excellent visibility. In these conditions catch rates of signal crayfish can exceed 50 individuals per hour of searching (Peay and Hiley, pers. comm.). There are extensive areas of the Wharfe channel and banks that are inaccessible to manual searching.

Although there may be some differences in density in the two established populations, the major factor is likely to be the conditions for searching. There is also the issue of diminishing returns. In the River Gwash each section was thoroughly searched several times to try to removal all crayfish. In the River Wharfe the intensive manual removal is for estimates of population only and consistency of survey intensity was more important.

**Table 4.1 Density estimates in signal crayfish populations**

<b>Species</b>	<b>Location</b>	<b>Habitat</b>	<b>Density</b>	<b>Notes</b>	<b>Reference</b>
<i>P. leniusculus</i>	France	Gravel pit	4.2-7.3	trapping	Laurent & Vey, 1986 (Hogger, 1988)
<i>P. leniusculus</i>	Bucks.	Gt Ouse River	2 (a), 15(b)	(a)– mean density, pools, (b) riffles, trapping, mark recapture and Surber samples	Guan & Wiles 1996
<i>P. leniusculus</i>	Leics.	Gaddesby Brook	1.4-14.5	Trapping mark recapture, adjusted to incl. 15-20mm	Harris & Young 1996
<i>P. leniusculus</i>	Avon	Broadmead Brook	36		Holdich et al 1995
<i>P. leniusculus</i>	California	Lake Tahoe	0.7-5.85		Flint, 1975 (Hogger, 1988)
<i>P. leniusculus</i>	California	Lake Tahoe	2.1	Night view	Abrahamsson, 1981
<i>P. leniusculus</i> + <i>A. astacus</i>	Sweden	Lake Skillotsjon	15.8 & 18.5	1m dredge-sampling	Soderback, 1995
<i>P. leniusculus</i>	Yorks.	R Wharfe	1 ave 1997 9 ave 2000	Manual searching	Peay, 2000 unpublished data

## 4.2 Effectiveness of Methods

None of the methods had any real chance of bringing the population of signal crayfish down to a level at which its spread would be halted. Not all crayfish are available to be captured, and there is no sampling method of sufficient resolution to detect when a signal crayfish population has been brought to such a low level that it can no longer spread (or reproduce). In practice, none of the methods made more than a minor difference to the population sizes, so the issue of whether or not an undetectably small number remained did not arise.

A control method may be assessed as having potential for eradication if it removed a substantial (e.g. half) portion of the actual population of signal crayfish. None of the methods achieved this. Because of the law of diminishing returns, it is likely that a 50 % efficient method would require repeating ten times in one year to get the population in the River Gwash down to below 50 individuals; twelve or more times to have a chance of getting it below the Minimum Viable Population Density. With such a huge effort there would be a large adverse impact on habitats within the river reach, with associated destruction of flora and fauna.

Most of the reports showed captures of 0-10 % of the trappable population. The best method reported appears to be the intensive netting carried out on Gaddesby Brook, in which some 30% of the larger signal crayfish appeared to be removed with 96 man-days' work. Here too the difficulty remains in estimating the true population. A very much smaller proportion of the smaller individuals are likely to have been removed.

Population estimates from the Huddersfield Narrow Canal during drawdown suggest that less than 10% of the total population is retrievable by manual removal.

Attempts to eradicate crayfish habitat are often incomplete. If any burrows, individuals or eggs remain after habitat destruction, recolonisation is inevitable. If nearby signal crayfish populations are not also eradicated, recruitment from these populations will again result in recolonisation.

By using a pheromone or other attractants, the efficiency of traps may be increased. This is discussed in more detail in Hiley (2000). For a pheromone or other attractant to offer a chance of achieving eradication, it would need to be effective on 100% of the signal crayfish present in a watercourse. Crayfish take two to three years, occasionally more, to reach maturity. Some large animals do not breed every year, as evidenced by the records of unberried females in surveys and removal exercises. A trapping exercise to remove 100 % of the susceptible individuals would have to be repeated at least every year for four years. Even with attractants, trapping efficiency would never be 100 % of the adult population. If immigration from uncontrolled areas were occurring, the trapping would have to be continued into perpetuity.

Carefully calculated use of degradable biocides appears to be the only viable option. Even these are likely to have only limited acceptable applications. The recent incidents of extensive signal crayfish kills due to synthetic pyrethrins in sheep-dip (e.g. River Wharfe and River Dove) were followed by recovery as many individuals survived and / or recolonised from unaffected areas. If a plug of pollutant travels down a river, concentrations may differ laterally, leading to survival in the less toxic areas. This incomplete dispersion problem is

one of several which could limit the effectiveness of biocides for control of signal crayfish. Biocides also carry a substantial risk of damage to aquatic organisms outside the target range.

The replacement of native crayfish by signal crayfish where both occur is complete, with no indication of a density below which a mixed population can be sustained. Control methods must therefore be 100% effective. This is a very severe constraint and so far only biocides and, in the case of the white-clawed crayfish, and any other European species, disease have shown any sign of having the potential to achieve such a result. The unavailability of part of the population to capture methods is the primary cause of the difficulty.

## **5. EVALUATION OF METHODS**

The following section provides a summary of the various methods used and their effectiveness, or otherwise, as a method of control for alien crayfish. The uses and limitations of the method are outlined, together with an appraisal of the potential for development of the method. Each section includes:

- description of method;
- rationale;
- case studies where the method was used;
- effectiveness for eradication;
- uses and limitations;
- environmental impacts of the method;
- scope for development.

The methods are as follows:

- Removal of crayfish - trapping
- Removal of crayfish - manual
- Habitat destruction
- Physical barriers
- Predators
- Disease
- Poisons

### **5.1 Removal of crayfish - trapping**

#### **5.1.1 Description of method**

Several different types of trap have been used. Originally, the Swedish Trappy, which is used for commercial harvest of marketable crayfish in Scandinavian countries was widely used in Britain. Recently, there has been a shift towards use of low-cost, fine-mesh traps. Both types consist of funnels which allow access to the baited traps, but limit exit. Traps are left in place overnight or for longer periods then lifted to retrieve crayfish. Currently, trials are underway to assess the effectiveness of refuge traps. These are un-baited and open traps that provide a tube or other habitat in which crayfish can take refuge.

#### **5.1.2 Rationale for trapping**

Although conventional trapping is known to be highly biased towards males and large crayfish, the aim of studies using trapping was to remove sufficient adult animals to reduce breeding success. It has tended to be used as a default option where other methods could not be used. It is the most common method that has been used in mark-recapture studies.

#### **5.1.3 Case studies where trapping was used**

Trapping was used at Reepham Fishery (Appendix 2) in a series of three intensive sessions of trapping and removal and in population studies in Ullesthorpe Pond (Appendix 6.1). Trapping was also used in the River Stour at Wixoe (Appendix 5), although here it was used primarily as a monitoring method. It was used at Wixoe as a control method to try to prevent



the intercatchment transfer of signal crayfish at a river abstraction site. It showed the marked seasonal variation in trappable population.

#### **5.1.4 Effectiveness for eradication**

Trapping is wholly ineffective as a method of eradicating or even controlling a population of crayfish.

Trapping only recovers a small proportion of the adult population that is active at any one time. As such, it has been shown to provide a sustainable harvest of crayfish for commercial use. None of the trapping studies have shown any reduction in population, even with repeated trapping. There is a possibility that intensive trapping may remove enough of the largest size classes for there to be a detectable reduction in the proportion of these classes in trapped animals (Sibley 2000). Even so, this will not have any appreciable effect on the total population.

Catches per trap tend to be higher in dense populations, but the proportion caught is likely to be the same or lower at high density. Observations of traps at night (Peay, River Wharfe pers. comm.) suggest that the smaller adults may enter traps if they find them first, but smaller animals tend not to enter traps once they are occupied by large crayfish. Small crayfish can easily escape from Trappies and do sometimes climb out of fine-mesh traps too.

Viewing at night suggests even intensive trapping at 1 trap per 5 m riverbank catches less than 10 % of the active population. Comparisons of night viewing and manual searching by day also suggest the total population is at least 10 times greater than the population seen out at night on any occasion.

Even fine-mesh traps only catch a small proportion of the population of signal crayfish of 40 mm CL or less and hardly any animals of 30 mm CL or less. This means there is always a proportion of the population that cannot be caught by trapping, but is sufficiently large to breed. Comparison with the manual removal data from the River Gwash shows crayfish of 30 mm CL or more represented only 15 % of the total catch. As the 0+ year class is undoubtedly under-represented even in the Gwash data it gives some indication of the very low percentage of the population in the potentially trappable size range.

There is a possibility that reduction in the predation by large crayfish and the dominance of the largest animals in breeding may even increase crayfish populations. This is difficult to confirm in the field, but has long been known in commercial farming, in which crayfish are grown in size classes to reduce predation.

#### **5.1.5 Uses and limitations**

There are no known circumstances under which trapping has any value as a method for controlling alien crayfish populations.

The strong size bias of traps and the low efficiency of trapping mean that the possibility of reducing a population of alien crayfish by any available method of trapping is remote.

Nonetheless it has been reported that when crayfish reach high densities in lakes and ponds, it is the largest animals that are most likely to take angling bait and hence provide a serious nuisance to anglers. It may be possible to reduce the nuisance to a degree, by trapping very intensively in every section in which crayfish are active. This might provide some reduction

in the larger animals. No examples have been identified in which there has been sufficient trapping to reduce nuisance, so it remains a possibility rather than a viable method. It would have to be continued indefinitely.

It must be emphasised that there is not likely to be any reduction in crayfish biomass. Any successful removal of large crayfish would favour growth in the smaller size classes, due to reduced predation. As stated above, trapping will not eradicate or even control a population of alien crayfish. Whether it is of any value in reducing impacts on angling amenity is not proven.

The main purpose of trapping (other than commercial harvesting) is for surveys. Its low efficiency means it is only suitable for high-density populations. This means it cannot be used to determine whether eradication has been successful, as there may well be a breeding population that is not detected by trapping. Allowance also needs to be made for factors such as sex bias, trap bias, seasonal factors and environmental conditions such as flow, local velocity and temperature.

The main advantage of trapping for surveys is that it can be used in water that is too deep or turbid for other survey methods. It can record crayfish that use refuges that are inaccessible for manual methods, especially in the banks.

#### **5.1.6 Environmental impacts**

The direct environmental impacts of trapping are generally low as there is no impact on habitats. However, funnel trapping has potentially some impact in terms of predation of any white-clawed crayfish captured in traps with signal crayfish; may increase population size in smaller size classes by selectively removing large predatory adults, and may occasionally drown small mammals, such as water vole (Rogers, pers. comm.) and water shrew (Peay, pers. comm.).

Both funnel and refuge trapping have potential to spread plague to previously uninfected populations of white-clawed crayfish, if traps are transferred between watercourses.

#### **5.1.7 Scope for development**

As an eradication method there is no scope for development.

As a survey method, there is scope to develop refuge-traps further. These have advantages of:

- negligible environmental impact;
- can be left *in situ* for long term monitoring;
- may be used by juvenile crayfish as well as adults;
- remove the risk of predation when used to trap white-clawed crayfish;
- pose no threat to water vole and other small mammals.

The effectiveness of refuge traps needs to be calibrated compared to manual search methods and may vary according to the availability of other in-channel refuges. It may be possible to influence the size distribution of crayfish using them on the basis of size. The effectiveness of refuge traps in low density populations needs to be investigated as this might possibly help to detect invading signal populations sooner than can be done by manual searching or funnel-trapping alone.

Ongoing research into the efficacy of refuge traps is being carried out by Adrian Hutchings (Sparsholt College), Nick Birkinshaw (British Waterways) and Erica Kemp (Scott Wilson Resource Consultants).

## **5.2 Removal of Crayfish – Manual**

### **5.2.1 Description of method**

This involves intensive manual searching of in-channel habitat. This usually involves searching under stones, where present. Sweep-netting is commonly used in aquatic vegetation, together with manual searching. Some projects have involved using sufficient surveyors to kick loose the full cross-section of a channel and catch crayfish in nets held immediately downstream. In some cases there has been excavation of crayfish burrows.

### **5.2.2 Rationale for manual removal**

The assumption here is that all or nearly all crayfish using a section of watercourse can be found and removed. In principle all size classes of crayfish should be available for capture.

### **5.2.3 Case studies where manual removal was used**

Most of the case studies in rivers have involved manual removal of crayfish. The numbers of surveyors involved and the frequency of removal have varied. The most intensive project so far has been the River Gwash (Appendix 4). This has involved approximately 100 man-days of effort on each of five sessions at six month intervals in 1300 m of a small stream. Other studies involving intensive manual searching and removal include West Tanfield (Appendix 1), Gaddesby Brook (Appendix 7.1), River Hamps (Appendix 7.2). Projects involving rescue and re-location of white-clawed crayfish prior to dredging or engineering works on watercourses have also been useful in showing the efficiency of manual survey methods compared to populations caught during intensive removal, for example Huddersfield Narrow Canal (Appendix 7.3), River Derwent at Ayton (Appendix 7.5) and Meanwood Beck, Leeds (Scott Wilson Consultants 1998).

### **5.2.4 Effectiveness for eradication**

Manual removal of crayfish has been the most popular method in projects to date. Nonetheless, despite the enormous effort put in to manual removal in some cases, notably the River Gwash, no eradication has been achieved, nor even a definite reduction in population density. Manual removal is not expected to be able to control populations because:

- it is not possible to be certain of the limits of spread of the population, so there is usually the opportunity for re-colonisation, and this may occur quickly;
- there are always areas within a watercourse (too deep or soft, in banks, under stones, roots, or other structures too large or embedded to move) which cannot be searched and can provide safe refuges;
- even experienced surveyors will miss a proportion of juvenile crayfish, especially 0+ and 1+, and
- if actual population density is in the order of 2-15 m<sup>-2</sup>, manual removal efficiency is likely to be less than 10 %, probably much less than 5 % - and less than natural mortality rates.

### **5.2.5 Uses and limitations**

Based on all the studies to date, manual removal cannot achieve eradication or even control at any level of effort that can practicably be resourced. Even with more repetitions and more destructive methods it is unlikely to achieve control of any populations of signal crayfish. Intensive manual removal studies and semi-quantitative surveys have helped improve understanding of crayfish ecology and populations. The manual methods are likely to continue to be the predominant method for surveys, although probably with much greater use of the semi-quantitative methods based on intensive sampling of transects or quadrats than has been the case in the past.

The major limitation is accessibility of habitat for survey. Manual methods are only effective in clear water of 60 cm depth or less. Silt and clay substrates, submerged and emergent plants, planktonic algae and naturally occurring peat-staining all reduce efficiency. Visibility is reduced by the action of manual searching. In turbid water the kick-sampling method is the only feasible one. In every semi-natural watercourse there are always areas of the channel and banks that cannot be searched except by total habitat destruction by drainage and full excavation.

### **5.2.6 Environmental impacts**

Walking around within a watercourse or pond causes damage to plant and invertebrate life, but is accepted as an inevitable part of the sampling process for environmental monitoring. If the process is repeated for more than a few minutes three or four times a year, detectable and observable damage begins to occur. Turning over rocks crushes organisms and loosens rooted plants even if the rocks are replaced. Intensive removal of signal crayfish by hand and net removal therefore has the potential to cause substantial, though localised, environmental damage.

As the presence of signal crayfish in itself has impacts on aquatic ecosystems, it may be considered that environmental impact during intensive removal is acceptable. The Gwash project does not appear to have caused any significant changes in the biological water quality (Richard Chadd, EA Anglian region, pers. comm.). It appears, however, that the twice-yearly sessions have not yet reduced the crayfish population and will not do so in future.

### **5.2.7 Scope for development**

There is little scope to improve manual methods for purposes of control or eradication. All indications so far are that manual removal is ineffective for this purpose.

The work in the fish farm stream at West Tanfield (Appendix 1) shows it is easier to find crayfish when the flow is wholly or partly diverted. This is confirmed by projects on rescue and relocation of white-clawed crayfish. Drawdown of streams or canals by the use of piped diversions or pumping encourages at least a proportion of crayfish to leave their refuges, making them easier to remove. Even with these methods, complete removal of the population is highly unlikely to be achieved.

The main purpose of manual methods will continue to be for surveys. Manual searching is the best available method for detecting the presence of crayfish, where conditions are suitable for survey. It is still subject to high variability however, depending on the habitat and surveyor skill.

## **5.3 Habitat Destruction**

### **5.3.1 Description of method**

This involves complete removal of crayfish and habitat, normally by mechanical excavation. It could, however, also include making some aspects of habitat unsuitable. For example, facing un-mortared stone revetments with concrete would remove the potential of the banks as refuges.

### **5.3.2 Rationale for habitat destruction**

If applied rigorously this method has potential to eradicate localized populations of crayfish by physical removal of animals and habitat.

### **5.3.3 Case studies where the method was used**

Llanfihangel Pond (Appendix 6.2) is the only available case study so far. It involved enlargement of a pond with signal crayfish in it.

### **5.3.4 Effectiveness for eradication**

Llanfihangel Pond was unsuccessful because crayfish had already escaped to a nearby stream from which they could recolonise. It is not certain whether the method is ever effective or not.

The best chance of eradication would be at a pond with a wholly enclosed population, with no inlet or outlet. The site would need to be drained and completely excavated to more than the maximum potential depth of crayfish burrows around the whole of the pond and its base. It might be necessary to erect temporary plastic sheet-fencing around the whole area prior to draining the site, to prevent crayfish wandering off over land (see physical barriers).

Routine drainage and dredging of ponds and lakes for fisheries management purposes is not effective. Signal crayfish can survive for months in burrows in the banks, so de-silting operations would not kill the whole population. Burrows may be several metres deep, so only an excavation that enlarges a pond in all directions may be effective.

The survival rate of signal crayfish in excavated spoil is not known. Nonetheless, large numbers of white-clawed crayfish were retrieved alive from shallowly dredged silt and plants from the River Derwent (Appendix 7.5). White-clawed crayfish also managed to crawl out of spoil from a section of bank accidentally dug out in advance of a rescue operation in Eller Beck (Peay, 1998).

As adult signal crayfish are larger and much better than white-clawed crayfish at surviving out of water, it is likely that at least some signal crayfish would survive in spoil. This means there is a high risk of signal crayfish re-colonising the site, or if the spoil is taken off-site there is the potential for the animals to escape to a new area.

There may be a better chance of successful eradication in an isolated pond that is small enough to drain, completely filled with clay or other suitable fill and compact – preferably within a single day. Such conditions will only occur rarely in practice. Even so, in the event of such a pond being found in a catchment that only has white-clawed crayfish, drastic action of this kind would be required to safeguard the white-clawed crayfish population in the long term.

### **5.3.5 Uses and limitations**

As outlined above, the method has only very limited applications and could only be used where it is certain that the whole population can be eradicated. There is no advantage in using this method if crayfish have already escaped.

### **5.3.6 Environmental impacts**

The method has substantial environmental impacts – total loss of aquatic habitat, at least in the short term. On aesthetic grounds and because of temporary loss of angling, this is likely to make it unacceptable to most pond owners. It might be acceptable where high density of crayfish is already causing significant reduction in angling amenity and where the owner wants to enlarge the facility. It is not suitable for ponds with inlet or outlet streams. By the time signal crayfish density reaches a level sufficient to interfere with angling, crayfish will already have spread widely from the pond.

Any proposed works on an existing stream, or channel diversion would have to be 100's metres to several kilometres to have any chance of isolating and eradicating even a recently introduced population of signal crayfish. It is likely that the environmental impact would be considered unacceptable.

### **5.3.7 Scope for development**

There is some scope for development, but probably only in conjunction with the use of biocides and only in very limited circumstances.

## **5.4 Physical Barriers**

### **5.4.1 Description of method**

There are several kinds of physical barriers, with varying degrees of potential effectiveness:

- reservoir dams;
- in-channel weirs;
- canal locks;
- screens;
- catchpit outfalls;
- fencing.

### **5.4.2 Rationale for use of barriers**

The rationale is that even if signal crayfish cannot be eradicated, it might be possible to put some kind of barrier in place that would prevent a population from spreading.

### **5.4.3 Case studies where the method was used**

Case studies described in this report include:

- River Rother at Durford Bridge (Appendix 3), where there were a couple of weirs in the river between a downstream signal crayfish population and an upstream white-clawed population; and
- West Tanfield (Appendix 1), where a catchpit was designed to try to prevent crayfish escaping from a lake.
- 

Other examples include existing canals and river abstractions.

#### 5.4.4 Effectiveness for eradication

None of these methods are effective for eradication and most are of only limited effectiveness for containment.

#### 5.4.5 Uses and limitations

- **reservoir dams** may be sufficient to protect a population of white-clawed crayfish in a reservoir from a population of signal crayfish invading a watercourse downstream of the reservoir, but only if the reservoir is very deep and the only outfall to the stream is via a large bell-mouth spillway or over the concrete face of the dam. Reservoir needs to be for public water supply so that normal abstraction from the reservoir means the bellmouth or dam face are normally dry. The dam should be 10's metres high and steep to be effective. If there is an open channel spillway, signal crayfish will eventually walk up it and colonise the reservoir.
- **in-channel weirs** are unlikely to be a barrier except in the short term. They are not a barrier to downstream movement. Even upstream, crayfish are likely to be able to climb up rough stone walls during low flows, especially if they are covered with growth of algae and bryophytes.
- **canal locks** may be a partial barrier to upstream movement of signal crayfish. However white-clawed crayfish have spread in at least some canals (Huddersfield Narrow, Grand Union). Locks have spillways, which could definitely be traversed by signal crayfish, at least during low flows and old locks can provide excellent refuges for signal crayfish, as found in the Calder and Hebble Navigation (Nick Birkinshaw, British Waterways pers. comm.). There is therefore great potential for inter-catchment transfer of signal crayfish via the canal system.
- **screens** on fish farm ponds are ineffectual. Any screens fine enough to be a barrier to crayfish tend to clog up with algae and other debris. In addition, signal crayfish can walk round them over land. Rotating band screens on river intakes are likely to prevent access to any adult crayfish entrained on the screens during abstraction, although they would not necessarily stop juveniles or eggs. Passive wedge-wire screens on intakes have a mesh size of as little as 2 mm and would be unlikely to allow access to juvenile crayfish. Very low intake velocity means crayfish would not be held on the screens by water pressure. The screens are very expensive to install and so are not widely used (R Lloyd, Yorkshire Water Services Ltd., pers. comm.).
- **catchpit** outfalls have the potential to be a barrier to crayfish, but are not yet proven. Essentially, the catchpit is a settling tank with smooth plastic interior and with a bellmouth outlet for water (see Appendix 1). Any crayfish entering the catchpit from the pond or lake need to be removed regularly from refuges installed for the purpose. A catchpit is only appropriate when the outfall is culverted for sufficient distance to a watercourse to prevent the crayfish walking overland to a stream.
- **fencing** has been suggested from time to time, but is limited by considerable climbing ability of signal crayfish and the difficulty or cost of maintaining fencing. Any fencing is only likely to be effective in the short term. The design of drift-

fencing used as a one-way barrier to amphibians may be of some use around small, enclosed ponds.

#### **5.4.6 Environmental impact**

In-channel structures will be a barrier to fish and there is a trend to remove redundant industrial weirs, rather than construct them. Catchpits have little or no impact, except possibly disturbance during construction.

#### **5.4.6 Scope for development**

The only method with scope for further development is the catchpit outfall. The size and detailed design depends on the through-flow of water. There is scope to improve the internal design to allow easier access and use of refuges from which crayfish can be easily removed for disposal. As indicated above, the applications are limited. It is only suitable for sites where the catchpit is the only practicable way out of the pond. At sites with a watercourse nearby, crayfish will walk out.

Temporary amphibian fencing may be useful to enclose ponds for effectiveness biocide treatment, but the durability of such fencing should be tested first.

### **5.5 Predators**

#### **5.5.1 Description of Method**

The approach considered was to remove “all” large crayfish then introduce eels and chub at very high stocking rates.

#### **5.5.2 Rationale for use of predators**

The rationale is that, in principle, an effective predator might be able to keep a population of crayfish below some critical population density above which competition encourages crayfish to seek new areas.

#### **5.5.3 Case studies where the method was used**

No case studies were identified during the R&D project. The River Gwash was considered as a possible site for introduction of eels. It was not taken further because:

- it was intended to be done after a reduction in population density by manual removal, which has not been achieved;
- there were difficulties in obtaining sufficient eels;
- there was no satisfactory means of determining what the density of eels was present after initial stocking;
- there was no method of preventing them from dispersing to other areas of the River Gwash and Rutland Water.

#### **5.5.4 Effectiveness for eradication**

Fish predators have no possibility of eradicating an established crayfish population and little chance of reducing the population. Trout and coarse fish, such as perch, do eat crayfish, especially juveniles, in the summer when they are present in abundance. Nonetheless there are numerous examples of signal crayfish populations that have developed from low numbers of stocked crayfish in ponds and lakes heavily stocked with fish.



Eels could enter at least some of the larger crayfish refuges and hence may be more effective predators, especially if they were able to attack from behind. It is unlikely that eels could be kept in sufficient density in a watercourse to have any significant impact on signal crayfish. Crayfish occupying burrows would be especially resistant to attack by predators. Even in a pond, it is doubtful whether predation pressure from eels would be greater than predation by crayfish.

#### **5.5.5 Uses and limitations**

As indicated above, predation is not considered to be an effective method of control.

#### **5.5.6 Environmental impact**

Very high stocking rates of introduced predatory fish, would have impacts on non-target fauna. The duration would depend on how long the fish were resident, i.e. whether or not they dispersed. Depending on density and species used and whether there was breeding of coarse fish there could be indirect impacts on the flora. The fish population can be the control factor that switches a waterbody that is dominated by aquatic vascular plants to one dominated by phytoplankton. Signal crayfish, however, will have impacts on aquatic macrophytes whether or not fish are introduced.

#### **5.5.7 Scope for development**

None.

### **5.6 Disease**

#### **5.6.1 Description of method**

There is no known disease which is selective to signal crayfish or other American species. All five European species of freshwater crayfish are highly susceptible to crayfish plague.

#### **5.6.2 Rationale for use of disease**

In principle, an unwanted population of Turkish crayfish or noble crayfish could be eradicated in a wholly enclosed waterbody by deliberate introduction of crayfish plague. In practice the risks of transmission to non-target areas would probably be considered unacceptable.

#### **5.6.3 Case studies where the method was used**

None.

#### **5.6.4 Effectiveness for eradication**

In principle, crayfish plague could be effective against susceptible alien species.

#### **5.6.5 Uses and limitations**

The risk of accidental transfer of crayfish plague to watercourses would be too high to make any use of disease acceptable even in enclosed waterbodies. It would be ineffective against signal crayfish. In theory a disease could be designed which was specific to signal crayfish. Even if it could be done, it would be unacceptable, given that keeping of signal crayfish is still legal in many areas of Britain and that elsewhere in the world signal crayfish are commercially important.

### **5.6.6 Environmental impacts**

High risk of transmission of disease to non-target crayfish populations or even other crustaceans.

### **5.6.7 Scope for development**

Unlikely to be any scope for development.

## **5.7 Biocides**

### **5.7.1 Description of Method**

Initial laboratory trials concentrated on using readily available chemicals which could be denatured readily. The most effective methods included: chlorine, low pH, un-ionised ammonia (ammonium sulphate/sodium hydroxide), deoxygenation (sucrose/soil or sodium sulphite), and permethrin.

### **5.7.2 Rationale for use of biocides**

Agricultural pesticides are known to cause mortality in crayfish. This has been found in crayfish farms in the USA using irrigation water contaminated with insecticides and in the UK in white-clawed crayfish and signal crayfish following runoff of permethrin-based sheepdips. The aim is to achieve 100 % kill of alien crayfish at a site, but the need to avoid or minimise impacts on non-target species means it is necessary to use biocides which can readily be de-natured after use. The use of chemicals in succession addresses the issue of exposure of the crayfish to the biocide. The first treatment is to encourage crayfish to leave refuges, where they are more readily exposed to the toxicant treatment that follows. Further treatment may be required to detoxify the water.

### **5.7.3 Case Studies Where the Method was Used**

Rotenone was given a laboratory trial (Holdich, Nottingham University), but was found to have relatively low toxicity and difficulties in handling due to foaming at high concentrations.

Laboratory trial of other chemicals was undertaken for this project (Appendix 8).

### **5.7.4 Effectiveness for Eradication**

Initial indications are that 100% kill can be achieved in laboratory conditions.

- **Chlorine** between 10 and 100 mg l<sup>-1</sup> is likely to kill signal crayfish within 24 hours of 1 hours exposure, although there is a delay of over one hour in response. De-chlorination is carried out using sodium thiosulphate saturated solution, a process used routinely in water treatment works. Chlorine is only suitable for use in clean conditions, with little or no organic matter. Its action may be enhanced by the addition of mineral acid.
- **pH 12 or higher**, using sodium hydroxide, is lethal to the crayfish following 1 hour exposure. The water is neutralised using mineral acid. Aeration of water of high pH is likely to create foams, so for field use neutralisation should be carried out before final aeration.
- **Ammonia** is not effective at neutral pH, but the un-ionised form is very much more toxic. A concentration of approximately 100 mg l<sup>-1</sup> (from addition of ammonium

sulphate) at pH 9 (following addition of sodium hydroxide) was used. This provided 100 % kill within 24 hours, following 1 hour exposure. Addition of mineral acid to reduce the pH to neutral reduces toxicity immediately, although it would require a few days for bacterial action to break down the ammonia.

- **Deoxygenation** with more than 500 mg l<sup>-1</sup> sodium sulphite produced behavioral responses in the crayfish within 15 minutes of exposure, including active attempts to climb out. Crayfish were killed within 12-24 hours. Soil and sucrose solution was not effective in laboratory conditions, but application of sugar has been used in angling ponds to bring excess fish to the surface for subsequent removal and may be effective in bringing out crayfish in field conditions. Deoxygenation can be neutralised by re-aeration.
- **Permethrin** concentrations of 0.006 mg l<sup>-1</sup> or more killed all the crayfish after an exposure of 1 hour. There was a delay in action, however, with crayfish becoming continuously active, then torpid for several hours before death. Permethrin has been reported as being denatured by chlorine, but this was not effective in the lab trial.
- **Other chemicals** low pH, potash alum and papain/salt were tested but were found to be ineffective.

The high pH alone is attractive because it is simple to create and neutralise these conditions. Using methods in combination may produce the best results. Indications are that the following procedure would be suitable:

- 1 encourage crayfish into movement by deoxygenation with sodium sulphite;
- 2 add a mixture of ammonium sulphate and caustic to provide un-ionised ammonia in conditions of high pH;
- 3 allow 1-24 hours exposure, remove or treat any crayfish which climb out;
- 4 neutralise pH and un-ionised ammonia by addition of mineral acid.

The laboratory trials were based on exposure times of only one hour. In practice, it may be possible to reduce the dose rates if longer periods of exposure are used.

One of the responses of signal crayfish (and white-clawed crayfish) to toxic conditions is to leave the water. This means that in a field trial there would need to be barriers in place to prevent crayfish leaving the area and either manual collection of emergent animals and/or application of biocides on the banks as well as in the water. Failure to do this would allow some animals to escape exposure and then subsequently re-colonise.

Permethrin would be effective at much lower dose rates than the other agents discussed. It does break down over time, but a method would be needed to de-nature it rapidly in the field.

### 5.7.5 Uses and Limitations

The tests show that there is potential for use of biocides in the field, using methods that are simple and low cost. All the methods are non-specific and would kill other invertebrates and fish. Chlorine, un-ionised ammonia and high pH also have the potential to damage aquatic plants. In all the methods considered the toxicant can be de-natured readily; the only exception is permethrin, which is effective at low concentrations, but has not been de-natured successfully in this trial.

As the methods will affect non-target organisms the uses will be very limited. In most cases a fish rescue will be required in advance. It is unlikely that any large-scale treatment of a watercourse would be acceptable. A wholly enclosed waterbody could be treated. A pond with a connection to a stream could be treated if it was temporarily isolated. It would not be worthwhile attempting any eradication on a pond with a connection to a stream, however, as there is a high risk that by the time the population in the pond was detected at least some crayfish would have escaped to the watercourse.

#### **5.7.6 Environmental impacts**

Severe impacts on non-target fauna means that few sites, if any+, will be suitable for treatment.

#### **5.7.7 Scope for development**

There is scope to develop a practicable field method for chemical eradication of alien crayfish, albeit in a limited set of conditions. Further work is required on the toxicology using laboratory trials, but there is already sufficient development of a potential method for a small-scale trial in the field. For any use of permethrins to be acceptable an effective method of de-naturing needs to be found.

There is also potential to combine the use of biocides with physical destruction of habitat. For example, on a wholly enclosed site it may be possible to carry out a series of operations, (repeated if necessary):

- treatment with biocides;
- partial/complete drainage;
- additional use of biocides;
- complete excavation of pond and banks to more than maximum depth of burrows, or infilling.

## 6. CONCLUSIONS

A brief view of the known distribution of signal crayfish (Figure 1.1) shows that there are populations in most river catchments and in a growing number of canals. There is no doubt that many more have already established in the wild, but are as yet undetected. Very poor water quality may act as a barrier in a few rivers, at least until they are improved under the national program of water quality improvement.

In some cases, very large weirs, waterfalls, locks, or limited habitat availability may also act as a temporary barrier. Nonetheless all the evidence points to the inexorable spread of signal crayfish upstream and downstream in every catchment into which they are introduced or escape. Typical detectable rates of spread are around 1 km per year in each direction. Even wholly enclosed ponds are only a temporary barrier to the movement of these exceedingly hardy animals, as the signal crayfish can walk over land and are increasingly likely to do so when the population reaches high density.

Signal crayfish are likely to spread to all parts of almost all river systems in England within the next few decades. No present method, including legislation and the cessation of issuing of permits for new farming locations, will prevent this. The spread into suitable watercourses in other areas of Wales and Scotland will also occur. Monitoring of this spread may reveal areas where the colonisation is incomplete. It is possible that this may then yield clues as to other potential control methods. Indications are that any habitat suitable for the white-clawed crayfish can be colonised by signal crayfish.

Only white-clawed crayfish in signal-free catchments or completely isolated populations have any long-term hope for survival. There is a constant risk of accidental or deliberate introduction of signals into these catchments. Potential pollution incidents, introduction of crayfish plague and other factors capable of eliminating crayfish populations means that the survival of white-clawed crayfish in these catchments is not guaranteed.

### 6.1 Potential for Eradication

It appears that there is no available method for eradicating, or even controlling the spread of signal crayfish populations, once they become established in watercourses. The best prospect for any eradication is the combined use of biocides and habitat destruction. These methods have high environmental impacts, as they are not specific to crayfish.

There are few circumstances in which an eradication using biocides is likely to be environmentally acceptable. The likely sites are small, wholly enclosed waterbodies from which crayfish have not yet escaped. It is also conceivable that on-line ponds or sections of watercourses could be treated, but the major problem is that the full extent of the colonising population will not be known. This will make it difficult to determine the area to be treated and would certainly necessitate severe impact on some areas which have not yet been colonised. The delay necessitated by the requirements for full environmental impact assessment could lead to a further increase in the area to be treated.

Despite limitations on the use of biocides, it is recommended that a field trial is carried out so that an effective method can be refined. Even if catchments contain only white-clawed crayfish, such as some of those in Cumbria, sooner or later there is a risk of finding a

population of signal crayfish within the catchment. If this occurs, only immediate and drastic action would have any hope of containing the signal crayfish. In this respect delay equals further loss of white-clawed crayfish populations.

## **6.2 Other Alien Species**

The signal crayfish has been the focus of this study as it is the most widespread alien crayfish species in Britain, is highly competitive, and can carry crayfish plague.

The noble crayfish has become established in at least one location, although there are no reports of colonisation. Similar in size to the signal crayfish, it also has potential to out-compete white-clawed crayfish if they occur together, however it cannot outcompete the more aggressive signal crayfish. (Holdich and Domaniewski, 1995).

The prior spread of signal crayfish throughout Britain makes extensive colonisation by noble or narrow-clawed crayfish less likely. Both are susceptible to crayfish plague.

The red swamp crayfish *Procambarus clarkii* is of potentially greater concern. It burrows extensively and can carry crayfish plague. This species is already very widely distributed in many areas of Europe. Although tending to occur in warmer water, it is possible it could survive and spread. It is likely to have similar river system impacts to signal crayfish. Given the threats already facing white-clawed crayfish, this species is likely to pose a substantial additional threat. All the same problems of affecting a control would apply to the red swamp crayfish. Again, rapid action with a biocide is the most feasible way of preventing the spread of this species when and if it appears in Britain.

## **6.3 The Spread of Crayfish Plague**

Continuous vigilance will be required to keep any catchment free of signal crayfish and crayfish plague.

Following the outbreak of crayfish plague on the River Ribble in 2000, the Environment Agency and English Nature quickly informed all the angling clubs on the Ribble of the need for measures to prevent transfer of plague. At least one angling club also fishes part of the River Eden, a SSSI and candidate SAC with an important population of white-clawed crayfish. Active cooperation was obtained from the clubs to avoid or at least reduce the risks of losing another population of white-clawed crayfish to crayfish plague.

## **6.4 Refuges for Native Crayfish**

If the white-clawed crayfish is to survive in Britain, conservation effort should be focused on the protection of signal-free catchments and the establishment of refuges for the native species. Refuges for white-clawed crayfish could be created in isolated areas, e.g. tributaries of heavily polluted rivers, or in some reservoirs, or quarries. Stillwaters with historical records of native crayfish, where the cause of extinction is known, could be restocked with white-clawed crayfish from threatened populations. Some stillwaters that are presently too acidic for crayfish could be treated with limestone and stocked. In this way a network of known and protected sites could be developed. Most are likely to be small enough that, should alien invasion occur, biocides or similar radical methods could be used to eliminate it, followed by restocking with native crayfish.

## **6.5 The Spread of Crayfish Plague Fungus**

It appears that not all signal crayfish populations are infected with crayfish plague, and the issue of its spread is not strictly relevant to the Eradication Project. It has been noted by Alasdair Scott, CEFAS (10<sup>th</sup> March 2000) that: ‘Crayfish plague spores can remain infective for 6-8 weeks’. This has implications for the proposal to hold fish in pathogen-free water for a period prior to stocking of lakes or rivers. The most effective method of spore removal from fish is to use malachite green, which cannot be used on food fish. Alternative treatments using agents which increase mucus production may result in a rapid clearance of any external spore burden on the fish. The severe outbreak of crayfish plague in the River Ribble is thought to have been caused by transfer of spores on stocked trout, or possibly on angling gear. Many anglers fish several rivers, which increases the risk of transfer of the disease to the few catchments that still contain white-clawed crayfish exclusively.

Crayfish plague is not a notable disease for fisheries, so controls are not in place to limit the stocking of fish farm farms with signal crayfish in catchments containing white-clawed crayfish populations. Continuous vigilance will be required to keep any catchment free of signal plague.

Following the outbreak of crayfish plague on the River Ribble in 2000 the Environment Agency and English Nature quickly informed all the angling clubs on the Ribble of the need for measures to prevent transfer of plague. At least one club also fishes part of the River Eden, a SSSI and candidate SAC with an important population of white-clawed crayfish. Active cooperation was obtained from the clubs to avoid or at least reduce the risk of losing another population to crayfish plagues.

## **6.6 Summary of Conclusions**

In summary, the findings of this R & D Project are:

- Eradication or control of a signal crayfish population is only likely to be achieved using chemical control (biocides).
- Survey methods for population estimation of all species of crayfish are imprecise, and require substantial development. No survey method is capable of demonstrating the absence of a viable population of native or signal crayfish.
- The concept of Minimum Viable Population Density, MVPD, shows that anything less than 100 % kill of the total population will lead to a requirement for massive effort, frequently and in perpetuity.
- Further eradication attempts using any of the methodologies trialed in the field so far will be unsuccessful.
- Wherever signal crayfish are currently found, there is no method of preventing their spread to all parts of that river/ stillwater system.
- Monitoring the spread of signal crayfish is not necessary, as they will spread throughout a watercourse no matter what actions (other than use of biocides) are taken. Monitoring

may be useful however, for detecting any signs of natural limitations on the colonisation ability of signal crayfish. Further studies may improve current estimates on the rate at which populations of white-clawed crayfish become extinct during colonisation by signal crayfish.

- Conservation effort should now focus on the prevention of further introductions, or prevention of transfer of plague and the creation of safe refuges for native crayfish.
- Current legislation is not sufficient to safeguard the future of the white-clawed crayfish in Britain, as the present distribution of the species fails to take into account the inevitable replacement of current populations by invading signal crayfish in the 87 % of catchments in which they currently occur.

## **6.7 Recommendations**

- No further research into manual removal methods is recommended. Manual removal is not effective at any level of effort attempted to date.
- Field investigations of chemical control (biocides) should be conducted, should this method be deemed acceptable.
- A strategy for native crayfish refuges should be initiated, accepting the ultimate spread of signal and other alien species.
- Monitoring methods should be further developed so that they are capable of detecting crayfish at a much lower population density.
- There may be role for the use of chemical attractants (pheromones) in improving monitoring sensitivity. Such methods are very unlikely to be sufficiently effective to provide any control of populations during the autumn breeding season. If such pheromones can be isolated and produced for use, they may allow the detection of low densities of adult white-clawed crayfish or aliens. Further research would be required.
- Investigations to estimate the minimum viable population densities of both signal and native crayfish would be useful for the future of eradication and restocking exercises.
- Further work on the use of barriers is recommended, notably on the catchpit design. A student project on the climbing ability of signal crayfish and the maximum distance for overland travel might help to identify appropriate conditions for establishment of 'signal-free' refuges.



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## **TECHNICAL APPENDICES**

These comprise the reports of the various studies that formed part of the R&D Project (Appendices 1-5), projects in the original series of projects where work did not proceed further for various reasons from the study (Appendix 6), plus other studies contributing to the conclusions of the project (Appendix 7). Appendix 8 reports the findings of laboratory trials into the potential of chemical control. All relevant information provided by the end of November 2000 has been used or referred to.

### **APPENDIX 1 WEST TANFIELD, RIVER URE, NORTH YORKSHIRE**

Signal crayfish were introduced to a 3 ha fishing lake a few hundred metres from the River Ure. The population built up in the lake and is harvested annually for a few weeks in late summer. Nonetheless, signal crayfish spread, via an outfall and long drainage pipe, to an open section of stream within a fish farm. From there they escaped to the adjacent River Ure, a large upland river with a strong population of white-clawed crayfish. Signal crayfish were recorded in a few 10's of metres in the River Ure in 1997 (David Rogers Associates).

The site was visited in April 1999 by staff from the Environment Agency and the project co-ordinator from Scott Wilson. The landowner and the tenant fish farm operator agreed to allow the EA access to remove crayfish from the stream within the fish farm and gave agreement in principle to installing measures to prevent signal crayfish from getting from the lake into the fish farm.

The fish farm operator was concerned about any procedure, which may cause a blockage in the system. The water supply to the farm was originally obtained from de-watering operations in the sand and gravel working which now forms the lake. Although still groundwater fed, water temperature and oxygenation are concerns at the fish farm, which has no power supply.

The fish farm stream is about 25 m long and links the upper part of the fish farm, where there is a narrow concrete tank, to the main concrete-lined ponds. From the lower ponds there is a cascade outfall down approximately 3 m into the River Ure. The fish farm stream is less than 0.5 m wide and only 10 cm deep. The channel substrate is sand with only a few cobbles and boulders on the bed, mostly along the margins where they have been placed to minimise erosion. The banksides are short grassland, with one overhanging tree. The fish farm lies within an area of wet woodland and is seasonally waterlogged. On closer inspection, the banks of the stream were found to be slightly undercut below water level. The grass and soil could be dragged back as a wad of turf, exposing cobbles and pebbles. Signal crayfish have burrowed into these areas.

## **A1.1 Objectives**

### **Original Study Objectives**

- to prevent the escape of signal crayfish from West Tanfield fishery lake by mechanical methods;
- to eradicate signal crayfish from West Tanfield fish farm stream and pond by mechanical methods, and
- to eradicate signal crayfish in the River Ure by mechanical methods.

### **R & D Project Objectives**

- to develop crayfish-proof outfalls to aid containment;
- to use artificial refuges as foci from removal and for monitoring, and
- to investigate the potential for eradication in a large, upland river with a mixed population of native and non-native crayfish.

## **A1.2 Results of Manual Removal from the Stream**

For spring and part of the summer, artificial foci were used on the sandy bed of the stream. These consisted of clay drainage pipes and roof tiles. Although crayfish were easier to remove from the refuges, many more were resident in the cobble and gravel of the banks.

Table A1.1, provided by Sue Pacey, (EA Dales Area), shows the results of the removal exercise. Despite the small size of the stream and intensive effort, there was no sign of any depletion in the first five sessions. Numbers increased markedly in August in the sixth session, as juveniles reached a size large enough to catch. A fish kill due to conditions of low oxygen during July. Because the fish farm was left un-stocked for a period, it allowed the stream to be piped into the ponds during the August session. This left the stream bed nearly dry and crayfish easier to remove. A total of 1304 crayfish were removed from approximately 12 m<sup>2</sup>. This is likely to be due to a combination of a high-density population and continued immigration from the lake.

In a site visit in September 1999, the EA found some adult crayfish in the fish farm tanks at the upper end of the stream. Survey was suspended in the stream because the fishery operator had lined the margins of channel with corrugated iron. This was intended to reduce the quantity of silt entering the fishpond. It is unlikely to reduce silt to any degree, but provided additional refuges for signal crayfish within the fish farm.

There is evidence that at least some of the signal crayfish move out to forage in the damp woodland at night. The trout farm operator reported seeing crayfish along the banks of the stream and the paths before the start of the crayfish removal.

**Table A1.1 Results of Removal from Fish Farm Stream, West Tanfield**

source: Environment Agency, Northumbria and Yorkshire Region, Sue Pacey, 1999

	29.4.99	12.5.99	21.5.99	27.5.99	3.6.99	5.8.99
Time hours	Initial visit	3.5 x 2	3.25 x 2	3.25 x 2	3.5 x 2	3.25 x 2
males	15	70	81	49	55	116
females	27	90	98	58	67	115
juveniles	0	0	0	25	40	398
berried	0	6	7	1	1	0
Total	42	160	179	132	162	629

Searched 25 m stream, total length, width c. 0.5 m

### A1.3 Results of Manual Removal from the River Ure

From the initial visit, it appeared that signal crayfish were still relatively restricted in distribution, within about 60 m of the outfall, although only low numbers were caught. The channel is more than 30 m wide and too deep for manual searching in mid channel and also in parts of the margins. The part of the right bank margin accessible for survey is restricted to a few metres in width into the channel.

The bed is covered with large boulders, many of which are too large to move, but may have crevices and overhangs which can be used by crayfish. There are overhanging trees along the near vertical bank, including areas that are a deeply undercut tangle of large roots, boulders and earth bank. This area is also inaccessible for manual searching. The river is often naturally coloured by humic acid from the upper catchment, which means the water may be very clear, but the brown colour makes daytime viewing difficult.

Detecting crayfish populations at low density is difficult in any river. The EA staff have found that even concentrating effort in the 30 m section known to be the centre of population can give very few catches, as there is so much stone to search. Table A1.2 shows the results of the removal exercise in the River Ure. The largest catches are related in part to days with lower flow, which make conditions easier for searching and more of the bed accessible for working.

Overall, it is likely that at least some of the channel occupied by signal crayfish has not been accessible for manual searching. The catch is highly unlikely to represent the entire population, as juveniles are likely to have been under-represented in August.

The downstream limits of the signal population are not certain, but there are indications that signal crayfish have already started to spread out from their source. The EA has had a report of a signal crayfish several miles downstream of the site at West Tanfield, at Sleningford Mill.

**Table A1.2 Results of Crayfish Removal from River Ure**

source: Environment Agency, Northumbria and Yorkshire Region, Sue Pacey, 1999

	29.4.99	3.6.99	18.6.99	15.7.99	5.8.99
Time (hours)	1 x 3	1.25x 2	2x 2	3x 2	3x 2
males	9	0	1	20	16
females	5	0	3	24	32
juveniles	0	0	0	0	9
berried	1	0	0	0	0
Total	14	0	4	44	57

Searched up to 100 m section and up to a few metres from bank

Concern by English Nature about the impact of signal crayfish population on the sections of the River Ure which are within a SSSI led to a separate study being commissioned to consider the potential cost of an eradication programme of sufficiently large scale to achieve eradication (David Rogers Associates). This was followed by a pilot trial of trapping in summer 2000. As this yielded fewer than seventy crayfish in six weeks, most of which were found in supplemental manual searching, trapping was abandoned as a method.

#### **A1.4 Design of Crayfish Resistant Outfall**

In order to prevent further escape of crayfish from the lake, Scott Wilson staff proposed a series of measures intended to contain the population. Unfortunately, there is insufficient space to install any catchpit system on the existing outfall from the ponds to the river. In addition, there is evidence that foraging signal crayfish are leaving the stream and can already bypass the fish farm ponds and access the river.

The recommendations were to:

- Install a vertically mounted bell-mouth to the outlet pipe from the lake. The outlet originally consisted of an open pipe, which was supported on a low wooden trestle from deep water to the margins.
- Seal the pipe system. This previously contained a shallow boarded enclosure in the margins of the lake, which was readily accessible to crayfish. A pipe led from this into the outfall system.
- Construct a new catchpit in the field between the lake and the fish farm. Install a vertical bellmouth outlet and provide refuge areas that could be pulled out and checked regularly for crayfish.
- Install refuge traps in the old catchpit to check on effectiveness of the system.

Signal crayfish may get into the new catchpit but if the system works, none will be found in the original downstream catchpit.

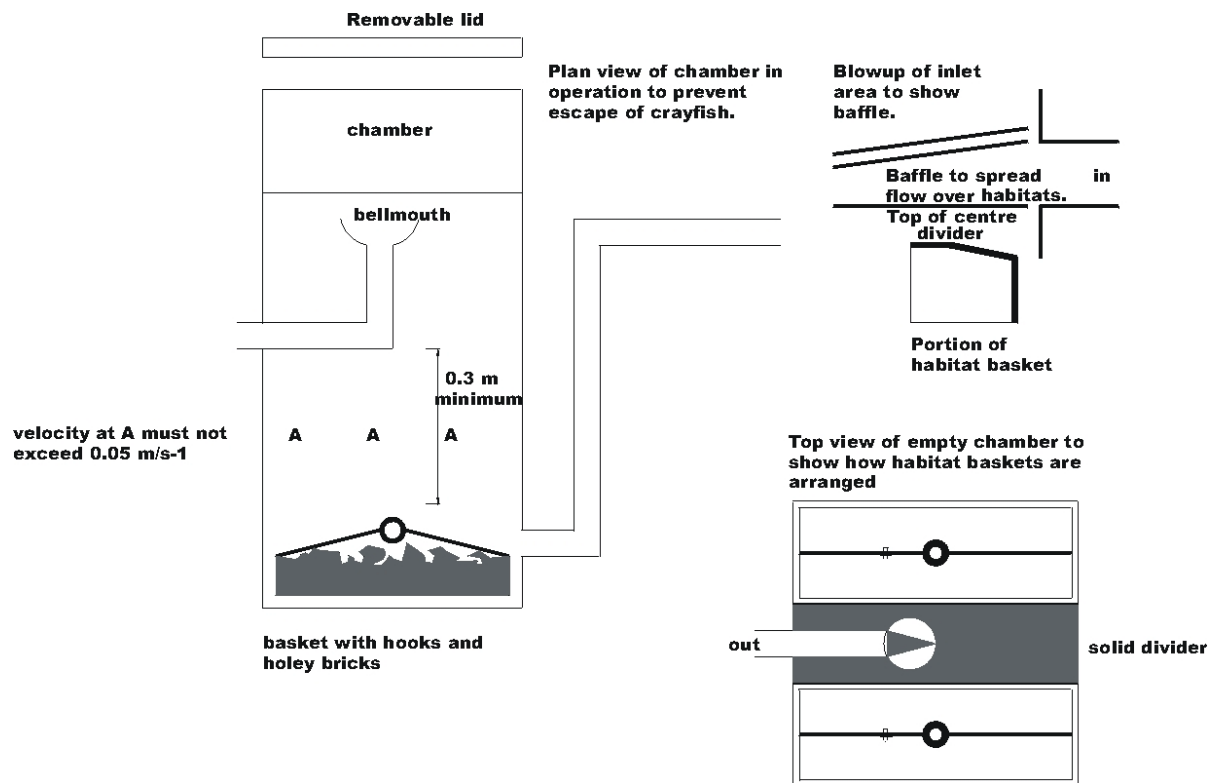
#### **Design of Crayfish Interceptor Chamber**

The catchpit aims to prevent colonisation of downstream watercourses by signal crayfish by preventing passage through the chamber by swimming, crawling, or passive carriage.

The chamber was designed to include the following features:

- Upward velocity below  $0.05 \text{ ms}^{-1}$ , which is less than the empirical estimates of passive falling velocity of a juvenile signal crayfish (Attachment 2).
- Minimum height of chamber between top of habitat and base of bellmouth to be 30 cm to reduce the chances of an escape-swimming crayfish going through the bellmouth.
- Bellmouth rises from a sidearm so that crayfish cannot crawl out from the sides, up and over into the outflow pipe.
- Chamber sides to be smooth glass-like material to prevent climbing and consequent access to bellmouth e.g. fibreglass with a smooth finish.
- Chamber sides to be cleanable and kept clean of attaching growths
- Chamber to be dark to minimise filamentous algae growth on the sides.
- Habitat on the base to minimise aggression and consequent escape swimming activity, in the form of 2 mm mesh trays filled with suitable media, (a selection of plastic or mineral media of different sizes).
- Habitat to be emptied frequently, to prevent more than 20 animals per  $\text{m}^2$  accumulating

Chamber size was dependent on knowledge of the maximum flow or discharge through the inflow pipe. The design is shown in figure A1.1.



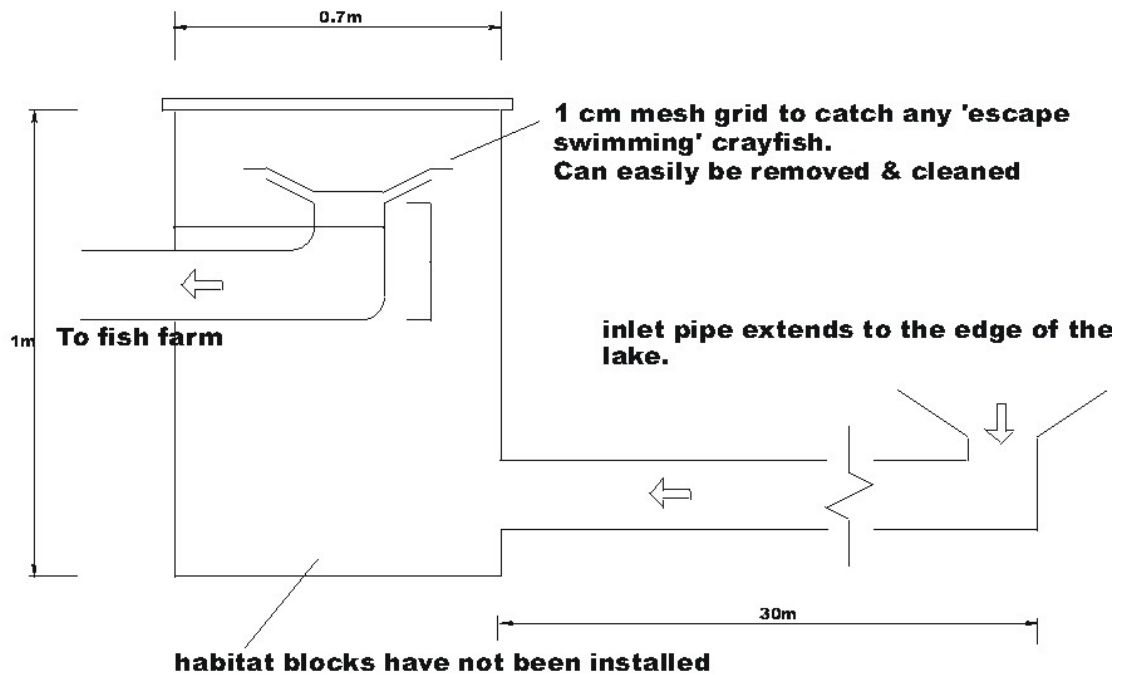
This design was produced Scott Wilson Resource Consultants in September/October 1999.

### Figure A1.1 Design of Crayfish Interceptor Chamber

The catch-pit system was installed in May 2000, the cost being grant-aided by the EA with the landowner paying for installation. The work was carried out by a local agricultural drainage contractor. The completed catchpit, as installed, is approximately 1 m deep and 0.7 m across. It exhibits some deviation from the original design. The catchpit as built, is shown in Figure A1.2. Detailed dimensions had not been provided by the contractor by autumn 2000. These main points of deviation are indicated below:

- The inlet bellmouth is currently at the edge of the lake rather than in deeper water. However the inlet pipe is to be extended out into the lake by the lake owner, with a sealed pipe running through to the catchpit.
- Habitat blocks have not been used in the catchpit chamber, as they were considered to be too labour intensive to remove and check. With an empty chamber, crayfish removal can be accomplished quickly and easily using pond net sweeps.
- To minimise the chances of escape-swimming crayfish gaining access to the outlet pipe bellmouth, the risk of which is increased by the lack of habitat, a 1 cm mesh grid has been fitted over this bellmouth to catch escapees. The outlet may block, if any debris comes into the chamber, but the grid is easily accessible for cleaning. The mesh would block larger crayfish, though juveniles could pass through it.





**Figure A1.2. Catchpit as built**

Monitoring of the new catchpit and the original chamber downstream were carried out by the EA during 2000. Detailed results have not been produced as yet, but limited findings are outlined here. At first, several large crayfish were caught in the observation chamber, but as these had been seen within the pipework it is likely they were resident. The numbers declined, suggesting that crayfish were no longer able to travel from the lake. Signal crayfish may still be able to enter the new catchpit from the lake, until the bellmouth inlet is repositioned.

## **A 1.5 Summary**

With respect to the case study objectives, trapping and manual removal have failed to eradicate signal crayfish from West Tanfield fish farm stream and pond, despite intensive efforts in the stream. This project has clearly illustrated the difficulties of trying to eradicate crayfish from even a very small watercourse. It has also failed to eradicate crayfish from the River Ure, and it appears to be too late to try to control the spread of signal populations in this river. A potentially crayfish-proof outlet has been designed and installed (Section A1.4), but no results from this work are available as yet. If the catchpit design is successful, this could be of benefit in tackling crayfish farms where the signal crayfish have not yet escaped.

The R & D Project objectives for this project have been met in part. Although it has not been possible to use artificial refuges as foci for removal and monitoring, it is hoped that the crayfish-proof outfall will prove to be effective. Findings from this study indicate that eradication of signal crayfish by mechanical methods in a big upland river with a mixed population is not possible with any current technique. Based on the rates of colonisation of the River Wharfe, which is similar to the River Ure (Peay, 1997), there is likely to be continued expansion of the signal crayfish population and loss of the native species of crayfish.

## **Acknowledgements**

This project was coordinated by Sue Pacey, Environment Agency, North-East Region.

## APPENDIX 2 REEPHAM FISHERY, RIVER WENSUM

This site consists of a spring-fed fishing lake and some adjacent small ponds. The fishing lake drains into Reepham Stream and from this to the River Wensum. The latter watercourse is a SSSI and has a scattered population of white-clawed crayfish in the headwaters (Rogers and Holdich, 1997).

### A2.1 Objectives

#### Original Study Objectives

- To eradicate signal crayfish from Reepham Carp Fishery by mechanical and biological means (originally).

#### R & D Project Objectives

- contribute to understanding of population dynamics in lakes
- trial new trap with potentially greater value for capturing juveniles and small adults

### A2.2 Results

An intensive trapping session was carried out in autumn 1997. It consisted of three trapping periods, each of three nights, using 100 traps, equivalent to 900 trap-nights. Swedish 'Trappy' traps were set at 2-3 m intervals around the margin of the lake. A subsequent intensive trapping session in October 1998 used the same methodology. In winter 1998/99, Steve Lane of the Environment Agency in Anglian Region designed a trap of similar size to the Trappy, but using finer mesh (8 mm). Traps were made to very high standards using cut sections of drainage pipe to reinforce and support the fine mesh. Intensive three-night trapping studies were carried out in March and April 1999. These studies used 50 Trappies, and 50 of the smaller mesh traps, and aimed to compare trapping efficiency of the two types. Figure A2.1 depicts the carapace length/ frequency analysis of the two traps.

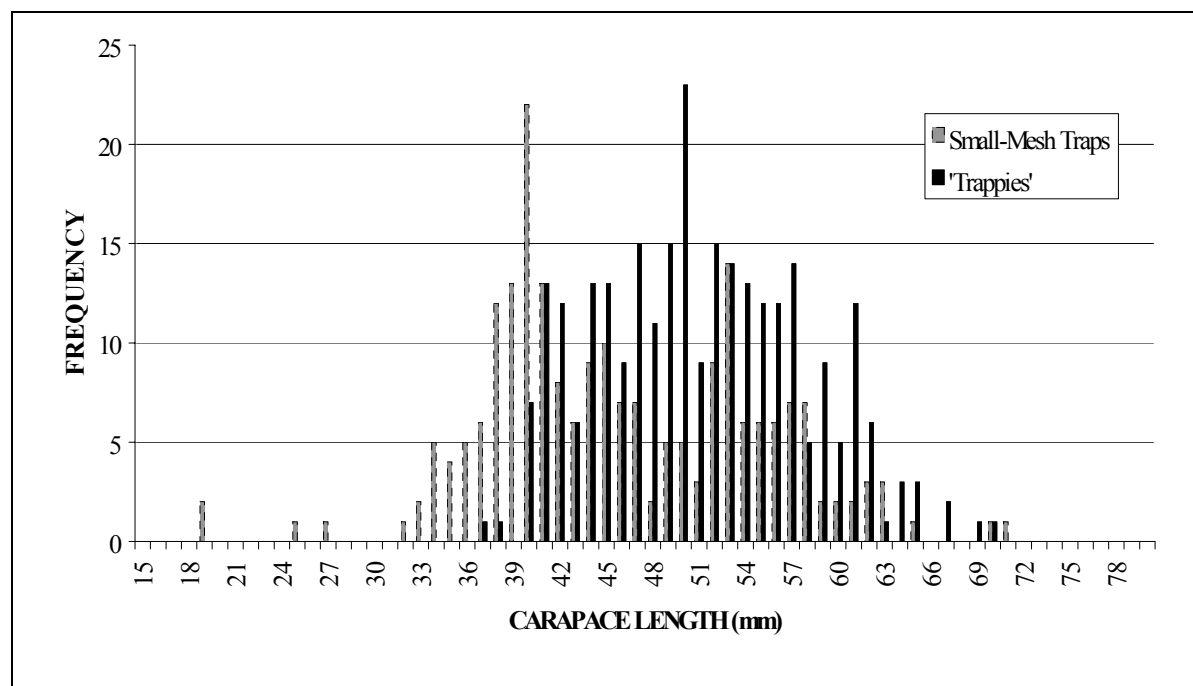


Figure A2.1. Length/ frequency analysis of signal crayfish trapped in Reepham Fishery.

The fine mesh traps proved to be more effective than Trappies at capturing smaller crayfish. The modal size of crayfish caught by Trappies was 50 mm CL compared to 40 mm CL for the fine-meshed traps. With the exception of a few individuals, the Trappies caught mainly individuals of about 40 mm carapace or more. Fine-mesh traps caught a higher proportion of smaller sizes, with an overall range of 19 mm to more than 60 mm CL. The fine-mesh traps were more effective than Trappies for crayfish 30-40 mm CL, but still showed a marked reduction in trapping efficiency in this size range.

It was intended to carry out a survey and removal exercise from the stream below Reepham Fishery and in the River Wensum nearby in spring or summer 1999, using manual searching, artificial refuges and night survey. Other commitments of the EA fisheries team prevented this work being carried out.

The EA intended to carry out a survey and removal exercise downstream of the Reepham Lake, but high flows prevented any action before the end of 2000. There has been at least one report by an angler of signal crayfish in the River Wensum (Steven Lane pers. comm.). The survey by David Rogers and David Holdich in 1997 confirmed the presence of signal crayfish at a site 13 km upstream of the Reepham Stream confluence at Swanton, Morley, which was thought to be the result of a separate introduction or escape.

Indications are that the intensive trapping regime is not controlling this population. As signal crayfish have now been reported in the River Wensum, extinction of the white-clawed crayfish population in this watercourse is inevitable.

### **Acknowledgements**

This project was coordinated by Steven Lane and Robin Burrows, Environment Agency Anglian Region.

### **References:**

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## **APPENDIX 3 DURFORD BRIDGE, RIVER ROTHER**

In 1997 the upper Rother in Hampshire/West Sussex was found to contain a population of white-clawed crayfish extending over at least 3-4 km in the headwaters. The population was discovered during a survey by Adrian Hutchings's team at Sparsholt College, commissioned by the EA, Southern Region. The downstream limit of the white-clawed crayfish population appeared to be above Durford Bridge, just beyond the West Sussex border. There is a population of signal crayfish in the lower Rother, which is reported to have originated in the 1970's (Mark Elliott, EA Southern Region) and has certainly been present in the lower Rother since before 1990. The extent of the signal population is not known, but is thought to extend for many kilometres of the lower Rother, probably throughout most of the lower river.

### **A3.1 Objectives**

#### **Original Study Objectives**

- To prevent the upstream spread of signal crayfish.

#### **R & D Project Objectives**

- To investigate the role of physical barriers in limiting the spread of signal crayfish.

Two small weirs between the populations were thought to be providing at least a temporary barrier between the two populations. In 1997, trapping surveys showed that the signal population had spread upstream of the downstream weir, a structure about 0.3 m high. At that time there were no signal crayfish detected in surveys upstream of the upper weir, a higher structure up to 1m high.

The signal crayfish population does not appear to be carrying, or at least not expressing crayfish plague. EA biologists kept a signal crayfish and white-clawed crayfish in a tank for several weeks, with no sign of any on-set of plague in the white-clawed crayfish.

Most of the native population is in an area of shallow, stony stream, which is feasible for manual searching. Unfortunately, the section between the two weirs is deep, silty and largely unsuitable for manual searching.

### **A3.2 Results**

The project team considered a very intensive and sustained programme of trapping in an attempt to keep the signal population low enough to slow the rate of spread in the short term.

In practice, signal crayfish were detected upstream of the upper weir by 1999. Any barrier effect of the weir was only temporary.

As there is now an established mixed population of signal and white-clawed crayfish no intensive removal was attempted.

In the medium term, there is likely to be a build up of the signal population downstream, which will increase the pressure for colonisation downstream and upstream.

Bearing in mind current estimates from the Wharfe (Section 1.2.5), that white-clawed populations can be lost within 4-5 years of arrival of an apparently plague-free population of signal crayfish, (Peay & Rogers, 1999), there is little hope of long term survival for this last remaining river population of white-clawed crayfish in West Sussex. Translocation of the population to a 'safe' refuge site is likely to be the only way of ensuring its survival.

### **Acknowledgments**

This project was coordinated by Mark Elliot, Environment Agency, Southern Region and Adrian Hutchings, Sparsholt College.

## **APPENDIX 4: GUNTHORPE BRIDGE, RIVER GWASH**

Signal crayfish were introduced into the River Gwash in 1987 upstream of Gunthorpe Farm Bridge. By 1997 the population was estimated to extend 500 m upstream and 700 m downstream of the bridge. Areas of stream at the upstream and downstream limits were heavily poached by livestock, leading to very silty conditions, considered to be less favourable for crayfish. The watercourse between has areas of very favourable habitat, with stones, emergent vegetation, overhanging trees, undercut banks and small pools. Some sections of the bed are shallow with gravel, pebble and cobble substrate. The deeper pools have a silty clay substrate.

### **A4.1 Objectives**

#### **Original Study Objectives**

- to eradicate signal crayfish by mechanical and biological methods.

#### **R & D Project Objectives**

- to develop better understanding of crayfish population density and habitat;
- to develop techniques for manual eradication, and
- to contribute to development of monitoring protocol.

### **A4.2 Methodology**

#### **Mechanical Removal**

A programme of intensive manual removal was carried out in May-June 1998<sup>1</sup>, October-November 1998<sup>2</sup>, May-July 1999<sup>3</sup>, October-November 1999<sup>4</sup> and May-June 2000<sup>5</sup>. Exercises one, three, four and five consisted of 100 man-days work, carried out by a team from The Rutland Water Conservation Volunteers, led by Ron Follows and Kate Smithers. Exercise two consisted of 60 man-days work.

Survey methodology involved stone turning and capture of exposed crayfish in areas of clear water. Where high levels of suspended solids rendered this method ineffective, a modified form of kick sampling was used. This involved drag netting, with a line of large hand nets each staggered a foot behind the next. The nets were overlapping to maximize the catch. Teams of four or five people worked upstream within a 25 m section, and some sections were trawled many times in succession until no more crayfish were caught. Overhanging banks were searched by pushing a net under the overhang and dragging up the bank and along the roof of the overhang. During exercises four and five bigger teams were used to give the same number of man-days work over a shorter time period.

The study reach of 1350 m is divided into numbered subsections of 25 m length. It was thought to extend beyond the limits of the signal crayfish population, which has spread upstream and downstream from the point of introduction at Gunthorpe Bridge. Sub-sections are referenced according to distance from the bridge. The watercourse is about 4 m wide, hence the subsections average about 100 m<sup>2</sup>. Subsections were marked with coded wooden

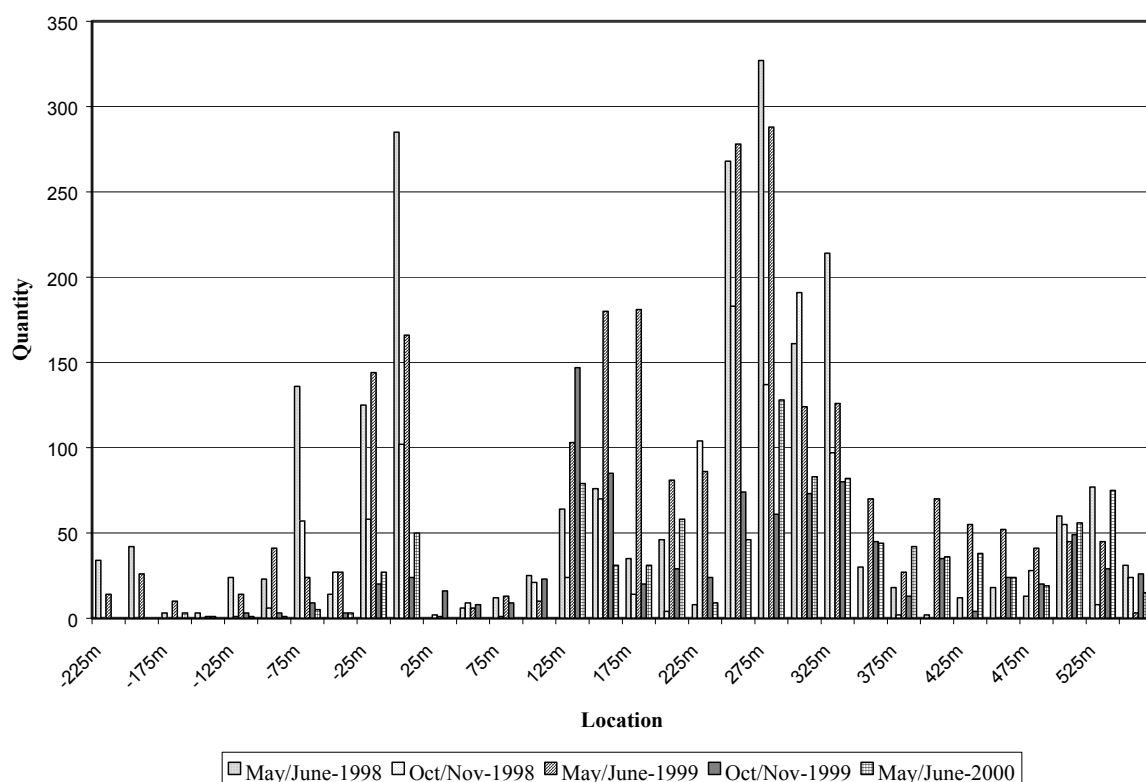
marker posts at 25 m intervals along the whole survey reach. Catches for each 25 m subsection were recorded separately.

### Biological Control

It was proposed to stock the reach of the Gwash very heavily with chub and eels in order to increase the predation pressure on the signal crayfish, especially juveniles. Initially this had been programmed for summer 1999. It was recommended, however, that fish were not introduced because any effects would not be determined separately from those of the on-going sessions of manual removal.

### A4.3 Results

Results from all five surveys show enormous variation in numbers of crayfish captured in different subsections (Section 4.1). The sections with the highest counts of crayfish are those with the most favourable areas of crayfish habitat, which can be limited to particular portions of a sub-section. Four sections from U250 up to U350 consistently showed the highest counts, typically 100 to 300 crayfish captured per survey. Another “hotspot” was found in the two sections immediately upstream and downstream of the bridge, where there are moderately deep pools and lots of boulders. By contrast, in the latest survey, 33 sections had 10 or fewer crayfish captured. Table A4.1 shows crayfish distribution by section over the five exercises.



**Figure A4.1 Crayfish distribution by section in exercises 1-5.**

Catches in the three sections furthest upstream were 60 (U500-U525), 77 (U525-U550) and 31 (U550-U575), during the first survey. The totals in the third survey were 45, 45 and 3 in the same sections respectively. However, this reduction in captures was not maintained, with totals from the fifth survey for the same sections being 56, 75 and 15. At the downstream



end, numbers in the lowest three sections (D700-725, D725-D750, D&50-775) were 3,0 and 0 in the first session, in 1998; all 0 in the second and 16, 2 and 13 in the third session in 1999. During the fourth and fifth sessions, numbers caught in these sections returned to zero. However, given that signal crayfish can migrate downstream at a rate of 1 km per year (Peay and Rogers, 1999), it is highly probable that this population has already colonised Rutland Water.

The number of crayfish caught during each capture period is shown in Table A4.1. It can be seen from this Table that the first three sets of results were 2227, 1227 and 2550 animals, indicating that no depletion was apparent. The lower capture obtained during the second session is a reflection of the time of year surveying occurred (October/November in Session 2 and May/June in Sessions 1 and 3) and the lower number of man-days effort put into this exercise (60). When adjusted for catch per unit effort, the three sessions caught 22.3, 20.1 and 25.5 crayfish per man-day's work.

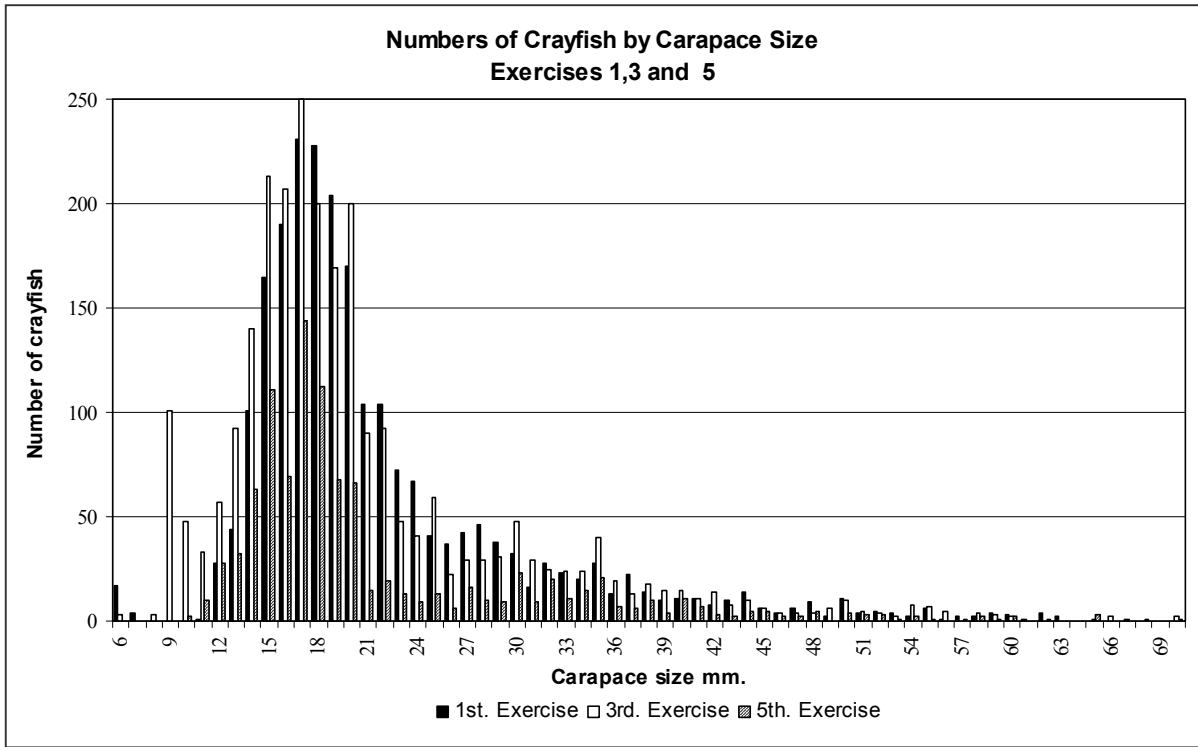
**Table A4.1 Total crayfish captures in relation to hours worked**

Session Number	Capture Period	Total no. of crayfish captured	Total man-days work	Catch per manday
1	May-June 1998	2227	100	22.3
2	Oct-Nov 1999	1227	60	20.5
3	May-June 1999	2550	100	25.5
4	Sept-Oct 1999	965	100	9.65
5	May-June 2000	1009	100	10.1

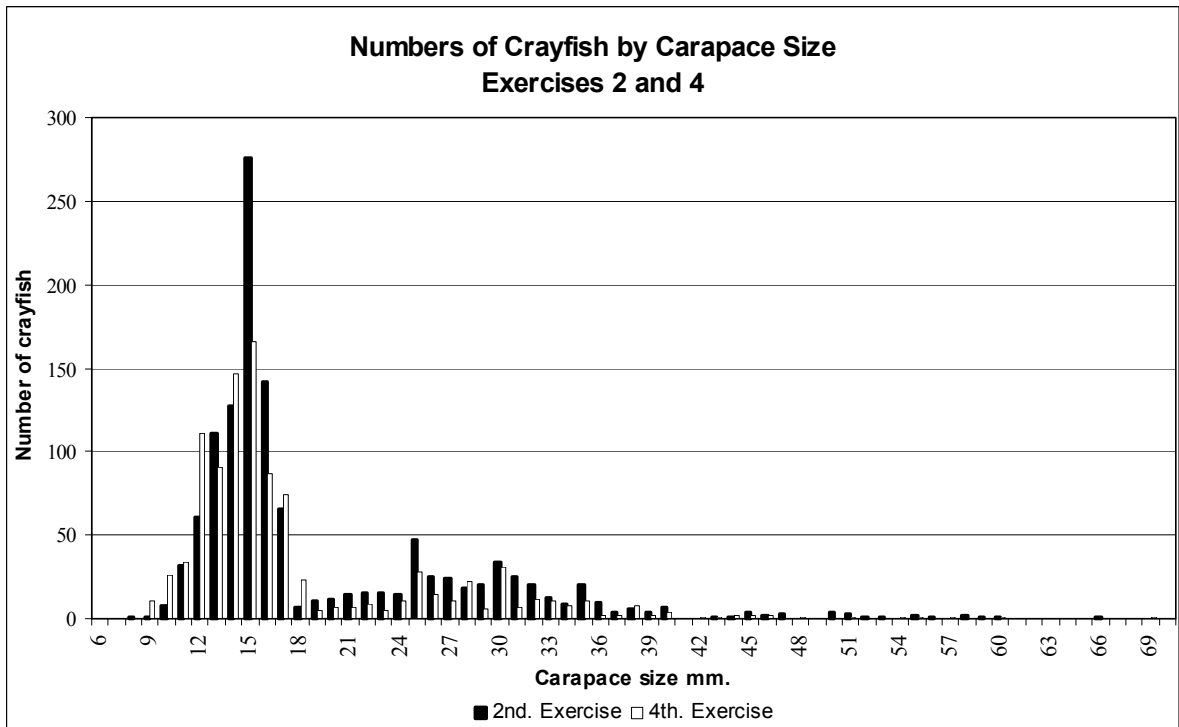
A reduction of over 50 % was achieved in the number of crayfish caught during exercises four and five, when compared to previous results (1008 and 1009 respectively). However it should not be inferred from this data that a reduction in population size caused by the capture scheme is necessarily responsible for these results. Other possible reasons for the observed decrease in number of crayfish captured include:

- The change in survey methodology during exercises four and five (Section A4.2) and;
- Possible inexperience of additional surveyors used during exercises four and five, Or alternatively,
- Population decrease due to unrelated causes e.g. flooding, pollution incident.

There was no reduction in the modal size of crayfish captured during the study period, with spring exercises one, three and five giving a modal size of 17 mm (Figure A4.2), and autumn surveys two and four giving a modal size of 15 mm (Figure A4.3). This difference may be due to the effects of juveniles joining the population in summer. Size ranged from juveniles as small as 6 mm carapace length (CL) to a couple of crayfish in the third survey with 70 mm CL.

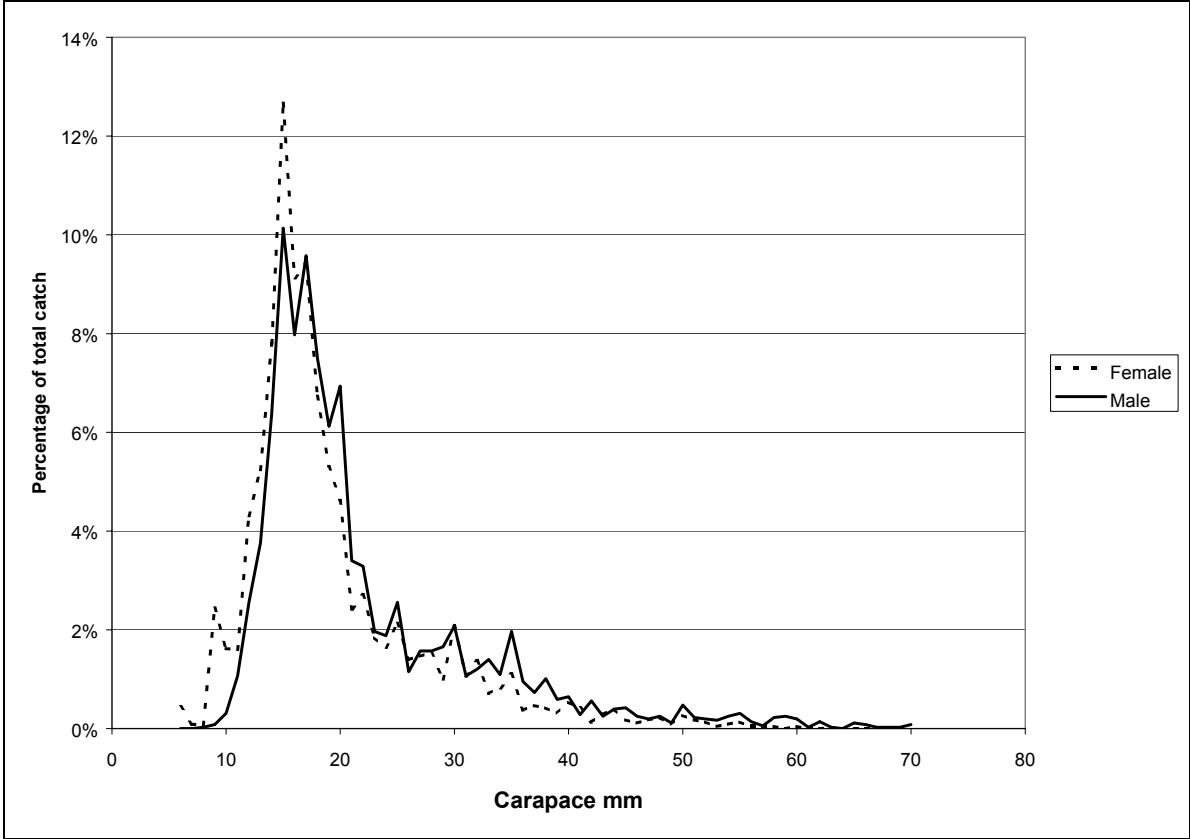


**Figure A4.2** Numbers of crayfish by carapace length caught during spring capture sessions



**Figure A4.3** Numbers of crayfish by carapace length caught during autumn capture sessions

As discussed in the main text, in all capture sessions the juvenile size classes predominate, with only 22 % of the total crayfish caught achieving a carapace length of 25 mm or more (Section 4.1, Figure 4.3). The age and size at which signal crayfish reach sexual maturity varies. Breeding can occur in crayfish as small as 25 mm CL, although 30 mm is more common. Only 15 % were of 30 mm CL or over (Figure A4.4).



**Figure A4.4 Percentage of total catch by carapace length**

**A4.3 Night Viewing**

Scott Wilson’s project co-ordinator, joined by a small group of EA staff and Rutland Water Conservation Volunteers, carried out a night viewing survey in part of the project reach, prior to the start of the removal period. Marking methods were demonstrated. Survey results are given in Table A4.2. Night viewing is simply a monitoring tool and like trapping is not an appropriate method for any eradication programme.

The removal programme was 100 man-days over 54 sub-sections, an average of about 2 man days per 25 m section but with greater effort spent on sections with high density of crayfish. The large numbers of burrows means that the crayfish probably spend more time sitting in the burrow entrances at night than wandering about on the bed of the channel.

The night survey was carried out on May 4<sup>th</sup> 1999 from approximately 22:40-02:15. This includes time spent extracting crayfish from burrows and in discussion on methods. The survey involved 5 surveyors surveying 2-3 abreast depending on the width of the channel. Flow rates were moderate to low and falling. Deeper sections were not suitable for viewing as the clay substrate impaired visibility.

There were a number of small crayfish, less than 25 mm CL active on the bed, just under half those recorded. This is a much lower proportion of juvenile than in the manual removal exercise which followed. Night surveys in other watercourses, e.g. Wharfe and Meanwood Beck (Peay and Hiley, pers. comm.), have also observed predominately adult activity, even when high proportions of juveniles are known to be present in the population.

Occupation of burrows in the soft clay banks could often be confirmed by the presence of a claw or antennae protruding from the burrow. Night viewing also demonstrated that superficially unsuitable areas could include hidden refuges. A section immediately above a low weir where the bed had been surfaced with concrete to create a flat and uniform surface with no refuges was found to have become eroded along the margins, creating crevices. These had been exploited by the crayfish, which had burrowed beneath the concrete to create inaccessible refuges, which would be resistant to all but the most catastrophic floods.

The numbers of crayfish recorded using night viewing and manual removal techniques are shown in Table A4.2. It can be seen from this Table that the total number of crayfish recorded during night viewing was low (17), compared to the 207 removed subsequently in the same 15 subsections. With an adjustment made for effective survey time in the session (approximately 8 man hours) the catch per unit effort was about 2 per man hour. This low efficiency may in part be due to the date of survey, as higher viewing efficiencies have been recorded during night viewing surveys in July and August, when water temperatures are higher (Peay, pers. comm). However, on rivers with favourable conditions for survey and well-established populations of signal crayfish, the numbers of crayfish detected by manual survey may easily exceed 10 times that observed by night viewing (Peay, pers. comm.). On the basis of catch per unit effort, the intensive manual removal in the same sections was about 10 crayfish per man/hour. This is a relatively low efficiency compared to selective manual surveys at sites with a well established population at high density where, by contrast, favourable habitat which is easy to search can be surveyed. In the Gwash, the attempt to remove all crayfish, by necessity gives lower rates of return.

**Table A4.2 Comparison of night viewing and manual removal efficiencies**

Section Number	Crayfish numbers recorded during night viewing (4 <sup>th</sup> May 1999)	Total number of crayfish captured during manual removal session 3
U0-U25	4	166
U25-U50	4	1
U250-U275	1	278
U275-U300	6	288
U300-U325	0	124
U325-U350	2	126
U350-U375	0	70
U375-U400	0	27
Total no. crayfish recorded	17	1080
Man hours worked	8	111
Catch per man hour	2.1	9.7

#### **A4.4 Fish stocking**

Because of the importance of determining the effects on the crayfish population of intensive manual removal, it was agreed that stocking would be deferred. Potential problems with containing the eels within the section, and concern for their effect on the river ecosystem has led to these proposals being deferred indefinitely.

**Table A4.3 Results of a Single Session of Night Viewing and Total Removed in May-July 1999**

Section upstream of bridge	(m signal recorded carapace mm)	crayfish (sex, length,	Notes	Total removed in May-July survey
U0-U25	M 41 out F28 out F22 out M37 out		near left bank near left bank near bridge under bridge, (seen on repeat transect at end of session)	166
U25-U50	F 14 not out M14 not out ? 8.5 not out		under stone under stone under stone	1
U50-U250	large crayfish out not surveyed		burrow under concrete at left bank Some sections too deep to work, or poor visibility.	660 (all sections worked)
U250-U275	M 42 out, missing claw			278
U275-U300	F 14 out juv. out F 14 not out juv. not out F 25 out F21 out		from burrow  under stone under stone on stones near river bank near burrow	288
U300-U325	none seen out			124
U325-U350	F25 out		in mouth of burrow large crayfish in mouth of burrow on left bank	126
U350-U375	none seen out			70
U375-U400	none seen out			27
U400-	not surveyed			
	<b>Total caught</b>	14	<b>Males out</b>	3
	<b>Total not caught</b>	3	<b>Female out</b>	6
	<b>Total out</b>	12	<b>Sex unknown out</b>	3
	<b>Total not out</b>	5	<b>Males not out</b>	1
			<b>Females not out</b>	2
	<b>Grand total seen</b>	17	<b>Sex unknown not out</b>	2

### Acknowledgements

This project was coordinated by Richard Chadd, Environment Agency, Southern Region and Martyn Aspinall, Anglian Water Bird Centre.

## **APPENDIX 5: WIXOE, RIVER STOUR**

Signal crayfish, *Pacifastacus leniusculus*, were first recorded at a single site at Great Thurlow in the upper River Stour in 1991. During the 1997 routine fisheries survey, the crayfish were found to have colonised the river for 9.2 km from Little Thurlow to Wixoe.

The population of signal crayfish at Wixoe is of particular concern as water from this river is transferred by the Ely Ouse to Essex Water Transfer Scheme (EOETS), to the Pant and Blackwater catchment where there is a history of native crayfish populations. The transfer begins with water being taken from the Cut Off Channel at Blackdyke and pumped over the watershed to the River Stour at Kirtling Green. Water is then abstracted from the River Stour at Wixoe and transferred to the River Pant/Blackwater at Great Sampford where it flows to support abstractions at Langford for supply to Hanningfield Reservoir in South Essex. At Stratford St Mary and at Cattawade on the lower Stour water is abstracted to supply Abberton Reservoir. The EOETS provides the potential for the spread of non-native species of crayfish and, by association, crayfish plague throughout the Stour and Blackwater catchments and also into Hanningfield and Abberton Reservoirs, both of which are designated sites of special scientific interest (SSSI's).

In order to ascertain the status of crayfish populations in Essex and Suffolk rivers a trapping survey was carried out under licence from English Nature. The survey was conducted in conjunction with the Environment Agency's routine rolling fisheries survey programme for the Essex and Suffolk areas. In 1997 a survey of the River Stour catchment was carried out and the results demonstrated the overwhelming presence of non-native signal crayfish, *Pacifastacus leniusculus*, populations (Table 1) in the upper reaches and the Turkish crayfish, *Astacus leptodactylus*, in the lower Stour. Native crayfish were only found in Chad Brook, a tributary of the Stour.

### **A5.1 Objectives**

#### **Original Study Objectives**

- to eradicate signal crayfish from the upper River Stour at Wixoe by mechanical methods, or at least prevent its transfer to other catchments.

#### **R & D Project Objectives**

- to improve understanding of seasonality and its role in eradication projects;
- to improve understanding of the spread of signal crayfish, and
- to improve understanding of the effectiveness of continuous removal.

Whilst the Environment Agency recognised that total eradication of signal crayfish from the River Stour as not impossible for an attempt was to be made to prevent the transfer of signal crayfish through the EOETS to the Pant/ Blackwater catchment. An intensive and ongoing trapping programme was therefore initiated in 1998 at Wixoe Pumping Station on the River Stour. The study aimed to gain information on the colonisation of rivers by signal crayfish and to determine the effectiveness of trapping as a technique to prevent further expansion of the signal crayfish population.

## **A5.2 Methodology**

After initial trapping studies, sustained trapping of signal crayfish was started at Wixoe early in 1998 and is on-going, with weekly recovery of trapped crayfish at sites in or close to the abstraction site.

The traps used for the crayfish removal were the commercial ‘Trappies’ (cylindrical trap 50 cm x 20 cm with a diamond mesh diameter 33 mm x 23 mm and conical entrance funnel of 5 cm diameter). Traps were baited with pieces of fish and set in pairs along approximately 250 m of the river. The section included the part of the river from which water is drawn into an adjacent sump before being pumped to the Pant/Blackwater catchment. Efforts were made to maintain 10-12 pairs of traps actively fishing, although numbers were occasionally, and only temporarily, depleted due to unforeseen circumstances.

Traps were set from September 23 to November 1997 and have been in continuous use from 8<sup>th</sup> June 1998 until mid June 2000. On 26<sup>th</sup> April 2000 the pairs of Trappies were replaced with a single Trappy paired with a fine (8 mm mesh) trap of ‘in house’ construction. These traps were cylindrical, 50 cm x 15 cm with a conical entrance funnel also of 5 cm. Throughout the programme the traps were emptied, re-baited and re-set at least on a weekly basis. All species of crayfish caught were measured (carapace length, mm), sexed and their reproductive status (whether they were berried or carrying young) was recorded. All alien species of crayfish that were trapped were subsequently removed. Water temperature and dissolved oxygen levels were also recorded on each visit to the traps.

## **A5.3 Results**

### **Annual Catches**

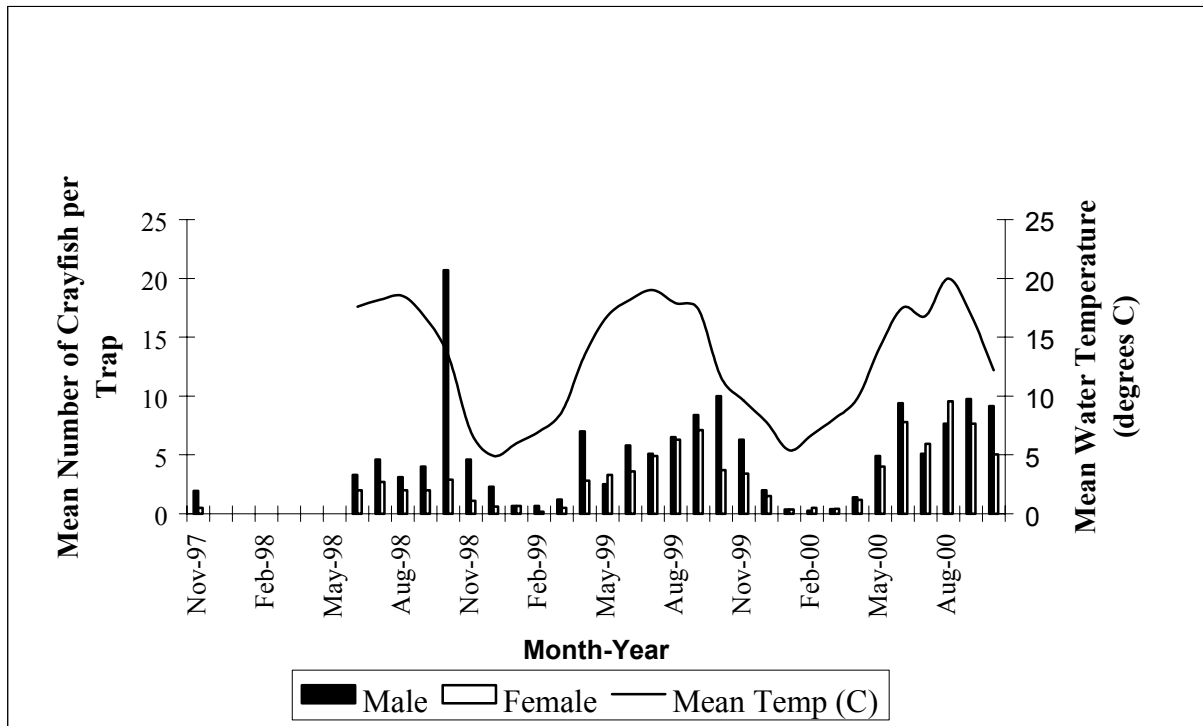
Only signal crayfish were caught throughout the duration of the study at Wixoe. In the initial trapping exercise from September – December 1997, a total of 68 crayfish were caught. From June to December 1998, a total of 794 were removed; during the whole of 1999 numbers totalled 2028 and from January 2000 until May 2000 a further 201 were removed. A total of 3091 signal crayfish have been removed from this 250 m section of river over a 28 month trapping period.

### **Seasonal Cycle**

The mean numbers of male and female signal crayfish caught per trap per month and mean monthly water temperatures are shown in Figure A5.1. The results clearly show cycles of crayfish capture which correspond closely to seasonal variations in water temperature. Catches of both sexes began to rise when the mean water temperature reached 8<sup>o</sup> C, and increased steadily with temperature increase. The peak in numbers caught in September/October are likely to be as a result of changes in behaviour associated with reproductive activity. Thereafter catches declined rapidly, and reached a minimum by January/ February when water temperatures were also at a minimum.



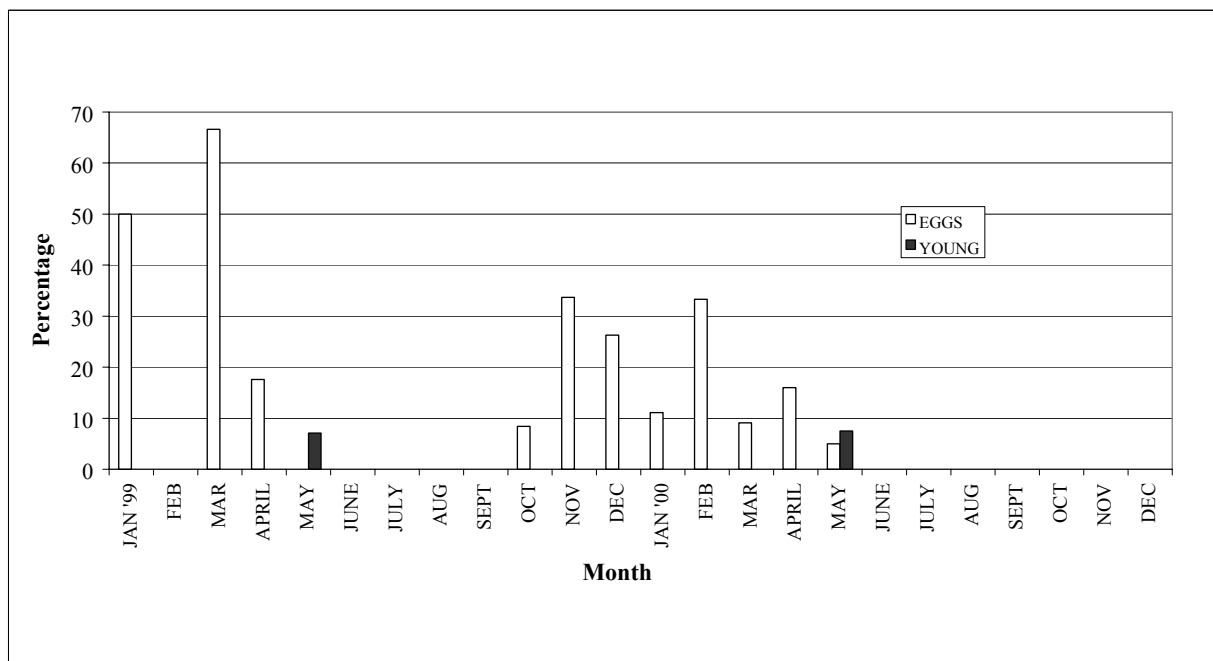
Fig. A5.1 Seasonal Male/ Female Trapping Ratios



**A5.3.1 Reproductive Cycle**

Although trapping captured more males than females during the warmer months, this differential increased between September and November as the crayfish entered their breeding season (Fig. A5.1). Females carrying eggs were trapped throughout the winter and early spring, between the months of October and May, although numbers caught were at relatively low levels. Females carrying young were only recorded in May (Fig. A5.2).

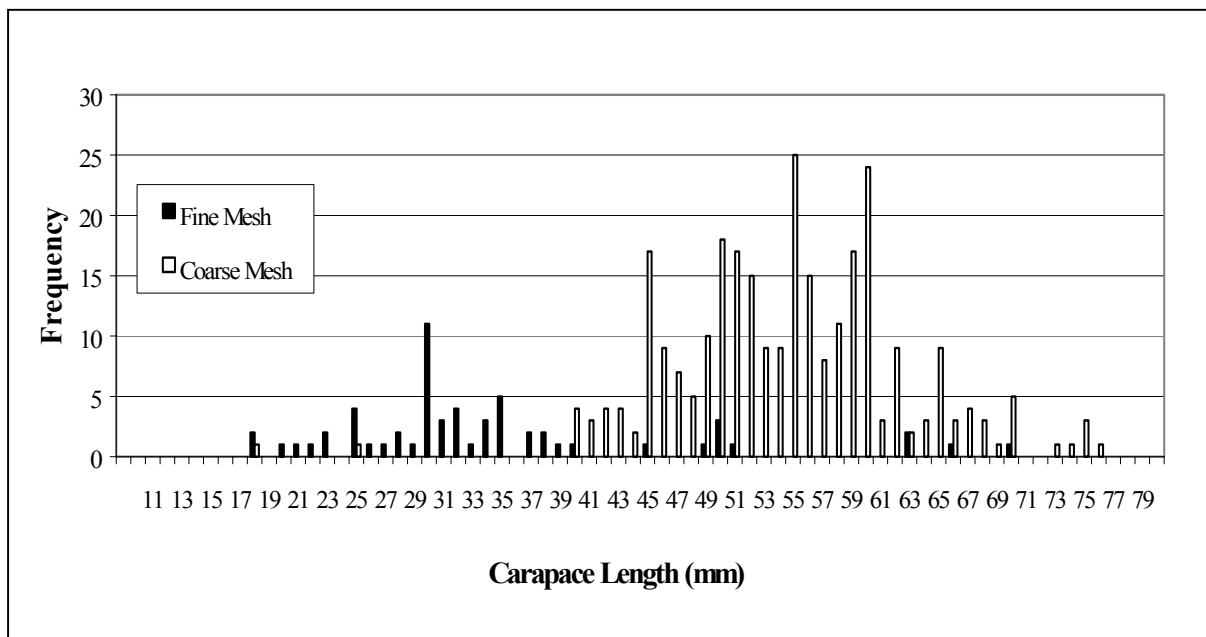
Fig A5.2 Percentage of females carrying eggs/young



### A5.3.2 Trap Selectivity

Fig. A5.3 shows the length/frequency distribution of signal crayfish of both sexes trapped during the period from April to June 2000 when both coarse mesh (Trappies) and fine mesh traps were used in combination. The mean carapace length of crayfish captured in the commercial Trappies (coarse mesh) was 54 mm ( $\pm 0.96$  mm), with few crayfish less than 40 mm carapace length being caught in these traps. The fine mesh traps caught smaller individuals with a mean carapace length of 31 mm ( $\pm 2.87$  mm) down to a minimum of 18 mm carapace length. The size selectivity of the two trap types is shown in Figure A5.3

Fig. A5.3 Length/ frequency distribution of signal crayfish trapped in fine and coarse mesh traps (April – June 2000).-



### A5.4 Discussion

The crayfish survey of the Stour Catchment in 1997 indicated that Wixoe was approximately at the downstream limit of colonisation by signal crayfish as no further captures were made in downstream survey sites. The numbers subsequently caught at Wixoe are increasing annually, indicating that immigration from upstream is continually occurring.

Prior to April 2000, the only traps used were 'Trappies' which proved to be size selective, catching few crayfish below 40 mm carapace length. However, although there was no evidence of large numbers of small crayfish present at Wixoe a trapping programme, using fine meshed traps, was implemented. The Environment Agency had previously undertaken an intensive removal of signal crayfish from Reepham Carp Fishery, Norfolk (Appendix 2), in an attempt to prevent the spread of signal crayfish into the River Wensum, which is a SSSI and is known to have native crayfish populations. Fine meshed traps were used in conjunction with 'Trappies' and a range of crayfish from 19 – 72 mm CL were caught (Steve Lane, pers. comm.). In the present study the length frequencies caught in each type of trap at Wixoe were similar to those observed at Reepham. The reason why similar numbers of larger individuals were not caught in both types of trap was unknown given that the diameter of the entrance funnels was the same. However, it has subsequently been observed that larger crayfish do enter the fine meshed traps but they are able to escape. The overall diameter of these traps is

less than that of Trappies and the decreased internal distance between the base of the trap and the entrance hole enables the larger crayfish to reach up to the entrance funnel and climb out of the trap.

The seasonal catches of crayfish are undoubtedly related to activity that depends on water temperature. In general, more males than females are caught, probably because of behavioural differences rather than a skewed population. Certainly this is the case during September/October when females are less active after mating and males are at their most active whilst seeking out females (Holdich & Lowery, 1988).

## **A5.5 Summary**

Based on the results of the present study the following conclusions have been drawn.

1. The most effective time of year (in terms of numbers caught per trap) to trap signal crayfish is the period from August to October.
2. Berried females may be caught in the winter months, but numbers of crayfish caught are at their lowest level at this time of the year. Trapping in late April/ May, when temperatures are at or above 8 °C, will result in catching greater numbers of berried females or those carrying young, due to the increased activity of the population at this time of the year.
3. The size range of the crayfish caught is dependent upon the type of trap used. 'Trappies' are most efficient at capturing crayfish greater than 40 mm carapace length, but finer meshed traps make it possible to capture smaller crayfish (down to 18 mm carapace length in our 'in house' traps), so pairs of these traps provide a means of removing an extended size range of crayfish. However crayfish are able to escape from traps, especially when numbers accumulate.
4. Further work is needed on the design, mesh size and density of trap setting to establish the most effective means of trapping.
5. Trapping is effective only as a survey methodology, not as an eradication technique, and even then cannot be used to reliably confirm absence of crayfish from a watercourse.

## **Acknowledgements**

**This project was coordinated and reported here by Rosalind Wright, Environment Agency, Anglian Region.**

## A5.6 References

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## **APPENDIX 6: DISCONTINUED CASE STUDIES**

This appendix contains details of projects originally intended to contribute to the R & D project, which either were not taken further or where on-going work would not make a new contribution to the R&D project.

### **A 6.1 Ullesthorpe Pond, Leicestershire**

The pond has a high density of fish and a large, burrowing population of signal crayfish, which has developed since the 1980s. The original proposal set out in the Phase 1 project report was to drain the ponds and attempt to control the signal population with rotenone. The project was not taken further because of concerns about interference with the fishery and the laboratory trials at Nottingham University which indicated it would not be as effective in field conditions as had been hoped.

Matt Sheehy of Leicester University is now supervising a project which started in spring 1999, to study growth rates and aging in signal crayfish, using Ullesthorpe Pond as a study site. The primary aim is to investigate the value of lipofuscins as a means of determining the age of individual signal crayfish. Adult crayfish of the same size can be many years different in age, depending on the growth rate of the individuals (Belchier *et al*, 1998)).

#### **A6.1.1 Objectives**

- to eradicate signal crayfish primarily by a chemical method (superseded)
- to determine growth rates and age structure in an enclosed population

#### **A6.1.2 Results**

Regular visits were made to the site during summer 1999. More than 1000 crayfish were caught in the larger sizes and about 300 of these were tagged. Recapture rates were in the order of 10-30 % in this enclosed waterbody. Estimates of the trappable population are approximately 3000 based on the mark-recapture study. Future studies will include work on the age structure of the capture population using lipofuscins as biochemical indicators of crayfish age. This is likely to yield more information on the population than size class studies alone. All captured crayfish from the final session of the project will be removed. It will not achieve eradication, but the principal benefit is from the population study.

#### **Acknowledgements**

This project was coordinated by Matt Sheehy, Leicester University.

#### **References**

Belchier, M., Edsman, L., Sheehy, M.R.J., Shelton, P.M.J., (1998). Estimating age and growth in long lived temperature freshwater crayfish using lipufuscin. *Freshwater Biology*. **39**. 439-446.

## **A6.2 Llanfihangel Pond, River Vyrnwy**

This site is a small pond at the headwaters of the River Vyrnwy with a formerly dense and escaping population of signal crayfish, which exhibited burrowing behaviour. This site was proposed for the R & D project because of its potential to provide information on the feasibility of eradicating isolated signal populations within a small physical area by mechanical removal. The pond was drained and enlarged to improve it as a fishery. Spoil was removed away from the watercourse. It was hoped that this would destroy all crayfish and crayfish burrows. The Environment Agency carried out some survey and manual removal of crayfish in the stream during this period. Subsequently, difficulties over permission for access discouraged any further monitoring. In 1999 the Environment Agency was able to carry out monitoring in the pond itself, plus the stream. This confirmed the presence of a sizeable population of signal crayfish in both the pond and the stream. (Vicky Ellis, per. com.) Signal crayfish are known to have escaped into the stream prior to the dredging operation. It is impossible to say whether or not the eradication effort in the pond was successful. The signal crayfish from the stream may have re-colonised the pond.

### **Objectives**

- eradicate crayfish by physical and mechanical methods (unsuccessful).

### **Acknowledgements**

This project was coordinated by Alan Jones, Environment Agency, Midlands Region.

## **A6.3 Tetford Pond, River Lymn**

This pond is immediately adjacent to the River Lymn, separated only by a 4 m strip of land, a distance which may easily be crossed by signal crayfish within minutes. The crayfish population on site are burrowing into the banks and causing leakage, and there are indications that signal crayfish have already reached the river via a drainage pipe.

### **Objectives**

- to eradicate signal crayfish from Tetford Pond primarily by chemical means (not attempted).

In 1998 a feasibility study was carried out for a trial of chemical control using rotenone (Chris Robinson, 1998). Following this study it was decided not to proceed with this project. The reasons for this decision are indicated below

- Results from laboratory trials indicate that crayfish are relatively tolerant to rotenone. Concentrations sufficient to exterminate the signal population would be prohibitively expensive;
- The EA was concerned about the acceptability of a trial of a biocide;
- Although the owner was broadly cooperative, he would require considerable reassurance that the pond could be fully restored following treatment.

There are no current proposals to proceed with work on Tetford Pond.

## **Acknowledgements**

This project was coordinated by Nick Bromage and Chris Robinson, Environment Agency, Anglian Region.

## **A6.3.2 References**

Robinson, C. (1998). *An investigation into the feasibility of eradication of a population of signal crayfish Pacifastacus leniusculus from a small pond adjacent to the River Lymn, Tetford, Louth, Lincs.* Environment Agency Report, Anglian Region, Manby.

## **APPENDIX 7: OTHER PROJECTS**

Projects in this section are not part of the national R&D project, but information on other projects was collected on an ad hoc basis, where there were elements of the work relevant to eradication projects.

### **A7.1 Gaddesby Brook, Leicester**

Gaddesby Brook has been known to support a population of signal crayfish since 1990. It runs for approximately 15 km before connecting to Queniborough Brook, approximately 2 km upstream of the River Wreake. The River Wreake contains a native crayfish population in some reaches and tributaries, which are threatened by the ongoing expansion of the nearby signal population. This population of signal crayfish in Gaddesby Brook has been the subject of detailed surveys and attempts to control it using trapping. A trapping study was carried out in autumn 1995 (Robert Harris and Helen Young, University of Leicester). The EA carried out further intensive trapping at selected sites in subsequent years, whilst in some areas there was commercial harvesting of crayfish from the river.

A more recent study (Harris, 1999) has shown trapping to have had a detectable effect on the size structure of the population. The larger size classes of 60 mm CL, or more, have been reduced. Subsequently a study by Peter Sibley (Environment Agency, Midlands Region) has been carried out.

#### **Objectives**

- estimate total population relative to total capture by manual removal;
- determine actual captures and estimated population from mark-recapture using manual removal; compared to previous estimates from trapping studies;
- estimate home range and emigration of crayfish;
- confirm habitat suitability within sub-sections of the channel; and
- determine the effectiveness and suitability of these methods for eradication or monitoring.

The study also aimed to determine whether, even if it proved impossible to eradicate signal crayfish populations by repeated sessions of intensive manual removal, the residual populations could be kept in check by predation of juveniles by large male crayfish. This is a return to the key issue of whether there is a critical population density for any particular habitat, below which spread is limited and above which there is rapid expansion.

This work has been carried out in three phases between June 1999 and July 2000.

#### **A7.2.1 Methodology**

Studies by Harris (1996, 1999) relied primarily on the use of Swedish crayfish traps (Trappies), which were modified by wrapping in fine mesh and constriction of the apertures. This aimed to increase the size range of animals captured using Swedish traps.

The three phase study carried out by Sibley utilized a combination of hand searching and modified kick sampling as used in the River Gwash (see Appendix 4 for full methodology), complemented by occasional night surveys. Four key sites at Newbold, Twyford, Ashby Folville and Gaddesby, were surveyed in 25 m sections. Previous studies had shown



population densities to be high at Newbold and Twyford (Harris 1999), and survey lengths were 500 m at these sites, compared to 150 m at Ashby Folville and Gaddesby.

All crayfish were measured and sexed where possible. Females and small males were removed, whilst large males (CL >50 mm) were marked by uropod clipping, and returned to the brook. This was intended to regulate population growth by:

- Increasing predation pressure on juvenile size classes
  - Suppressing daily juvenile activity, thereby reducing productivity
- (Momot, 1993)

### **A7.1.2 Results**

Estimates of the population were obtained in 1995 and 1998 using trapping and mark recapture caught. Few crayfish below 35 mm were caught and the modal class was 40-45 mm CL. A peak density of 9.4 m<sup>-2</sup> was recorded at 1998 at Newbold in the trappable size classes, compared to 12.5 m<sup>-2</sup> in 1995. The trappable populations of crayfish had reduced at a further two sites from more than 3 m<sup>-2</sup> to less than 1 m<sup>-2</sup>.

Despite this heavy trapping activity, the detected population has extended its downstream range at an average rate of 1 km per year since 1992 (Sibley, 2000), and is now within 5-6 km of the River Wreake. This expansion of range, despite the lower population density, implies factors other than population density e.g. territoriality may be at least partially responsible for downstream movement.

The three phase capture, marking and release of large male signals carried out by Peter Sibley and team has been completed. Data from phase III has not yet been analysed, but results from phases I and II indicate that this selection in favour of large males has had no short-term impact on recruitment in the areas concerned. Full results from the study will be reported as available, and also aim to obtain some estimates of the total population.

A report by Paul Stammers (1999) shows that a total of 96 man-days between late October and mid December 1999 resulted in the capture and removal of 6,507 crayfish. By July 2000, approximately 10,000 signal crayfish have been removed from over 1 km of Gaddesby Brook using the netting and hand searching method.

The combined research on this site shows that intensive trapping may have some impact on the largest size classes of signal crayfish. There is unlikely to be any significant depletion of the youngest breeding females. Removal of larger animals may result in the increased growth of remaining juveniles and small adults. Efforts to compensate for this effect by the selective removal of female and small male crayfish do not appear to have been successful.

### **Acknowledgements**

This project was coordinated by Peter Sibley, Environment Agency, Midlands Region.

### **References**

Harris, R. H. (1999) *An assessment of signal crayfish in the Gaddesby/Twyford Brook, Leicestershire and River Greet Nottinghamshire*. Report to Environment Agency Trent Region.

Harris, R. H., Young H. J. (1996) *Distribution, densities and population characteristics of signal crayfish, Pacifastacus leniusculus (Dana), in the Gaddesby Brook, Leicestershire*. Report for the National Rivers Authority.

Momot, W. T. (1993) The role of exploitation in altering the processes regulating crayfish populations. *Freshwater Crayfish*, **12**, 665-676.

Sibley P. (2000) *Signal crayfish management in the River Wreake catchment*. Environment Agency Report, Midlands Region.

## **A7.2: River Hamps, Staffordshire**

This project started following a workshop on crayfish issues sponsored by the Peak District National Park Authority. Other representatives include the Environment Agency, English Nature for Cheshire and for Staffordshire, the National Trust and the Cheshire and Staffordshire Wildlife Trusts. Its aims are:

- to conserve the populations of white-clawed crayfish in the Manifold and Dove rivers
- to control the signal population in the Hamps and any other locations which threaten the target white-clawed populations.

Main threats to the white-clawed population are:

- signal crayfish spreading down the River Hamps, a tributary of the River Manifold;
- a newly discovered signal population at Fenny Bentley in the Bradbourne Brook, a tributary of the River Dove close to Ashbourne;
- pollution incidents from pyrethroid sheep dip - a severe and prolonged episode on the upper Dove in autumn/winter 1998 and probably sporadic occurrence on tributaries too;
- Turkish crayfish in a pond on the upper reaches of the Manifold.

### **A7.2.1 Methodology**

The Staffordshire Crayfish Action Group held a weekend removal session for volunteers on 11-12 September 1999 to tackle the signal population in the River Hamps. About 25 people attended on the first day and 15 on the second. Information on the survey and removal has been provided by Phil Wormald (Environment Agency, Lichfield) and Roger Catchpole (English Nature, Derbyshire). The event involved use of 70 traps and intensive manual removal in as much of the channel as could be assessed in about 3.5 km between the villages of Onecote and Winkill (SK 547056 – SK 519064). In the 500 m further downstream relative few crayfish were removed, but at the centre of population at Ford, the team pulled out over 150 signal crayfish in the first hour in a boulder riffle. A total of 1500 individual crayfish were removed.

However, re-sampling of selected areas on the second day showed that there were still many crayfish in areas, which had been intensively worked the previous day. Some areas of favourable habitat still contained 3-4 crayfish m<sup>-2</sup>.

The median size for trapped crayfish was 47 mm CL. The median size for manual catching was 40 mm CL., much higher than usual for manual catching. A relatively low proportion of

the total catch was in the size groups 21-30 mm and 20 or less. This is partly a reflection of the conditions, as there is a great deal of stone to be searched. It may also be due to volunteer inexperience, as practice is required to become proficient at catching juveniles.

A further 2-day removal session was held in May 2000. Numbers of crayfish caught were substantially lower than those captured in the previous session. However, high flow rates and flooding, which occurred during the early months of the year, may have been largely responsible for this decrease, along with reduced numbers of volunteers. The width of the river, the very favourable habitat and the length of river known to be colonised make it inevitable that signal crayfish will continue to spread in the catchment.

### **Acknowledgements**

This project was coordinated by Philip Wormald, Environment Agency, Midlands Region and Roger Catchpole, English Nature, with substantial contributions from other members of the Staffordshire Crayfish Action Group.

### **A7.3: Huddersfield Narrow Canal**

The Huddersfield Narrow Canal is currently being restored to navigable standard as part of a socio-economic regeneration scheme for the region. The canal supports a large population of native crayfish between Linthwaite and Paddock. As a part of the restoration, it was necessary to drawdown a section of the canal containing white-clawed crayfish in order to allow repairs to a leaking aqueduct, and replacement of a bridge. Advice on mitigation measures was provided by Stephanie Peay (Scott Wilson). Nick Birkinshaw, the Project Conservation Ecologist, assisted by Stuart Silver, a student at the University of Huddersfield carried out a mark-recapture survey in this section.

Signal populations have been recorded in the canal system in Yorkshire, in the Calder and Hebble Canal. Both this and the Huddersfield Narrow Canal join the Huddersfield Broad Canal so there is potential for signals to access the Huddersfield Canal by this route. In addition, the Narrow Canal is a trans-Pennine link, which joins the Ashton Canal in Manchester. The Ashton is linked to the Peak Forest Canal, which also contains a signal population. There are also unconfirmed reports of the presence of Turkish crayfish *Astacus leptodactylus*, in Aspley Marina Basin, the junction between the Huddersfield Narrow and Huddersfield Broad Canal (John Spicer, University of Sheffield, pers. comm.).

It is not known how much of a barrier locks are to the movement of crayfish. In the Calder and Hebble Canal signals have established refuges under the partly perished wooden floor of a lock. Even if the locks are a barrier to upstream movement the associated spillways could be readily travelled by signal crayfish. Although some sections of canal have limited habitat, there appears to have been ready colonisation of many sections of the canal, by white-clawed crayfish, despite the requirements historically for occasional drainage of canal pounds for maintenance works.

### **Trapping studies**

Scott Wilson and British Waterways use crayfish traps constructed of stiff green plastic 3 mm mesh. This material is commonly found for sale in garden centres. The trap design was developed by Stephanie Peay in association with Gill Baldwin of GB Nets. It is now

available from GB Nets in flat-pack at a fairly low cost. The traps consist of a roll of mesh assembled using plastic cable ties, with cones of mesh inserted to form the trap mouth at each end. There are plastic stud-popper fastenings along the opening along the topside. Mesh purses are used as bait-bags. The traps are light and easy to carry, but must be weighted in order to sink properly. This can be achieved by placing small stones within the traps, although care must be taken to ensure that both ends of the trap are evenly weighted. If stones are not placed centrally in the trap, crayfish are capable of escaping.

The stretch of the Huddersfield Narrow Canal containing crayfish is subject to extensive angling activity and high levels of public access. Initial trapping studies were subject to a high level of interference from both anglers and members of the general public, traps frequently being disturbed or stolen. Trappies were more vulnerable to disturbance as they are more brightly coloured. Owing to the urban nature of the canal, there is a noticeable quantity of litter on the surface. British Waterways ecologists attached small plastic drinks bottles as floats to the trap lines, dramatically reducing trap interference. Traps were dropped into the canal and retrieved later using a boat-hook or a botanist's plant grapnel.

Survey work was carried out in summer 2000 used mark-recapture techniques in conjunction with stone-turning, torchlight survey and drawdown (Erica Kemp, Staffordshire University unpublished MSc thesis). The aim was to compare the relative efficiency of different capture and survey methods. A 100 m section was repeatedly searched using trapping, stone-turning and night-viewing techniques. Trapping density was at 1 trap per 3 linear metres. A total of 12 crayfish were captured over five trapping nights, with a recapture rate of 30 %. Peterson Population Estimates therefore placed the population at 24 individuals in the trappable size classes. Average carapace length was 36 mm, and only male crayfish were captured. Five hand searches caught an average of 43 crayfish per survey. Females accounted for between 38 % and 46 %, and juveniles were under-represented at approximately 10 % of the catch. Recapture rates were in the region of 25 %.

When this section of the canal was drawn down to enable essential dredging works, 252 crayfish were captured over a 4 hour period, 51 of which fell within the trappable size classes. This indicates that at least 50 % of the trappable size classes were not susceptible to trapping, and thus that a significant proportion of individuals of trappable size will not be detected by this method. It is not expected that this drawdown removed all crayfish from the section, and it is anticipated that, as removal was carried out manually by experienced and inexperienced volunteers, it is unlikely that the age classes are proportionally represented in this catch. Juvenile size classes are again likely to have been grossly under represented. However, the trappable size ranges accounted for only 20 % of the catch, clearly demonstrating the inefficiency of this method in obtaining representative samples of the population.

The population estimate obtained by trapping gave less than 10 % of the population found at drawdown. The actual population size may well increase by a similar factor.

Preliminary results from the canal using refuge traps indicate that these traps capture a wider size range of individuals, but further work is needed to assess their effectiveness as a quantitative survey methodology.

## **Acknowledgements**

This project was coordinated by Nick Birkinshaw, British Waterways, with additional research carried out by Erica Kemp, Staffordshire University and Stuart Silver, University of Huddersfield.

### **A7.4 River Yare, Norfolk**

Signal crayfish were discovered at the upper end of the River Yare in 1999 (Steve Lane, Environment Agency, Norwich, pers. comm.), and a population of white-clawed crayfish was discovered in the middle Yare. The source of the signal population is an old trout fishery, a 1 km long lake at Marlingford Hall with an outfall to the river. Rogers & Holdich (1997) reported the introduction to have been made in 1989. There is an active and burrowing population of signals close to this confluence. Fisheries staff of the EA in 1999 attempted to eliminate this population by manual removal and trapping

About 600 m of the River Yare was searched manually. The channel is only about 2 m wide. Some areas are lined with concrete rubble, but other areas are silty and hence difficult to search, although they are therefore likely to be less favourable habitat for crayfish. Most of the population found seems to occur within 50 m of the confluence. The Environment Agency considered starting a trapping programme in October 1999 or 2000, using about 150 traps. Other work commitments and concerns about the low efficiency of trapping meant the work was not carried out. There are no plans to recommence trapping at present.

An additional difficulty is the detecting of the limits of a signal crayfish population in a silty, lowland river. Measures would also be needed to stop the spread of signals from the lake, if any medium or long-term success is to be achieved.

## **Acknowledgements**

This project was coordinated by Steven Lane, Environment Agency, Anglian Region.

### **A7.5 River Derwent, West Ayton, North Yorkshire**

A survey and removal exercise was conducted prior to dredging work in a 1 km reach of the Derwent. This section of limestone river had been over-deepened in the past and had become a very silty reach with abundant macrophytes. The aim was to restore the original channel, for nature conservation and to protect groundwater resources locally. In this case only native crayfish were involved and all were returned to the river after the engineering work was finished. Night search with three operators retrieved around 100 animals from those parts of the silty channel which could be accessed by wading. Prior work retrieved around 25 animals with three operators during the day. Within 7 days this section of riverbed was dredged, with each bucket of silt and plants removed mechanically being searched and washed to remove crayfish. A further 900 animals were obtained. This confirms the low efficiency of manual survey and night viewing in conditions, which are physically difficult to search. Silt and beds of submerged aquatic plants may be less favourable than stone substrates for crayfish, but the animals are still distributed throughout in these areas. Crayfish are very difficult to record in silty habitats. Nonetheless it should not be assumed that crayfish are absent from silty habitat or that such areas form any barrier to the movement of crayfish. All animals were returned to renovated habitats within the river.

**Acknowledgements**

This project was coordinated by Pete Hiley, Scott Wilson Resource Consultants for Yorkshire Water Services Ltd.

**A7.6 Catton Park Lake.**

The Environment Agency received complaints from anglers in August 1999 about a signal crayfish population which had reached a high enough density to interfere with angling. 87 Trappies were reset weekly in the lake. In 17 weeks 1236 signal crayfish were captured. Concern was expressed about the efficiency of the trapping. Trapping did not appear to reduce the angling nuisance. The lake overflows occasionally into the River Trent, so it is likely that this river system will (or already has) become colonised by signal crayfish. The river is also only a few 10's m from the lake so overland movement of crayfish is also possible.

**Acknowledgements**

This project was coordinated by Ruth Herring, Environment Agency, Severn Trent Region

# **APPENDIX 8 ERADICATION OF ALIEN CRAYFISH – POTENTIALS FOR ENVIRONMENTAL MANIPULATION**

## **A8.1 Introduction**

The following programme of tests has explored 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. More detailed research and development should take place first in the laboratory then on a small scale in the field, before a working method is attempted in a larger water body. Since there is no specific toxicant or infective agent against crayfish or even against Crustacea, major damage to other aquatic organisms is an inevitable consequence of control by such means. Loss of all the aquatic fauna 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 crustacea 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. It is the persistence of synthetic pyrethroid sheep dips which is leading to kills of crayfish and other invertebrates in headwater streams in many rural areas of the UK. Therefore the work concentrated on non-specific toxicants in order to ensure that environmental effects could be reliably limited to the target area.

The hard choice is between allowing an invasion of alien crayfish to continue, with consequences on the whole aquatic ecosystems, or taking effective action when a new colonisation is discovered – for example following an accidental or malicious introduction to a tributary or pond in a catchment which has a major population of white-clawed crayfish.

The methods investigated here concern the extermination of animals in the water. It is likely that some individuals would crawl out of the water during such a process and would also need to be destroyed. Although not specifically tested on animals out of water, it has been assumed that spraying a pesticide like permethrin would be suitable, although the persistence of the insecticide means that spraying the non-specific chemicals used in the trial may be required.

## **A8.2 Methods**

### **A8.2.1 Outline**

Potential toxicants were selected from the experience of Pete Hiley (Scott Wilson Resource Consultants) and by reference to the Phase 1 R&D report in which a literature search was conducted. Checking the likely toxic concentrations was done 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 possible 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 4 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. If any effects occurred out of sequence, this would indicate that too few animals were tested and a repeat was to be run with larger numbers. Controls were run if most animals were likely to be affected.

The symptoms recorded were:

**OK** = animal sits quiet for most of time, escape reflexes if container tapped, attacks probe.

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

## A8.2.2 Chemicals

In order for a control method to be seen as practically acceptable for use in the field, it should employ chemicals that 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 one-hectare lake.

The veterinary insecticide Ivermectin 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. If natural pyrethrum is available, this is recommended as it is naturally degraded in sunlight. The literature on the use of natural pyrethrum use in infestation control in water supply mains indicates that it is readily degraded with chlorination. Testing of natural pyrethrum was not carried out due to the continuing world shortage – around half a litre was located (but not purchased) for use in this project at the time.

The chemicals used were:

- Permethrin, 0.6% solution in commercial formulation (Homebase)
- Hydrochloric acid, 10Molar
- Sodium hydroxide, 5% approx W/V
- Sucrose, saturated solution
- Sodium hypochlorite, household bleach
- Soil suspension
- Sodium thiosulphate, saturated solution



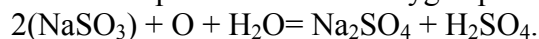
- Sodium sulphite, saturated solution
- Ammonium sulphate, saturated solution
- Papain/salt powder (meat tenderiser)

In addition, tests were performed using 1-14 pH papers and chlorine test kit range 0.1-2 mg<sup>l</sup><sup>-1</sup>.

All mixing and diluting processes were carried out in glass equipment. The concentrations of saturated solutions were obtained from the tables in the “Rubber Handbook”. 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 tap water that had been standing for 24 hours in the laboratory in open containers.

Sodium sulphite reacts with oxygen probably as follows:



i.e. there will be a pH reduction as oxygen concentrations are reduced. 2 moles of NaSO<sub>3</sub> will combine with 1 mole of oxygen. Therefore (126\*2)g of NaSO<sub>3</sub> will combine with 16g of O, a ratio of approximately 16g of sulphite to 1 of oxygen. Thus a concentration for effective deoxygenation of approx 10 mg<sup>l</sup><sup>-1</sup> oxygen in water would be 160 mg<sup>l</sup><sup>-1</sup> 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, which is understood to be a minute quantity of a molybdenum compound for which an environmental assessment exists. (This information was not available at the time.) Sodium sulphite solution is saturated at approximately 150 g<sup>l</sup><sup>-1</sup> at 10°C, i.e. 1 ml of saturated solution should be sufficient to deoxygenate 1 litre of water at this temperature.

Ammonium sulphate is saturated at 450 g<sup>l</sup><sup>-1</sup> at 10°C. 1 ml of this in 100 ml of water gives 4,500 mg<sup>l</sup><sup>-1</sup>. The molecular weight of ammonium sulphate is 122 therefore 28/122=0.23 correction factor to give results “as N”.

The laboratory temperatures were 15°C on 20<sup>th</sup> and 21<sup>st</sup> March 2000, 13°C on 22<sup>nd</sup> March 2000, 14°C on 24<sup>th</sup>, 15°C on 27<sup>th</sup> and 30<sup>th</sup> March 2000.

### **A8.2.3 Sources of animals**

Initially seven crayfish suppliers were contacted and several indicated that, either by collecting themselves or allowing Scott Wilson staff to collect, it would be possible to supply 500 0+ and 1+ signal crayfish. However, all but one set the cost too high, at between £1 and £1:20 per animal. All stated that during April –May it would be possible to obtain neonates from berried females, but none of them was carrying out intensive rearing in which young were reared in isolated tanks, so a supply of small ones depended on being able to trap or collect them.

At the same time sources for direct collection were contacted. These included White Beck (near Kilnsey on the River Wharfe), a beck at Rutland, and a pond on a golf course near Halifax. Site investigations of White Beck, Captain Beck, Kilnsey crayfish ponds and the River Wharfe at Grassington on 17/03/00 demonstrated that only in the River Wharfe could

small individuals be collected at a fast enough rate to be economic. The low river temperatures made it possible to collect these small animals by stone turning (around 8 °C) whereas later in the year this is more difficult due to their high degree of activity. On 20/03/00 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, although some cannibalism is likely to have taken place. The animals were sorted into three size categories for transport and storage, to reduce the risk of cannibalism (approximately 8-12 mm, 16-20 mm and 24+ mm carapace length).

The laboratory was in a secured area of Bradford University. The site was licensed by MAFF as a suitable place for containing signal crayfish, following an inspection by Environment Agency staff (Jonathan Brickland) and CEFAS (Alisdair Scott) on behalf of MAFF.

#### **A8.2.4 Denaturing of toxicants**

In order for a control method to be seen as practically acceptable, all changes of conditions should be reversible so that the original environment can be restored after the alien species has been eliminated.

A toxicity test was carried out following the test treatments. *Daphnia obtusa* were used as a substitute for crayfish, 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.

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 un-ionised ammonia could be reversed by reducing 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. Permethrin was reported to be readily denatured in the presence of free chlorine, but this was checked by adding *Daphnia* in a controlled test after denaturing. Concentrations of permethrin were found to be toxic to the *Daphnia*. 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*.

#### **A8.2.5 Action of adjuvants**

While low oxygen should bring the crayfish 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. The main objective of these tests was to confirm the degree of deoxygenation that would bring them into actively seeking the surface. 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.

### A8.2.6 Experimental conditions

Collected animals were stored in net bags whilst in the field, which were frequently wetted. These 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° and 10 °C. The maximum time between collection and installation in the laboratory was 24 hours. The animals were maintained in the laboratory in 150 litre aerated tanks in the dark at 13-15 °C, with an excess of suitable size homes (plastic horticultural plug trays) unfed. Some of the 0+ animals were maintained in 15 litre aquaria with black plastic netting as homes. Since they can climb up an air line if it rests against the tank side, care was taken to ensure that air lines were held at some distance from the tank side.

We are most grateful to Bradford University, Professor M R Seaward of Environmental Sciences, for the use of a lockable basement laboratory that met the criteria for safe keeping of signal crayfish. The laboratory was licensed for the keeping of signal crayfish by MAFF. 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 River Aire that is too polluted in this reach 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, open tanks containing clean tap water and *Daphnia obtusa*, a species with a high sensitivity to pesticides and toxic metals, were maintained around the laboratory for 14 days. These cultures were unfed and were replaced every 3-5 days. This process began on 7<sup>th</sup> March 2000. All the vessels used for the tests were similarly treated and the plastic containers were found to be toxic on first filling with water (after 4 days from 16<sup>th</sup> March), but on subsequent fillings, no toxicity to *Daphnia* was found.

1+ and larger crayfish were tested in 2 litres 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 1 or 2 individuals in 200 ml of water. No deaths of controls were recorded and all animals appeared unstressed after 24 hours in such conditions, without homes. It was assumed that the relatively low temperatures (13-15 °C) and low light levels (one small N-facing window) were contributory factors.

## **A8.2.7 Tests Conducted**

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

### ***Chlorine***

The tests were carried out using cheap domestic bleach with no stated additions of detergents, which was thus assumed to be basically water, sodium chloride and sodium hypochlorite.

Dilutions of 1 ml and 0.5 ml in 250 ml were made on 20<sup>th</sup> March. From these 10 ml were taken and added to two further flasks containing 25 ml of water. In turn these were also diluted 10 ml into 250. Finally 1 ml of these was added to 250 ml to give eight flasks with a wide range of chlorine concentrations. One 1+ animal was added to each flask as soon as the dilutions were prepared. To release more free chlorine from the hypochlorite (the main component of bleach) 0.5 ml acetic acid (5%) was added to all flasks. The use of acetic was a mistake since it denatured the chlorine by being oxidised. A mineral acid should be used if required to achieve this effect in future. The actual chlorine concentrations were determined using the test kit on dilutions of the test waters prior to acid addition (i.e. 5 ml in 1 litre yielded 100 mg l<sup>-1</sup>).

The second test (21<sup>st</sup> March) used a 10\* series of dilutions in 2 litre plastic containers with 2+ animals, starting with the same concentration as the first test.

The third test (22<sup>nd</sup> March) exposed 0+ animals to chlorine concentrations of 200 to 2 mg l<sup>-1</sup> for one hour before placing them in clean water.

### **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.

Solutions were prepared by adding 1 ml of sodium hydroxide solution to one flask containing 200 ml of water, 0.5 ml to a second flask, and then serially diluting each 1:100 three times. Thus eight flasks each of a different concentration were prepared. The resulting pHs were taken after 30 minutes' exposure (on 21<sup>st</sup> March): One 0+ animal was added to each flask.

The test was repeated on 22<sup>nd</sup> March contacting the animals for one hour with dilutions of 4, 2, 1 and 0.5 ml in 200 ml, and then removing them to clean water.

### **Low pH**

5 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 on 21<sup>st</sup> March and observed after 1 hour and 24 hour. The pH in each flask was measured after 30 minutes and again after 24 hrs.

### **Potash alum**

A saturated solution of pharmaceutical alum was prepared. To each litre of water in plastic vessels was added 10, 5, 1 and 0.1 ml of stock saturated solution, plus a 1+ animal on 22<sup>nd</sup> March. Since no pH correction was made, the alum should remain in solution as the tap water was around pH 6.5-7. Alum may be more toxic as it precipitates, but this is a difficult reaction to perform given the requirements to contact every individual within a field situation.

### **Ammonium sulphate/sodium hydroxide**

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 flasks of water to which a 0+ animal was added immediately, on 22<sup>nd</sup> March.

The toxicity of ammonia is greatly increased if it is converted to a high proportion of the unionised form by increasing the pH, e.g. with sodium hydroxide. By adding 0.1 ml of stock sodium hydroxide solution to each flask, pH 9 was obtained in all concentrations.

The test was repeated on 24<sup>th</sup> March 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. 2 g and 1 g per litre were realistic solutions for economic field use and they were tested with two 1+ animals each, on 22<sup>nd</sup> March.

### **Deoxygenation with sucrose/soil suspension**

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. Commercial sugar was dissolved to saturation at laboratory temperature. The soil suspension made from damp soil should have provided sufficient bacteria.

The aerators were removed from 5 plastic containers each filled with 2 litres 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 hours.

### **Deoxygenation with sodium sulphite**

Sodium sulphite is used in the commissioning of aeration equipment in wastewater treatment. The aeration basins are filled with water then the sulphite is added to remove the dissolved oxygen. The time that the aerators take to restore a given concentration of dissolved oxygen is a measure of their efficiency. The sulphite will work on its own, but it is understood that the addition of a catalyst makes the deoxygenating reaction much faster. Since the details of the catalyst were not available, the salt was used on its own. 1 ml of saturated solution should

be sufficient to remove approximately 10 mg<sup>l</sup><sup>-1</sup> of oxygen at the laboratory temperature, i.e. achieve deoxygenation of an air-saturated water.

A large excess of sodium sulphite was added to 3 litres of water in a glass tank with a 1+ animal on 22<sup>nd</sup> March. More excess sulphite was added plus four more 1+ animals on 24<sup>th</sup> March, this time with continuous observation.

### **Permethrin**

A commercial pesticide claiming an active ingredient of 0.6% permethrin was used to prepare a 60 mg<sup>l</sup><sup>-1</sup> stock solution by diluting 1 ml of this in 100 ml of water. It became clear that the diluted solution degraded after 24 hrs, as in the results section, so a fresh dilution was made up for the final tests. Since it was not established whether this denaturing was by adsorption to the glass or by decomposition, and it is known that permethrin remains active when adsorbed, no assumptions on likely degradation times in the field could be made.

In the first test additions of 2.4, 1.2, 0.2 and 0.05 ml of stock (60 mg<sup>l</sup><sup>-1</sup>) solution were made to each of four 200 ml flasks, giving the following concentrations to which were immediately added (on 21<sup>st</sup> March) a 0+ animal in each. Observations were made after 30 minutes, 1 hr and 24 hr.

The test was repeated on 22<sup>nd</sup> March with lower concentrations and removal of the animals after one hour.

### **Combination of deoxygenation and permethrin**

Sometimes a stress, such as deoxygenation, has an influence one way or another on the effects of a toxicant. To ascertain if the obvious increase in activity recorded with deoxygenation would alter the toxicity of the permethrin, further tests were carried out. This was a preliminary test, using sodium sulphite solution calculated to deoxygenate with little excess. One tenth the concentration of permethrin as in the previous tests was used on 27<sup>th</sup> March, with 3 0+ animals per concentration (i.e. 12 animals), after pre-exposure for 30 minutes to 0.1 ml sodium sulphite in 200 ml. The animals were removed to clean water after 1 hr exposure to permethrin and observed for 24 hours.

### **Permethrin with denaturing**

Using one-tenth the concentrations of permethrin that were shown to be toxic in the previous tests (on 27<sup>th</sup> March), 3 animals per concentration being removed after 1 hr, then 0.2 ml bleach (giving a measured 5 mg<sup>l</sup><sup>-1</sup> chlorine) being added for 1 hr followed by 0.15 ml of thiosulphate which was found to be effective in completely denaturing the chlorine. At least 10 *Daphnia* were added to the water this process created and observed over a 24 hour period. The waters from the tests in 3.11 were also treated in this way, and it was found that since the sulphite also denatured chlorine, 0.4 ml of bleach had to be added to generate >2 mg<sup>l</sup><sup>-1</sup> of chlorine.

The process was repeated on 30<sup>th</sup> March 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 minutes of contact with bleach then 10 minutes with thiosulphate before adding 4 0+ animals and >10 *Daphnia* to each resulting solution.

The test was repeated on 31<sup>st</sup> March with two animals in each of 4 flasks containing 0.1 ml of stock permethrin in 200 ml of water as controls and the same concentration detoxified with 1 hour contact with chlorine then 15 minutes with thiosulphate.

### A8.3 Results

**Table A8.1 Chlorine – First Test**

mg l <sup>-1</sup> chlorine	120	60	4.8	2.4	0.2	0.1	0.001	0.005
pH prior to acidification	9	<8	<8	<8	<8	<8	<8	<8
pH after acidification	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d
Result after 30 mins	Stagger	OK	OK	OK	OK	OK	OK	OK
Result after 16 hours	dead	dead	OK	OK	OK	OK	OK	OK

**Table A8.2 Chlorine – Second Test**

mg l <sup>-1</sup> chlorine	100	10	1	0.1	0.001
pH	9	8	7.5	7	6.5
Result after 4 hours	OK	OK	OK	OK	OK
Result after 24 hours	dead	torpid	OK	OK	OK

**Table A8.3 Chlorine – Third Test**

mg <sup>l</sup> <sup>-1</sup> chlorine	200	100	10	2
Result after 1 hour	OK	OK	OK	OK
Result after 3 hours	torpid	OK	OK	OK
Result after 24 hours	dead	dead	OK	OK

In summary, a concentration between 10 and 100 mg<sup>l</sup><sup>-1</sup> of chlorine (hypochlorite solution) is likely to kill signal crayfish within 24 hr of 1 hour's exposure. There is a delay in response of over an hour that may not have been noted previously for this species. If lower concentrations of chlorine are used the risk of concentrations falling below lethal levels due to reaction with sediments and dissolved organic matter increases greatly. 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 in section 3.12.

### A8.3.2 Denaturing of chlorine

The results of this work are given in section 3.12.

### A8.3.3 High pH

**Table A8.4 High pH – First Test**

PH	12	12	9	7	7	6	6	6
Result after 2 hours	torpid	OK	OK	OK	OK	OK	OK	OK
Result after 24 hours	dead	dead	OK	OK	OK	OK	OK	OK

**Table A8.5 High pH – Second Test**

PH	14	14	12	12	7
Result after 1 hour	torpid	OK	OK	OK	OK
Result after 24 hours*	dead	dead	dead	OK	OK

\* in clean conditions after 1 hour 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, for example 24



hours using quicklime, the water should be neutralised with acid before being aerated or released downriver.

#### A8.3.4 Low pH

**Table A8.6 Low pH –First Test**

PH after 30 minutes	0.5	1	1	1
Result after 1 hour	torpid	OK	OK	OK
pH after 24 hours	1.5	2	n/a	
Result after 24 hours*	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.

#### A8.3.5 Potash alum

**Table A8.7 Potash alum - First Test**

Potash alum mg <sup>l</sup> <sup>-1</sup>	n/a	n/a	n/a	n/a
Result after 24 hours*	dead	dead	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.

#### A8.3.6 Ammonium sulphate/sodium hydroxide

**Table A8.8 Ammonium sulphate/sodium hydroxide –First Test**

Ammonium sulphate mg <sup>l</sup> <sup>-1</sup>	4,500	2,250	225	112
Ammonia ‘as N’	1,033	500	50	25
Result after 2 hours	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):

**Table A8.9 First Test**

pH	9	9	9	9	7
Result after 30 minutes	dead	dead	OK	OK	OK
Result after 24 hours	dead	dead	dead	dead	OK

After 24 hrs all the crayfish in the tests 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.

**Table A8.10 Second Test**

Ammonium sulphate $\text{mg l}^{-1}$	4,500	2,250	225	112
Ammonia 'as N'	1,033	500	50	25
Sodium hydroxide (strong)ml	0.1	0.1	0.1	0.1
pH	9	9	9	9
Result after 24 hours	dead	dead	dead	dead
Ammonium sulphate $\text{mg l}^{-1}$	4,50	2,25	22.5	11.2
Ammonia 'as N'	130	50	5	2.5
pH	7	7	7	7
Result after 24 hours	OK	OK	OK	OK

A concentration of around  $100 \text{ mg l}^{-1}$  ammonia (as N) at pH 9 is likely to provide 100% kill after 1 hour. 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  $25 \text{ mg l}^{-1}$  as N, at which concentration the correction of pH and some dilution may yield non-toxic water for release. With longer exposure times, yet lower concentrations could be used.

### A8.3.7 Papain/salt

**Table A8.11 Papain/salt First Test**

Papain/salt solution, g l <sup>-1</sup>	2	1
Result after 24 hours	OK	OK

This substance was not examined further.

### A8.3.8 Deoxygenation with sucrose/soil suspension

**Table A8.12 Deoxygenation with sucrose/soil suspension First Test**

Sucrose solution (ml l <sup>-1</sup> )	50	25	10	10	5
Result after 24 hours	OK	OK	OK	OK	OK

In these cool conditions with small volumes bacterial deoxygenation is difficult to achieve. It is well known that this is not true in larger volumes and at field scale, so the method remains with high potential for field use.

### A8.3.9 Deoxygenation with sodium sulphite

**Table A8.13 Deoxygenation with sodium sulphite First Test**

Sodium sulphite, mg l <sup>-1</sup>	>500
Result after 2 hours	OK
Result after 24 hours	dead

**Table A8.14 Deoxygenation with sodium sulphite Second Test**

Sodium sulphite, mg/l	>500	0
Result after 10 minutes	active	OK
Result after 15 minutes	rapid ventilation	OK
Result after 1 hours	active\climb out	OK
Result after 12 hours	torpid	
Aerated water (recovery)	dead	
Result after 1 hours	partial activity	

After 10 minutes activity increased, then after 15 minutes 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.

Thus a more reliable deoxygenation method was established for laboratory and potentially for field use also.

The use of sodium sulphite does appear to hold some hope of drawing animals out of their burrows. If carried out over perhaps 24 hours, it may bring 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 hours or more. Sodium sulphite with the catalyst could be used to achieve a similar effect in a river, over a shorter time span.

### A8.3.10 Permethrin

**Table A8.15 Permethrin – First Test**

Permethrin mg l <sup>-1</sup>	0.72	0.36	0.06	0.015	0
Result after 30 minutes	torpid	torpid	OK	OK	OK
Animals from highest two concentrations were placed in clean water					
Result after 1 hour	torpid	torpid	active	active	OK
Result after 24 hours	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.

**Figure A8.16 Permethrin – Second Test**

Permethrin mg l <sup>-1</sup>	0.06	0.03	0.015	0.006	0
Result after 1 hour	dead	torpid	slow	OK	OK
Result after 24 hours	dead	torpid	dead	dead	OK

It is possible that the stock was already degrading, having been made up for over 24 hours. This is the first test in which the effects were not in sequence. The repeats (see later) were run with more animals.

### A8.3.11 Combination of deoxygenation and permethrin

**Table A8.17 Combination of deoxygenation and permethrin – First Test**

<b>Sodium sulphite, ml</b>	0.1	0.1	0.1	0.1
Result after 30 minutes	active	active	active	active
Permethrin mg l <sup>-1</sup>	0.06	0.03	0.015	0.006
Result after 24 hours	OK	OK	OK	OK

The permethrin stock had probably degraded. Time was not available to repeat this test.

### A8.3.12 Permethrin with denaturing

**Table A8.18 Permethrin with denaturing – First Test**

Permethrin mg <sup>l</sup> <sup>-1</sup>	0.06	0.03	0.015	0.006	0
Result after 1 hour	OK	OK	OK	OK	OK
Animals removed					
Result after 24 hours	OK	OK	OK	OK	OK
Bleach added mg <sup>l</sup> <sup>-1</sup> Cl 5	5	5	5	5	0
1 hour later thio* added ml	0.15	0.15	0.15	0.15	0
Daphnia added					
Result after 24 hours	OK	OK	OK	OK	OK

\*Sodium thiosulphate

From this test it was concluded that the denaturing stages were not of themselves toxic, although the stock solution was degraded.

**Table A8.19 Permethrin with denaturing – Second Test (with freshly prepared stock)**

Permethrin mg <sup>l</sup> <sup>-1</sup>	0.06	0.03	0.015	0.006	0
Result after 1 hour	torpid	torpid	torpid	torpid	OK
Animals removed					
Result after 8 hours	dead	dead	dead	dead	OK

**Table 8.20 To separate vessels containing permethrin as above:**

Bleach added mg <sup>l</sup> <sup>-1</sup> Cl	5	5	5	5	0
30 min later thio* added ml	0.15	0.15	0.15	0.15	0
Daphnia and crayfish added					
Result after 8 hours	dead	dead	dead	dead	OK

\*Sodium thiosulphate

It was concluded that 30 minutes was too short a contact time for the chlorine to denature the permethrin. This also confirmed that the original stock solution had degraded.

**Table A8.21 Permethrin with denaturing - Third Test**

Permethrin mg <sup>l</sup> <sup>-1</sup>	0.06	0.03	0.015	0.006	0
Result after 1 hour	torpid	torpid	torpid	torpid	OK
	Animals removed				
Result after 8 hours	dead	dead	tor\dead	dead	OK

To separate vessels containing permethrin as above:

**Table A8.21 Permethrin with denaturing - Third Test**

Bleach added mg <sup>l</sup> <sup>-1</sup> Cl	5	5	5	5	0
1 hour later thio* added ml	0.15	0.15	0.15	0.15	0
	Daphnia and crayfish added				
Result after 8 hours	tor\dead	dead	dead	dead	OK

\*Sodium thiosulphate

The claim in Crowther and Smith (1982) that permethrin is chemically degraded by any chlorine residual is 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 reported 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 litres or so of concentrate, is obtained, this could be stored without degradation for many years.

In these permethrin tests the controls were blank, whereas they should have had bleach and sodium thiosulphate added.

#### **A8.4 Discussion**

This was a very rapid appraisal at a modest degree of precision, enabling the selection of some promising methods with the elimination of others.

The delay between contact with a toxicant and any apparent response was considerable, with deaths sometimes taking up to 24 hours to occur after a one-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. Suspicions of under-dosing based on such observations could lead to serious over-dosing.

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 identified.

## **A8.5 Conclusions**

There are four possible methods each of which could be used on its own to kill signal crayfish: pH 12+, 10-100 mg $l^{-1}$  chlorine, 10  $\mu g l^{-1}$  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 unless measures are taken to prevent it. Spraying of the margins with a pesticide like permethrin is a potential 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 used after deoxygenation, it would be important to ensure that all the sulphite had oxidised first, otherwise it would denature the chlorine.

The failure 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 Crustacea and insects would be damaged, leaving the remainder of the fauna and the entire flora intact.

All the exposures here were nominally one hour, to check if control in an isolated stretch of a small river would be feasible. This was found to be true. Very much lower concentrations of toxicant would be needed for 24-hour exposures.

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 °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.



## **A8.6 References**

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## **A8.7 Availability of 0+/1+ signal crayfish.**

It is recommended that, in order to secure a constant supply of animals of a size suited to testing, in April/May each year sufficient berried females are captured or obtained to yield a supply that can be maintained for the succeeding year in isolated, cool conditions. Such an approach requires a relatively modest facility, especially if the size distribution in each container is kept even. It may be possible to persuade a commercial supplier to do this, though some form of pre-payment is highly likely to be needed. A range of sizes of horticultural plug trays would be the easiest and cheapest method of providing individual homes at high density.

## **A8.8. Research Proposal**

There are now potentially, simple, inexpensive means of eliminating signal crayfish from waters where they are not desired to be present. However, these methods exist in outline only and require substantial development before they can be reliably used in the field. The following outline indicates how a 2 or 3-year research programme could lead to an effective control method. Although it could be used as a PhD study, there are times when several people would be required to perform the work. Therefore it is proposed that the student would work flexibly with a research group dedicated to ecological investigations.

It should be emphasised that this research project is about using readily available, readily decomposed chemicals to eliminate signal crayfish. Looking at other substances, hormones, diseases etc. should be the subject of a separate project.

### **Year 1:**

- Update and expand on the existing literature search that was done as part of the R&D report.
- Develop keeping methods for 0+ animals and do most of the laboratory investigations on animals of this size, confirming important findings on larger animals.
- (If permitted) Prepare a small stock of native crayfish by the same means, to be used to check if any differential response to any toxicants exists. If it does, this may offer hope of selective control. Because of the difficulty of distinguishing small specimens

from similar sized signal crayfish, under no circumstances should these young native crayfish be released.

- Check contact times and subsequent lethality of established toxicants. It is important especially in a river to keep contact times short. Use international QA procedures and publish results.
- Investigate sources of natural pyrethrum and attempt to obtain a supply sufficient for two or three field trials.
- Conduct sighting shot trials as above on other potential toxicants within the “cheap and easily degradable” definition.
- Confirm the extermination and denaturing methods in 500 litre simulated field (i.e. dirty) conditions.
- Investigate in-burrow behaviour under varying conditions of toxicity, to determine the extent (if any) of shielding that may be afforded.
- Determine the true lethal time for deoxygenation, as complete immobility may not in such a case indicate death.

#### **Year 2:**

- Perform at least three 0.1 ha sized field trials in stillwaters. Field investigations and trials will require the active cooperation of people experienced in treating large bodies of water, for example Environment Agency Environmental Protection staff.
- Attempt to perform at least one field trial on a small moving watercourse
- Establish the best combinations of substances and conditions (including temperature) to minimise potential environmental damage.
- Find a way of denaturing a synthetic pyrethroid like permethrin.
- Plan and calculate all quantities, costs etc for realistic extermination scenarios, prior to proposing a full-scale field trial.
- Develop ideas on further control methods based on the findings so far.

#### **Year 3:**

- Perform at least one full-scale field trial if possible. This will require the assistance of some high level personnel in order to tackle the public relations side. There is a danger throughout this project that adverse public opinion may result in failure of even small project proposals. However, with a well-judged approach, the short-term environmental harm can be seen as a justifiable price to pay for controlling the invasion.

Conduct confirmatory tests on further control methods.

- Write up in full and publish.