Centre for Environment Fisheries & Aquaculture Science

Cefas

C5775

Controlling invasive crayfish

Managing signal crayfish populations in small enclosed water bodies

---

Paul Stebbing, Nicola McPherson, David Ryder and Keith Jeffery
5th April 2016

Cefas Document Control

Submitted to:	Mrs. Angela Taylor (Defra)
Date submitted:	29/04/2016
Project Manager:	Mr. Keith Jeffery
Report compiled by:	Dr. Paul Stebbing
Quality control by:	Dr. Edmund Peeler
Approved by and date:	20/08/2016
Version:	V3.

Version Control History			
Author	Date	Comment	Version
Paul Stebbing	31/03/15	Draft submitted to Defra and NNSS for comment	V1.
Paul Stebbing	28/05/15	Comments received from Defra and NNSS	V1.
Paul Stebbing	19/01/16	Further comments from Defra	V1.
Paul Stebbing	29/04/16	Amended draft, incorporating phase 2 results submitted to Defra and NNSS for comment	V2.
Paul Stebbing	16/08/16	Amended text based on comments from Defra, including additional modelling work.	V3.

Centre for Environment Fisheries & Aquaculture Science

Cefas

Paul Stebbing	02/02/17	Comments received from customer	V3.
Paul Stebbing	31/03/17	Revision of document based on customer comments	V4.

Executive Summary

Introduction

- The signal crayfish is recognised as a threat to the native white-clawed crayfish through disease transmission and competitive exclusion. It also impacts the wider ecosystem e.g. by burrowing. These impacts may compromise progress towards good ecological status under the terms of the Water Framework Directive (WFD), therefore, non-native crayfish are a key contributing factor to water bodies failing to meet WFD targets.
- Work has been conducted over a 3-year period, with a view to developing methodologies by which signal crayfish populations can be managed. The project can be broken down into 5 main areas: 1) the development and implementation of trapping trials at selected study sites; 2) the development of a crayfish population model, which is refined using the trapping data; 3) the use of the model to investigate the long term effects of trapping, beyond the life of the project; 4) the effects of varying degrees of trapping intensity in relation to population level control and 5) examining the effects of other control methods (male sterilisation and biocidal control) on a simulated crayfish population.

Trapping programme

- Work was conducted at small enclosed bodies of water, where signal crayfish had been reported as present. Some sites had been previously trapped prior to the project, while one site had an establishing population.
- A total of 6 sites were selected for use in the study with the aid of the Angling Trust, although 1 site dropped out after one year of trapping. The sites varied in size from 0.67 to 19.09 acres.
- A short laboratory study was conducted to select the most appropriate trap, based on efficacy, availability and ease of use.
- A programme of trapping was developed in co-ordination with volunteers at each site, suitable for the collection of scientific data, but also within their means of delivery.
- Trapping was conducted at each of the sites from the beginning of 2015 to the end of 2016. Baited traps were emptied at least once per week for 52 weeks of the year, conditions permitting. The density of crayfish traps deployed at the sites varied from 1.3 to 45.6 traps per acre.
- Data on the total catch from each trap was recorded by the volunteers each time the traps were emptied, the total number of crayfish caught was recorded, along with the size category the animal was in (small, medium or large), the gender of the animal and if the female animals

were carrying eggs. Additionally, volunteers were asked to record further information pertinent to the trapping or general observations concerning the nature of the site.

- In the final year of study half of the traps were modified based on communications with commercial trappers with a view of increasing trap efficacy.

The effects of trapping on a population

- None of the populations were eradicated as part of the study (but this was not expected), however, valuable information in relation to the effects of trapping on crayfish populations has been gathered, increasing our knowledge in relation to the effort required to physically remove a crayfish population.
- Numbers of crayfish caught at all sites were highest during summer months in comparison to winter months, although more berried females were caught during winter months than at other times of year, emphasising the need to trap during the winter.
- In general terms trapping resulted in an increase in the proportion of females being removed and a decrease in berried females, with a decrease in the proportion of large crayfish being caught and an increase in small crayfish.
- The increase in proportion of small and female crayfish is likely to be a result of the removal of the larger animals, which act as a deterrent for female and smaller animals to enter traps.
- The decrease in berried females caught is likely a result of fewer suitable sized (i.e. large) males as partners, and therefore the frequency in successful mating events decreasing, combined with a reduction in total female numbers.
- The effect that trapping had on the site varied based on the size of the site, the density of trapping, and the status of the population (e.g. if it was establishing, or if it had been trapped before).
- In general, the data suggests a change in the crayfish populations occurs over time, where key phases in the process can be identified.

Trap modifications

- Traps were modified by increasing entrance size and decreasing mesh size.
- After modification traps were more likely to catch small and female crayfish than other classes.
- The results show that trap modifications can be used to manipulate the catch, influencing the size and gender of animals entering the trap, and could be improved on significantly with further refinement.

Predicting the effects of further trapping

- The population model was used to determine the effects of the continuation of current trapping effort on the crayfish population at all study sites.
- Under current effort, eradication was estimated to be possible at 3 of the sites between 2020 and 2022, these sites are the smallest in size and have the highest trapping density.
- In the case of two of the sites, trapping had been previously conducted at the sites in the previous three years, therefore the population had been depleted because of previous efforts before this study began.
- One population was establishing at the beginning of the study and was predicted to be capable of being eradicated per the model.
- With an increase in trap numbers being used (from current densities to between 50 and 100 traps per acre) eradication was estimated as possible at all sites, with the amount of time to eradication decreasing with the more traps being used.
- With an increase in the number of traps being used the number of visits required to achieve eradication decreases, but the effort required to empty the traps at any one visit increases. At large bodies of water, considerable effort would be required to achieve eradication using the trapping method described within this study alone. It was estimated that to empty the equivalent of 50 traps per acre at the largest of the study sites would take just under 153 person hours per week which would have to be sustained every week of the year over multiple years.

The effects of low intensity trapping

- Intensive trapping sustained over a long period with a view of eradicating a population may not always be a viable option, therefore alternative low level trapping has been investigated with the aims of controlling a population at a level where it no longer poses the same degree of issues to the water and stakeholders.
- Periods of intensive trapping were simulated for one and two years proceeded by low level trapping to examine if this was a viable management approach.
- With constant low intensity trapping all year round a population can be substantially controlled, potentially reducing the size by 75% over a 10-year period if 10 traps per acre are emptied once a week. Populations size can be decreased by about 50% with 6 traps per acre.
- One or two summers of intensive trapping preceding the constant low level trapping marginally decreased the time spent to reach a point of new equilibrium in the population.

- With one summer of intensive trapping, the population decreased in size, but once the trapping pressure had been removed or decreased the population size increased, exceeding its original density before returning to a point of equilibrium.
- With continuous summer trapping, between May and August, a level of control can be achieved, but much less than when trapping is constant throughout the year. With removal of this trapping pressure it is likely that the population will recover as observed previously.
- Low intensity trapping does present a viable management option for the control of a crayfish population where a reduction in the density of crayfish in the water may reduce issues associated with the presence of the crayfish. It should be noted however, that if trapping was to stop then the population would return to its previous density.

Simulating other control methods and combinations

- Alternative methods of control were examined to determine their relative effectiveness under simulation compared to trapping. Male sterilisation and the use of biocides as potential control methods were examined.
- A simulated crayfish population in a one-acre pond was used to estimate the effectiveness of the different control methods.
- Male sterilisation was very effective, even when a low (10 per acre) number of traps were used to collect the males for sterilisation, eradication was achieved by 2022, while without sterilisation (i.e. trapping alone at the same trap density, where animals were just removed) eradication was determined not to be possible.
- With an increase in trap number, and therefore the number of males being caught and sterilised, the time to eradication decreased to a minimum of March 2019 when deploying 100 traps.
- The effects of an ‘attract and kill’ biocide delivery mechanism was modelled.
- With a low number of doses per m^2 of the biocide, eradication was not achieved, but with 5 doses per m^2 eradication was achieved rapidly (by June 2017).
- Changes in the replenishment rate of the biocide had little effect on time to eradication.
- When a combination of the control methods was simulated (trapping, sterilisation and biocide control), eradication was achieved in all but one scenario, where only trapping was applied at a level of 10 traps per acre.
- Male sterilisation and trapping together achieved eradication quicker than trapping alone.

- Biocide treatment with only 1 dose per m^2 in combination with trapping achieved eradication more effectively than trapping alone, but was less effective than trapping and male sterilisation together.
- When biocide treatment with only 1 dose per m^2 was combined with trapping and sterilisation there was little marked difference in time to eradication compared with trapping and sterilisation.
- When using the biocide treatment at 5 doses per m^2 there was no marked difference in time to eradication between using the biocide alone or in combination with other control methods.
- These results suggest that biocidal control should be deployed in isolation at 5 doses per m^2 and should not be considered for deployment at a lower dose density.
- Sterilisation in combination with trapping is potentially a viable means of increasing the effectiveness of a trapping programme, although more work is required to determine the actual recovery rate of the sterilisation process used in this model.
- Biocidal control at the higher dose rate was the most effective means of control estimated to result in eradication within a year of deployment, however there are a number of assumptions made in relation to the attractiveness and therefore the efficacy of this methods which would still need to be determined.

Conclusion

- As a result of this study, additional insight into the effects of trapping on crayfish populations has been obtained.
- Phases in the response of crayfish populations to trapping have been identified.
- While eradication has not been achieved as a result of this study, it has been estimated using the developed population model to be feasible.
- The effects of low intensity trapping and the level of control this will exert on a population has been examined. With as few as 6 traps per acre emptied once per week throughout the year a 50% decrease in population density can be observed over a 10-year period.
- A suggested step wise process to developing a trapping programme has been provided, suggesting that trapping programmes following a similar design would require at least 46 traps per acre emptied at least once a week all year round if the aim of the trapping is to eradicate the population.

- A simulated population took 7 years to be eradicated where 50 traps per acre were deployed and emptied once per week for 52 weeks of the year. More frequent emptying of traps would shorten the time to eradication.
- Alternative methods of control have been examined, male sterilisation may be a valuable tool to enhance current trapping efforts, while ‘attract and kill’ biocides may be a method by which eradication could be achieved over a short period of time (less than 1 year).
- While the results of this study are directly applicable to small enclosed bodies of water some of the principles will apply to larger waters, but would need to be scaled accordingly.

Acknowledgements

This work was funded by Defra in support of the delivery of Water Framework Directive objectives on the management of invasive species. Essential input and support has been provided by the Environment Agency and Natural England in the development and delivery of this work. The Angling Trust have been key in identifying suitable sites, leasing with angling clubs and supporting the work area. Above all, the volunteers at each of the sites that have spent their own time trapping crayfish and collecting data, should be acknowledged and thanked. Without their hard work, commitment, informed input and dedication this work would not have been possible.

Table of Contents

1. Introduction

Non-native species of crayfish have been present in Great Britain (GB) since the 1970s: initially introduced for aquaculture, the ornamental trade, or human consumption, they have subsequently escaped, or been released into natural waters. There are seven species of non-native crayfish currently established in British waterways: signal crayfish (*Pacifastacus leniusculus*), Turkish or narrow-clawed crayfish (*Astacus leptodactylus*), noble crayfish (*Astacus astacus*), red swamp crayfish (*Procambarus clarkii*), white river crayfish (*Procambarus acutus*) spiny-cheeked crayfish (*Orconectes limosus*), and virile crayfish (*Orconectes virilis*).

While several of these species are considered invasive, the signal crayfish is most widely distributed in the UK and currently has the greatest impact. The signal crayfish is most recognised for the threat it poses to the native white-clawed crayfish (*Austropotamobius pallipes*) through disease transmission and competitive exclusion. It also, however, impacts on the wider ecosystem through various means including: a) negative effects on the wider invertebrate community; b) competitive interactions with native fish; c) predation on native species; and d) impacts on river morphology through burrowing and sediment mobilisation. Because of these impacts the signal crayfish can have a wide ranging detrimental impact on invaded ecosystems. Any of these impacts may compromise progress towards good ecological status under the terms of the Water Framework Directive (WFD). Therefore, non-native crayfish are a key contributing factor to water bodies failing to meet WFD targets. Furthermore, signal crayfish impact on ecosystem services, limiting the use and productivity of affected waters; for example, signal crayfish can have a detrimental impact on fisheries, where the crayfish may destabilise banksides, predate on fish and steal bait from anglers' lines. A recent case in Oxfordshire (2016) has seen historical structures built close to a river bank becoming destabilised through signal crayfish burrowing.

Given the wide-ranging distribution of signal crayfish within the UK it would seem unlikely that a national scale eradication of the species is possible given current technology, understanding and resources. Despite this, there are clear requirements for methods of control/eradication to be developed to manage signal crayfish and other invasive crayfish species under certain circumstances, for example, where they are impacting on ecosystems, the service they provide, environmental protected habitats or features or because of a rapid response to a newly discovered population.

There are methods of control/eradication developed and demonstrated to be successful under certain circumstances, such as the application of pyrethrin pesticide Pyblast. The current method of application of Pyblast is to dose the water column and bankside with sufficient quantity of the chemical to kill all crayfish. Despite being fast acting and effective, this method of pesticide application is not suitable for use in conservation areas, sensitive habitats or working fisheries due to their indiscriminate mode of action (i.e. they kill most things). In addition, dosing of the water column with pesticides is not suitable for application in flowing water or large bodies of standing water, is often expensive to apply and require specialist training and equipment. There are, therefore scenarios where control/eradication is required, but for which the currently available methods are not suitable. Over the years there have been several studies conducted on the effectiveness of crayfish trapping, what effect it has on populations of crayfish, and how effective it may be as a control method. Annex 1 provides a brief overview and summary of some issues relating to trapping. A common view of crayfish trapping is that it is an ineffective tool in the management of crayfish, and eradication is not possible with trapping alone.

The Defra funded work presented within this report examines how effective trapping is as a means of controlling populations of signal crayfish. Despite being labour intensive and potentially taking a very long time to eradicate a population (if at all), physical removal is comparatively easy to apply, is accessible to a wide range of people, as it does not require specialist training or equipment and does not have significant environmental impacts. This document reports on the findings of trapping field based studies conducted by a dedicated and highly motivated team of volunteers. Although the aim of the trapping at the study sites was to remove as many crayfish as possible with a view of eradicating the population, complete eradication was never perceived as a viable end point within the life time of the project. Data collected from the trapping study sites in turn has fed into a population model. The population model has then been used to estimate the effectiveness of the trapping programme and how much further effort is required to achieve eradication. The work has focused primarily on managing signal crayfish populations in small enclosed lakes, as it is within these environments that eradication is most likely to be achieved and therefore attempted. Furthermore, the work provides insight into how other methods of control can be applied with a view of eradicating a signal crayfish population, what methods may be of use in combination and how much effort would be required. When developing this work, the project has had contact with commercial trappers, who provided invaluable insight into how crayfish populations can be controlled (see Annex 2). We hope that all those involved in the management of crayfish will find information within this report of use.

2. Trapping trials set up

Field trials were set up to examine the effects of trapping on signal crayfish populations. The trials consisting of programmes of trapping run at 5 still water sites from across England over a two-year time period (2014 – 2015), a 6th site was trapped for one year but subsequently dropped out of the programme. Each of the sites was managed by a fishing club belonging to the Angling Trust. The clubs provided volunteers to undertake the trapping and disposal of animals. A process was set up to shortlist sites for possible inclusion into the trial, from this shortlist the 6 sites were selected. Annex 3 details the selection process, the information relating to the site and the processes set up specific to each of the sites.

The view was to implement trapping based management plans at the sites, which would not only provide information into the effectiveness of crayfish trapping, but which could also be easily replicated elsewhere. With a view of developing information on how a control programme could be implemented, efforts were made to ensure that the methods and materials used were easily applied and readily available. Therefore, a process was developed to select the most effective off the shelf trap design (see Annex 4). While these trials only looked at three trap types, there are many other designs available off the shelf which could prove as, if not more, effective than those used in this study.

At each site baited traps were to be set at predetermined locations. These locations were predominantly where the most suitable crayfish habitat was observed, but in some cases was restricted by other variables, such as public access. The number of traps varied between sites based on different trapping densities, to determine a range of effect, but was predominantly dictated by how many the volunteers at each of the sites were able to manage. The traps would then be emptied on a frequency agreed with the volunteers, although this varied with the time of year and between sites to some degree. When the traps were emptied the total number of animals was counted, the gender of each animal recorded, which length category the animal was in (small, medium or large) and the reproductive state of the females. Trappers were also requested to make general observations in relation to the crayfish and the site. Annex 5 provides more detail into how this process was established and the reasoning behind the approach, including the number of traps to be set and the frequency of emptying. Annex 6 provides a summary of the information on each site.

In 2015 half the traps (alternate trap numbers) were modified (see Annex 7) with a view to increasing trap efficiency. The modifications were based on discussions had with commercial trappers (see Annex 2). The reasons behind examining trap efficiency is that the more effective the trap then the quicker the population will be removed. In addition, if traps could be designed to target specific life stages or females then they may increase the likelihood of eradicating the population and decrease the time it would take.

The following sections present the analysis of the trapping data in relation to each site, in addition to how the trapping data was used to parameterise the population model in addition to examining the effects of trapping on crayfish populations.

3. The effects of trapping on population structure

The total crayfish count per trap per visit was plotted by the date the traps were set for each of the sites (figure 1). Strong seasonal patterns in the number of crayfish caught are visible at Bird in the Hand Pool and Yeadon Tarn, as well as, to a lesser extent, Thornhill Road, where trapping efficacy increased over summer. Each site had a period in the winter when no trapping occurred, and at Rookery Reservoir as a result of changes in management at the site. In the case of Starmount the site withdrew from the trapping programme in March 2015. A decrease in the crayfish caught per trap and the mean number of crayfish per trap can be observed Bird in the Hand Pool and Yeadon Tarn, and to a lesser degree at Rookery Reservoir, Starmount Fishery and Thornhill Road.

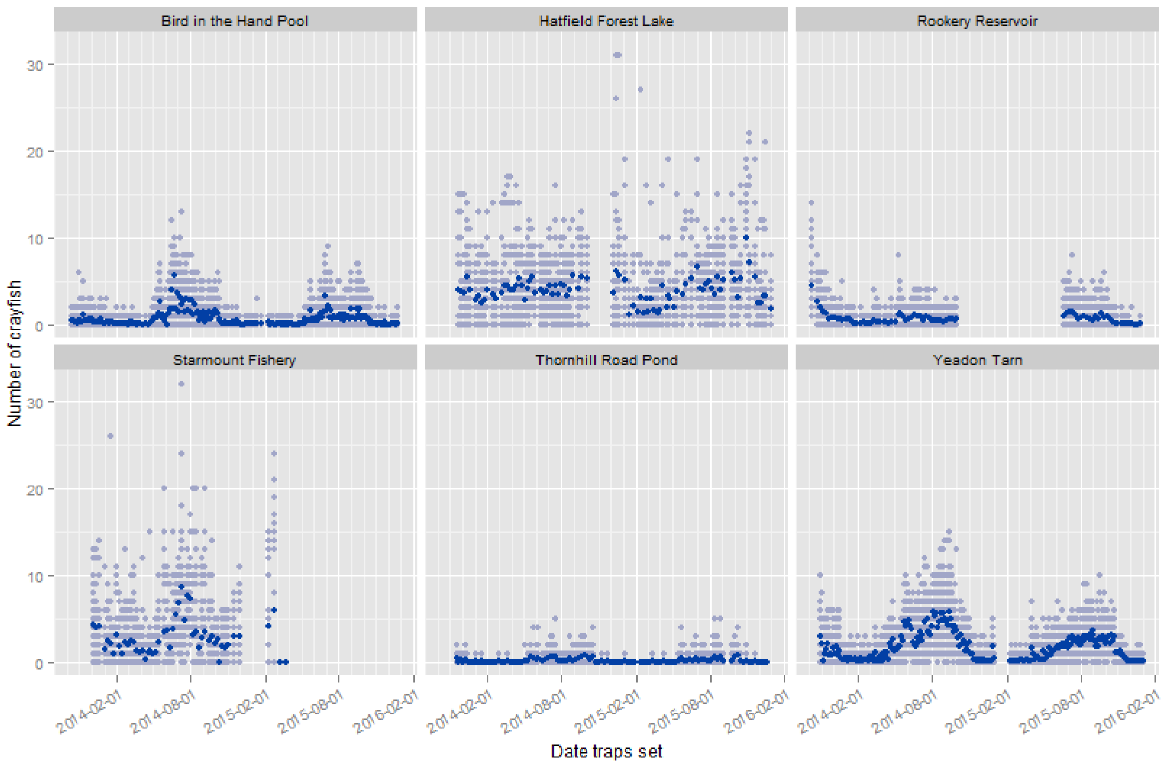

Figure 1: Light blue: crayfish counts per trap plotted against the date the trap was set. Dark blue: mean count per trap.

Size and sex structure

In figures 2 and 3 the trapping data has been manipulated to give daily totals, in order to make comparisons between the sites. While traps were emptied 3, 4 or 7 days after they were set, the count per trap has been averaged across the intervening days in these figures.

In figure 2 the small (dark blue), medium (light blue) and large (red) counts are shown. With the exception of Starmount Fishery and Thornhill Road Pond, there is a visible decrease in the number of large crayfish caught throughout the study. An increase in the proportion of small crayfish being caught, relative to other sizes, increased at all sites with the exception of Bird in the Hand Pool, where the number of small animals being caught decreased.

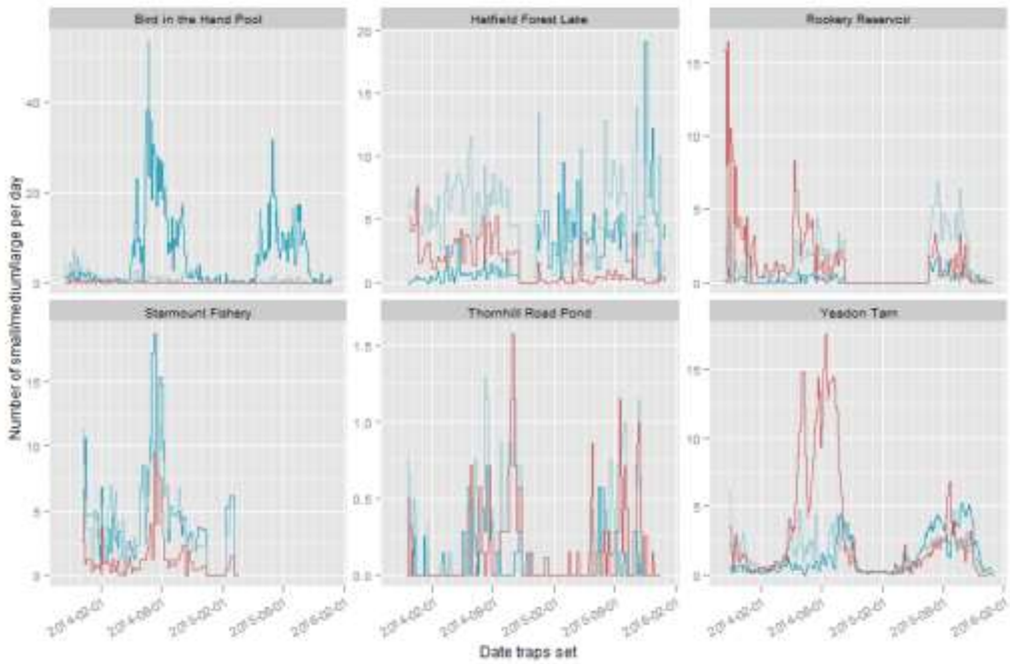

Figure 2: Daily totals per site: small crayfish in dark blue, medium in light blue and large in red.

In figure 3 the male (yellow) and female (blue) counts are shown. With the exception of Thornhill and Hatfield Forest there is a visible decrease in the number of male crayfish. A reduction in numbers of female crayfish is clearly visible at Yeadon Tarn, but less obvious elsewhere.

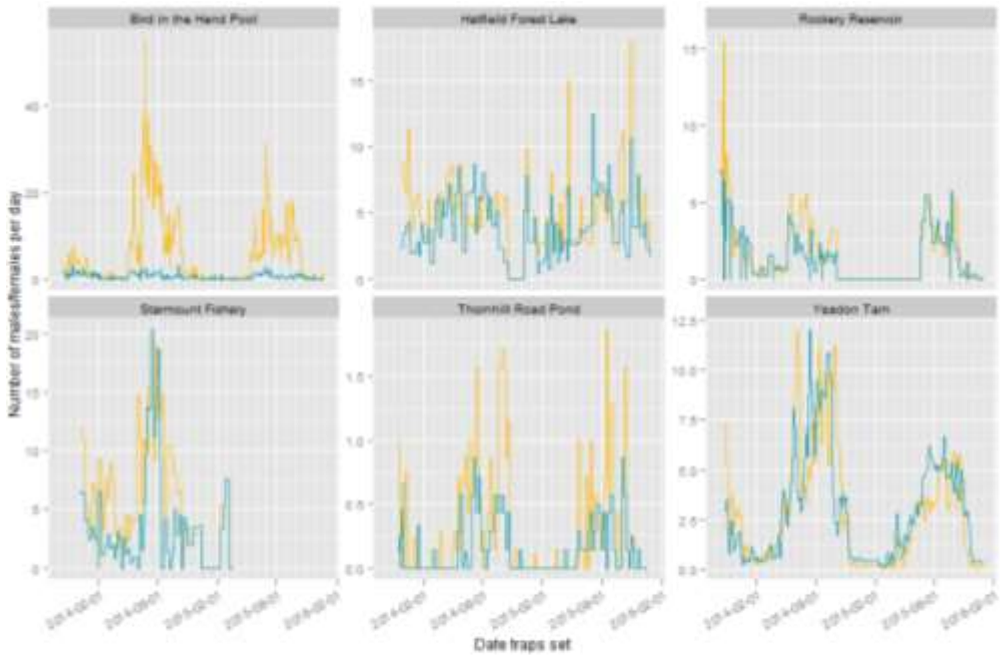

Figure 3: Daily totals per site; males in yellow, females in blue

Statistical analysis of the data (by binomial General Linear Models (GLM)) was conducted to compare the difference in proportion of crayfish being caught at the beginning and end of the study by size and gender for each site. The analysis of results can be found in Annex 8.

Figure 4 shows the proportion of females being caught at the beginning of the trapping exercise (grey dot) in comparison to the end (black dot) for each sites. There was no significant change in the proportion of females caught between the beginning and end of the trapping exercise at Thornhill Road Pond. Bird in the Hand Pool saw a decrease in the proportion of female crayfish being caught from 14 to 4% from the start to the end of the study, while at other sites the ratio increased from between 28-42% at the start, to 46-60% at the end of the study.

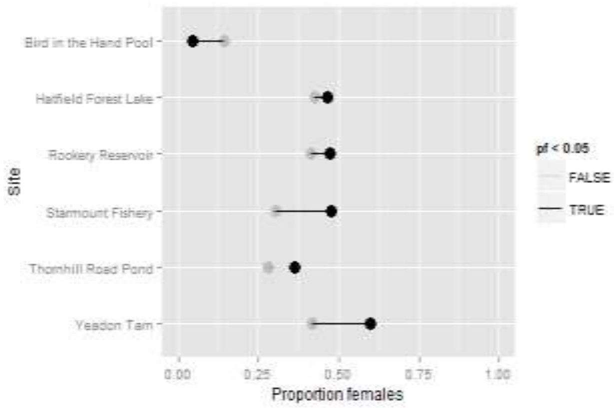

Figure 4. Start (grey) and end (black) proportions of small and female trapped crayfish for each site according to a GLM with time as an explanatory variable.

Figure 5, 6 and 7 show the proportion of female and male crayfish for each size category (small, medium and large) being caught at the beginning (grey dot) and end (black dot) of the trapping programme for each site.

There are many ways in which this data can be examined, either by size or gender. Potentially the most useful way, in relation to understanding the effects of trapping on the population structure is to examine the data by site. In general terms the proportion of small crayfish caught increased and large crayfish decreased.

At Bird in the Hand the proportion of small animals being caught increased from 16% females and 54% males to 99% for both, therefore almost all of the catch from Bird in the Hand by the end of the study consisted of small animals. The number of medium and large animals decreased accordingly, with a reduction from 77% to <1% observed for medium females, a decrease from 43% to <1% for medium males, a decrease from 12% to <1% observed in large females and from 4% to <1% in large males.

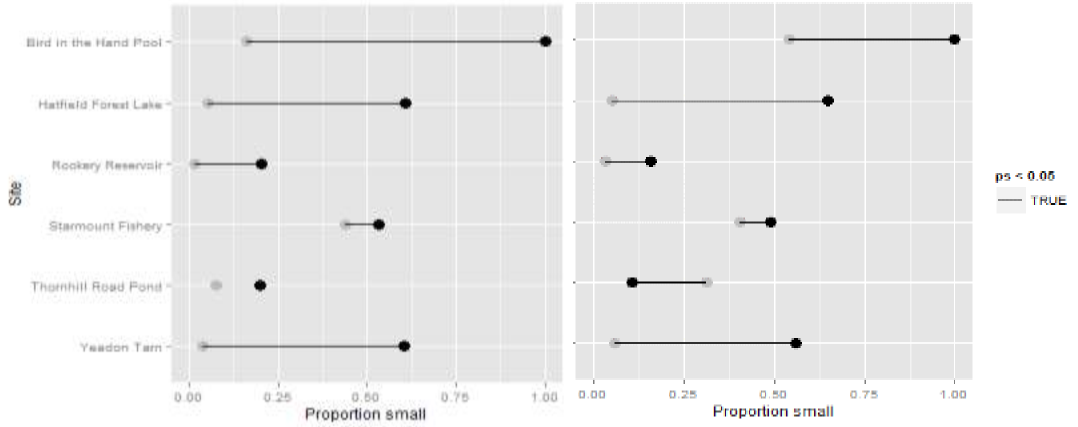

Figure 5. Start (grey) and end (black) proportions of small females (left) and male (right) trapped crayfish for each site according to a GLM with time as an explanatory variable. Examples where the relationship with time is significant are joined by a black line.

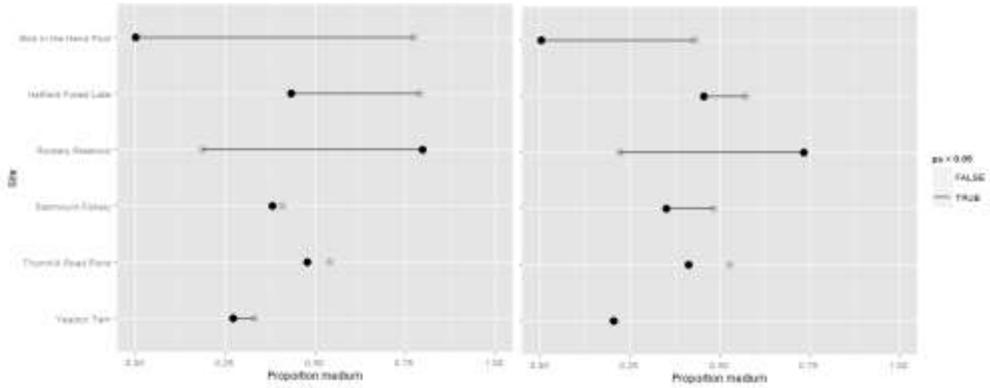

Figure 6. Start (grey) and end (black) proportions of medium females (left) and male (right) trapped crayfish for each site according to a GLM with time as an explanatory variable. Examples where the relationship with time is significant are joined by a black line.

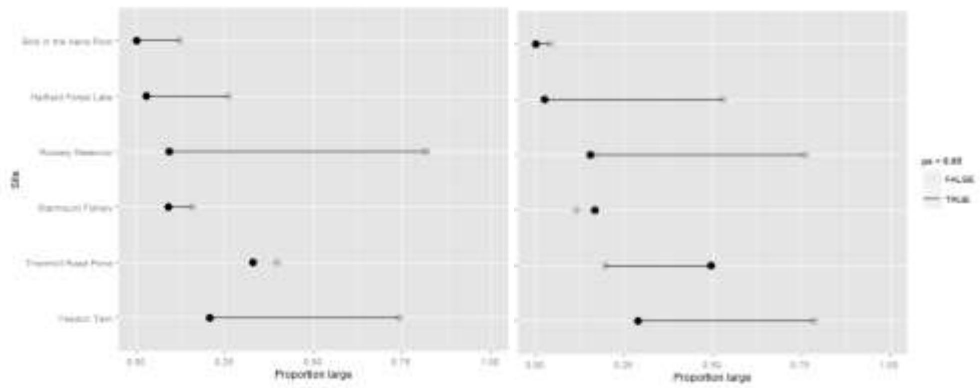

Figure 7. Start (grey) and end (black) proportions of large females (left) and male (right) trapped crayfish for each site according to a GLM with time as an explanatory variable. Examples where the relationship with time is significant are joined by a black line.

At Hatfield Forest the proportion of small animals being caught increased (5% to 60% females and 5% to 65% males). The proportion of medium animals caught decreased (79% to 43% females and 57% to 45% males). Likewise, the proportion of large crayfish caught also decreased (26% to 3% females and 52% to <1% males).

Rookery Reservoir showed a similar response with the proportion of small crayfish caught increasing (1% to 20% females and <1% to 16% males). The proportion of medium crayfish caught also increased (19% to 79% females and 22% to 73% males). The proportion of large crayfish caught at Rookery Reservoir decreased (81% to 9% females and 78% to 15% males).

At Starmount Fishery the proportion of small crayfish caught also increased (44% to 53% females and 40% to 49% males). Medium crayfish caught at the site decreased (41% to 38% females and 48% to 35% males), which was also the case for large females (16% to 9%) while the proportion of large males increased (11% to 16%) although not significantly. It should be noted that Starmount Fishery stopped trapping in March 2015, therefore making any direct comparison with other sites in this manner difficult.

Thornhill Road was unique in seeing an increase in the proportion of small female crayfish (8% to 20%) yet a decrease in small male crayfish (31% to 10%). The site saw a decrease in medium sized crayfish being caught (54% to 48% females and 53% to 41% males), and likewise for large females, (40% to 33%), but an increase in the proportion of large males being caught (20% to 49%).

Yeadon Tarn observed an increase in the proportion of small crayfish being caught (4% to 60% females and 6% to 56% males). The proportion of medium crayfish caught varied very little (33% to 27% females and 21% to 20% males), but significant differences were observed in the proportion of large animals caught between the beginning and the end of the programme (74% to 28% females and 79% to 28% males).

Females: Berried and normal

Figure 8 shows the number of females caught per trap through the trapping period, for both berried (carrying eggs in orange) and normal (not carrying eggs in purple). Berried females appeared to be most abundant over winter months, with the female proportion of some catches only consisting of berried females. This is most apparent in the plots for sites Hatfield Forest and Yeadon Tarn. The proportion of berried females decreased across the study at all sites.

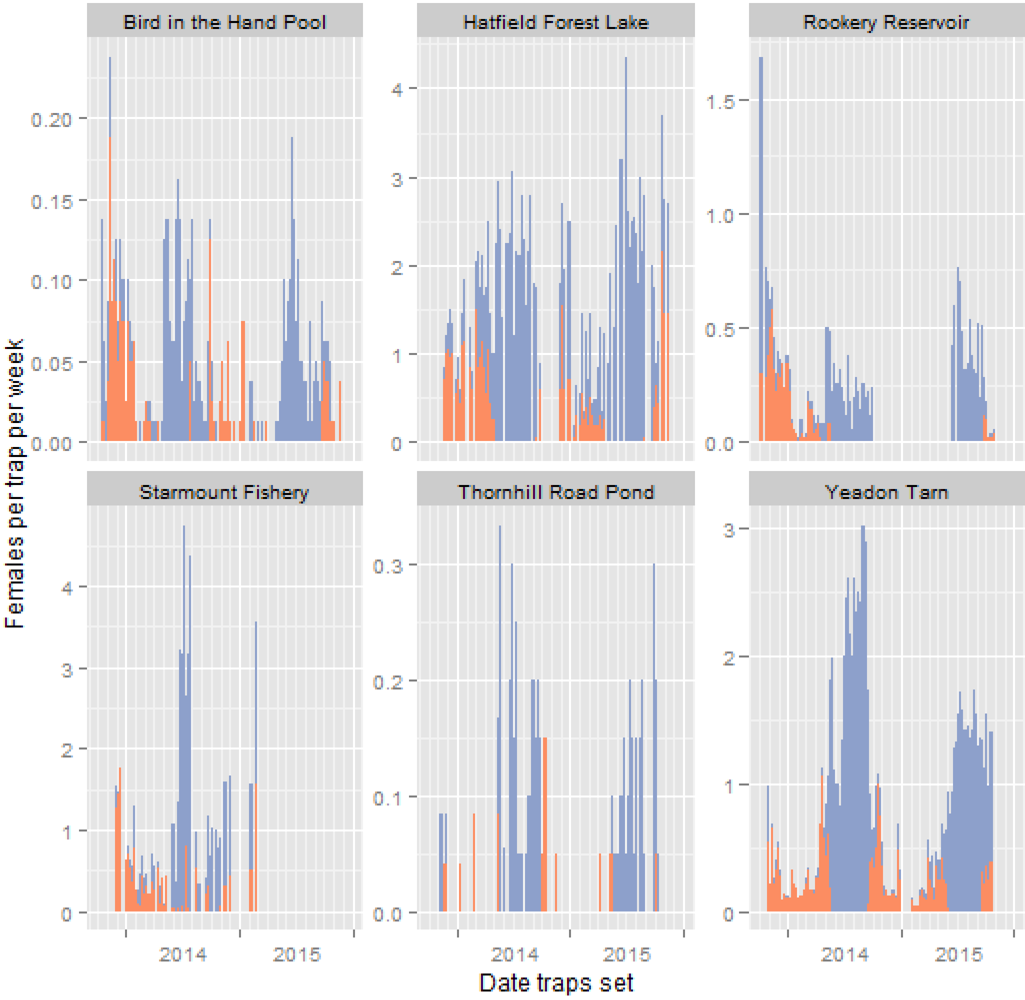

Figure 8. Females caught per trap per week; berried (orange) and normal (purple) – note the differences in scale.

Conclusions

- Although all sites had some gaps in trapping data as a result of cold weather, particularly over winter months, gaps also appeared for other reasons, such as a change in site management (Rookery Reservoir) or sites electing not to be part of the study (Starmount Fishery). The inclusion of these sites in the analysis of the effects of trapping on crayfish populations can confuse the overall conclusions.
- Numbers of crayfish caught at all sites were higher during summer months in comparison to winter months, although more berried females were caught during winter months than at other times of year, emphasising the need to trap during the winter.
- In general terms trapping resulted in an increase in the proportion of females being removed and a decrease in berried females being removed, with a decrease in the proportion of large crayfish being caught and an increase in small crayfish.

- The increase in proportion of small and female crayfish is likely to be as a result of the removal of the larger animals, which act as a deterrent for female and smaller animals to enter traps.
- The decrease in berried females caught is likely to be a result of fewer suitable size males as partners, causing a decrease in the frequency of mating events, combined with a reduction in total female numbers.
- For more in-depth assessment it is important to consider the history of the sites in addition to the trapping intensity being applied when examining the data. In summary the sites can be categorised as follows:

Site name	Traps per acre (at end of study)	Population status	Previous trapping (in last 3 years)?
Bird in the Hand Pool	46.511 (high)	established	Yes
Hatfield Forest Lake	1.761 (low)	established	None
Rookery Reservoir	27.322 (high)	established	Yes
Starmount Fishery	11.858 (low)	established	None
Thornhill Road Pond	29.851 (high)	establishing	None
Yeadon Tarn	1.310 (low)	established	None

- Bird in the Hand Pool is an established population that has already been trapped and therefore most of the large and medium crayfish have been previously removed. This has resulted in small decreases in large and medium animals being observed over the trapping programme, but large increases in the proportion of small animals being removed. This is also the only site where the proportion of females being caught decreased. This decrease was observed in small animals possibly as a change in the sex ratio of animals at recruitment in response to the trapping. Increases in male birth rate has been observed in many species as a response to decreases in population size.
- Hatfield Forest Lake is an established population which has not been trapped before, and therefore is responding to the initial stages of trapping. Despite the low number of traps, a decrease in the number of large and medium animals was observed with an increase in the proportion of small animals. This is the same for both genders.
- Rookery Reservoir has an established signal crayfish population, which has been trapped previously. As many large animals had already been removed as a result of the previous trapping, the proportion of large crayfish trapped decreased rapidly when trapping commenced as part of this programme and continued to decrease coupled with an increase in the proportion of medium and small crayfish caught. This was the only site where the

proportion of medium crayfish caught increased. This may be because of the previous trapping undertaken at the site, and a relative absence of large animals.

- Starmount Fishery contains an established population of signal crayfish, which had not been previously trapped. As the trapping data is incomplete it is difficult to draw clear conclusions in the same way as can be done for the other sites. However, there are some indications that the proportion of large and medium crayfish are decreasing coupled with an increase in the proportion of small crayfish.
- Thornhill Road Pond is unique amongst the sites as it is the only one containing an establishing population. As this is an establishing population the crayfish density is likely to be very low. There was an observed decrease in the proportion of small crayfish being caught with an increase in the proportion of large (when combining both genders). It is possible that the number of large animals in the population are rare in comparison to smaller animals, with the large animals being the founders and the smaller animals there off-spring.
- Yeadon Tarn contains an established population of crayfish and had not been trapped prior to this programme of work. Over the trapping period there has been a decrease in the proportion of large and medium animals and an increase in the proportion of small animals, despite the lowest trapping density of all of the sites.
- This data suggests phases in the response of crayfish populations to trapping assuming the trapping is of an established population which has not been previously trapped and trapping effort is sustained at a level at which eradication will occur (see further in the report):
    - Phase 1. Catches will predominantly consist of large male crayfish.
    - Phase 2. A decrease in the proportion of large male crayfish caught, with an increase in the proportion of medium male crayfish and all sizes of females being caught.
    - Phase 3. A decrease in the proportion of medium crayfish caught, with an increase in the proportion of small crayfish caught.
    - Phase 4. A decrease in the number of small crayfish caught, coupled with a decrease in the number of females.
    - Phase 5. Suppression/eradication.

4. The efficacy of trap modifications

Alternate traps at each site (5 total) were modified from spring 2015 to ensure that both types of trap were evenly distributed throughout the waters. Details on how the traps were modified can be found in annex 7, but in general terms, the entrance size was increased, the mesh size was decreased and guards were put in to stop animals from escaping through the entrances. Other than the modifications the modified traps were handled in exactly the same way as normal traps. Furthermore, data from the corresponding period in 2014 was used to determine whether the positions of these traps were more or less effective prior to the modifications.

Figure 9 shows the number of crayfish caught, categorised by site, year and type of trap. Data is shown for 2014, before the traps were modified, and 2015, when the traps were modified. The traps that were subsequently modified in 2015 are labelled as “Pre-modified” traps in the 2014 data to show whether these traps were more or less effective prior to modification. The pre-modified (2014) and modified (2015) traps are compared with the unmodified traps from the corresponding year.

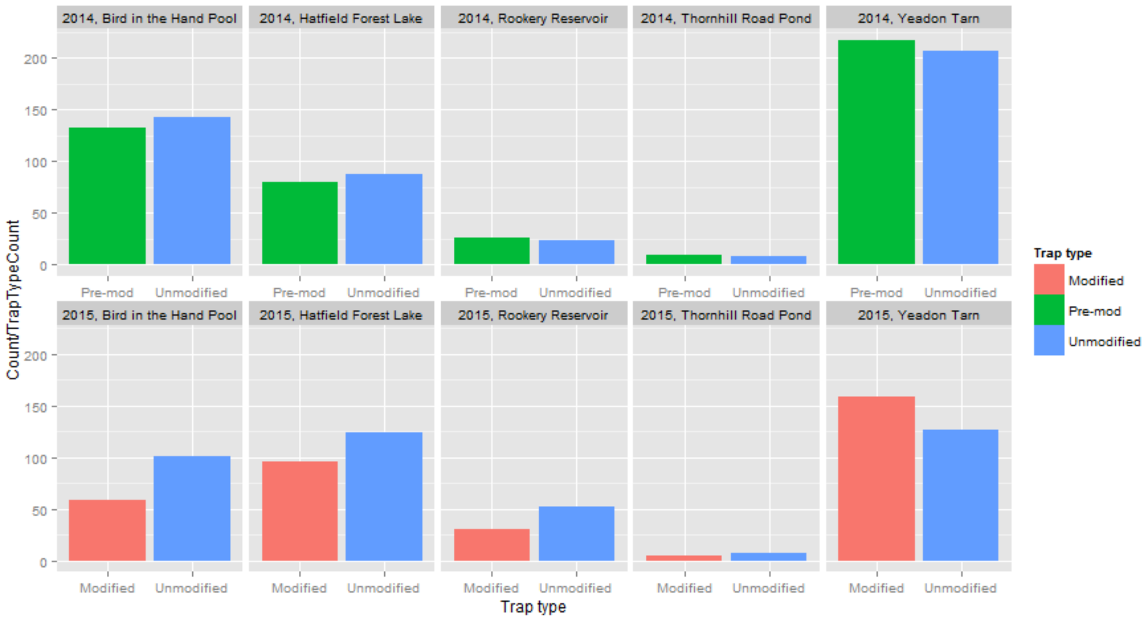

Figure 9. Number of crayfish trapped by year and trap type, divided by number of traps falling into each category.

Generalised linear models were used to determine differences between the efficacy of modified and unmodified traps. The pre-modified traps caught slightly less than unmodified traps in 2014 at all sites with the exception of Yeadon Tarn, but in none of the differences were significant. Once modified in 2015 the traps caught less animals at all sites with the exception of Yeadon Tarn. The mean catch was significantly lower at Bird in the Hand, Hatfield Forest Lake, Rookery and Thornhill Road.

Further analysis looking at the size of the crayfish in modified traps in comparison to the unmodified traps showed that the modified traps caught more small animals, this is in addition to the overall increase in small crayfish caught in 2015.

The same analysis was run to see if the sex ratio caught was different in modified traps. While the proportion of female crayfish caught increased in 2015 compared to 2014, a further increase was also observed in the modified traps when compared to unmodified traps although this was not significant.

Conclusions

- Although traps selected for modification were less effective than those left unmodified, statistical analysis show that the traps selected for modification were not significantly different in terms of size and sex ratio than the other traps prior to modification.
- After modification traps were more likely to catch small and female crayfish than other classes.
- The total number of crayfish caught in the modified traps was lower than unmodified traps.
- The results show that trap modifications can be used to manipulate the catch, influencing the size and gender of animals entering the trap, and could be improved on significantly with further refinement.
- Further refinements to the trap modifications are required to fully realise how much trap efficacy can be improved, these include:
    - The stockings used to reduce mesh size proved impractical and may reduce the attractiveness of the trap, therefore other alternative mesh should be looked into.
    - The zip ties facing into the main body of the trap, while preventing animals from escaping, also prevented larger animals from entering the trap.

5. The population model

The signal crayfish population model used deterministic compartmental mathematical models developed to describe the basic dynamics of a closed (no immigration or emigration) population of signal crayfish. Each compartment relates to a specific life stage of a crayfish for each gender. Animals will move between the compartments dependent on the growth rate and density of the population in addition to the time of year. The models are based on a series of coupled non-linear ordinary differential equations that described the change in density (per m^2) over time of each subset of the crayfish population (figure 10). These equations were solved numerically using R.

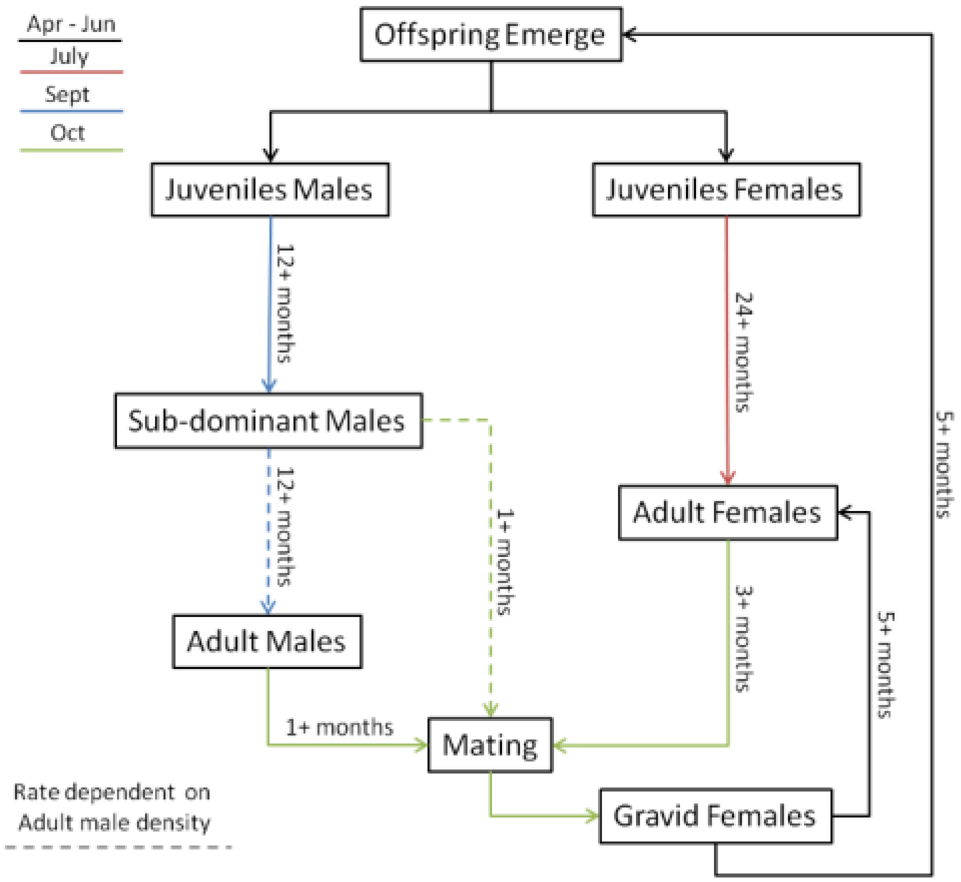

Figure 10. Life-cycle of signal crayfish in the UK. Colours denote the months in which transition between states occur.

The population model was refined in a number of ways over the course of the project to better reflect what was observed in wild populations. Data from the trapping programme was used to improve the predictive robustness of the model. This included the addition of temperature dependant seasonality into the model, adjustments were made to better accommodate the density dependent element and additional compartments were added to better represent the life cycle of signal crayfish within the model.

The aim of this modelling work was to produce a model which described all of the sites studied, with a minimal amount of parameterisation. To determine how well the model fitted each site the output from the model was compared to the data collected. Accordingly, for each site the model was run from 1980, and seeded with a small number of crayfish in the year that the species was first recorded as being present at the site. The trapping, as undertaken at each site, was simulated using the model and compared with the actual results collected over the same time period. This provided an estimation of how well the model fitted the actual data and therefore how good it is as a predictor. Figure 11 shows a graphical representation of the outputs from the comparison of the model outputs and the real trapping data collected from the sites. The red areas on the bar graph show where the model and actual data agree; the dark grey areas are where the model underestimated the number of animals being trapped (more animals were actually trapped than the model predicted should be) and the light red/transparent areas show where the model overestimates the number of animals being removed by the trapping taking place (less animals were actually trapped than the model predicted should be).

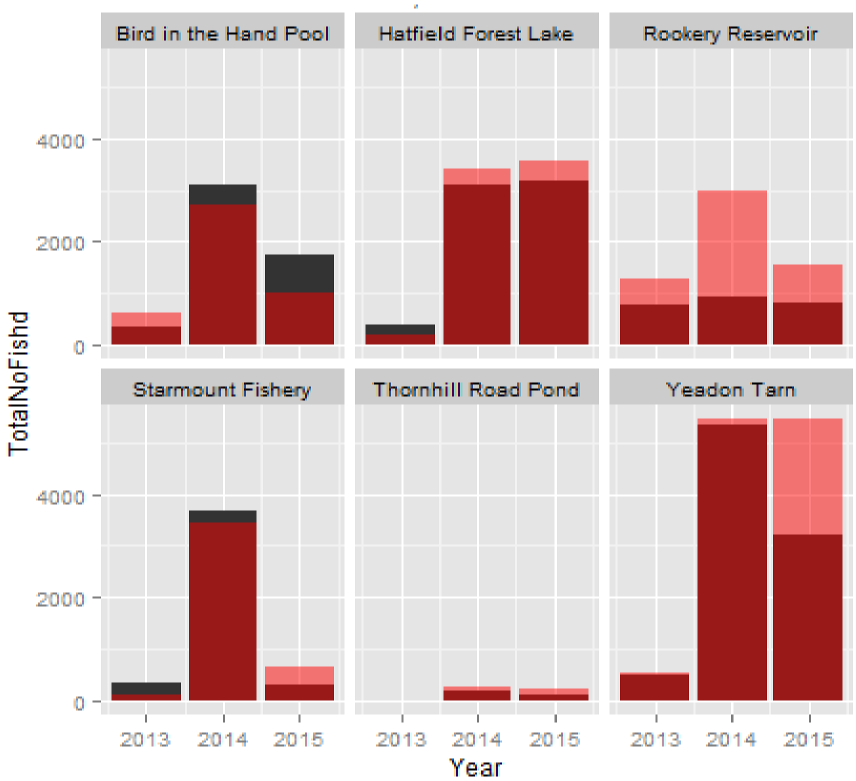

Figure 11. Total number of crayfish caught in 2013, 2014 and 2015 as predicted by the model in red, dark grey/black areas show where the model has overestimated the effects of the trapping in comparison to the live data and the transparent, lighter red areas show where the model has under estimated the effects of trapping.

Trying to create a model that fits all of the sites is challenging, but the model is supposed to provide a best fit under all scenarios. As can be seen in figure 11, there are occasions where the model has under or overestimated the effects of trapping. Across the full dataset and model simulations, the models explained upwards of 90% of the variance in annual counts between sites. The fitted models were able to pick up significant trends such as increases and decreases in capture rates between years, however the predictive value of the model was limited in some cases. At Yeadon Tarn in particular the model did not predict a strong decline in the number of crayfish caught in 2015 relative to 2014. The notable decline seen at Yeadon Tarn between the first and second year is surprising given the relatively low density of traps, but may be explained by the fact that the crayfish is relatively new to this water (3 years' presence prior to the study). Alternatively, the habitat at this site may not be suitable for sustaining as high a density of crayfish as the other sites, making this population less resilient to even small-scale trapping. It was not possible to set traps at locations within Yeadon Tarn where the populations may be densest e.g. along the dam wall and near fixed jetties. Not trapping the population in its entirety, especially in areas where the population density may be high may help to explain some of the discrepancy between the model output and the trapping data.

6. Model predictions of continued trapping

The population model was used to predict the on-going long term effects of trapping at each of the sites. The model was run for each site from January 1st 2016 until the end of 2030, to estimate the outcome of continued trapping. It was assumed that the same number of traps currently present at the site would be set and emptied weekly for the entirety of this period.

The models were run with starting population densities equal to those predicted by the model; and with equivalent trapping levels (in terms of traps per acre), to determine how many traps per acre would be required for eradication. Eradication is defined here as the point at which the population drops below a density of one crayfish per acre, and dates are rounded up to the nearest month (see figure 12).

According to the simulations the earliest that the crayfish could be eradicated is 2020 at Thornhill, where the population was not fully established prior to the commencement of trapping, and Bird in the Hand Pool, where the trapping rate is much higher than the other sites, and where trapping occurred prior to this study. The other site where eradication was determined to be possible was Rookery Reservoir, by 2022, where trapping also occurred prior to this study. These 3 sites are those where the highest density of trapping has been conducted. Eradication was not determined to be possible at the other sites with current trapping effort.

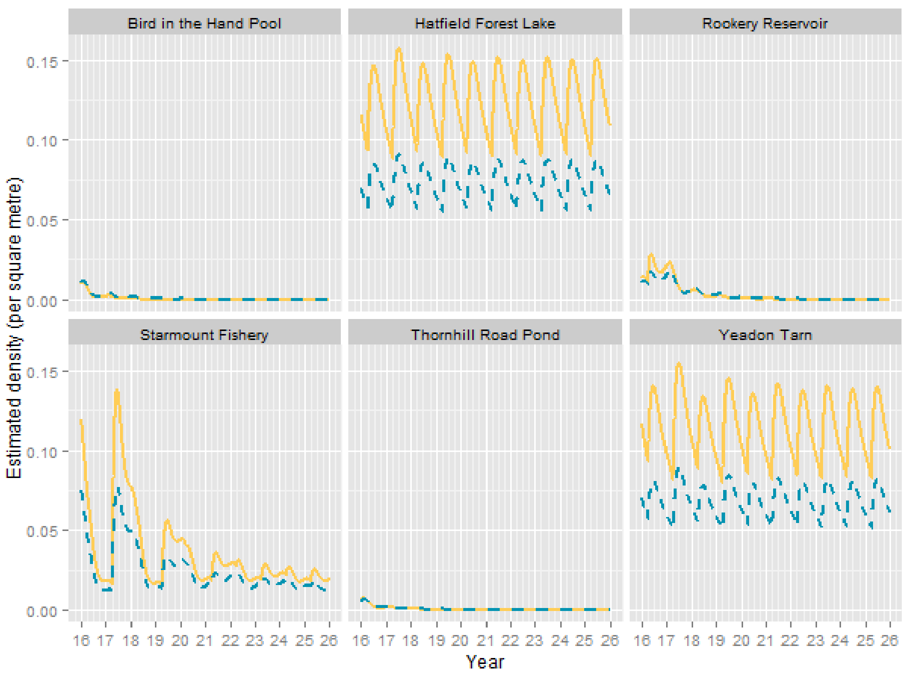

Figure 12. Crayfish population density estimates from 2016 to 2025 with continuation of current trapping effort. Dashed blue lines represent female crayfish; yellow solid lines represent male crayfish.

Alternative trapping level simulations

The model was used to estimate the effect of trapping if the number of traps was increased to 50 traps per acre and 100 traps per acre for each site. Table 1 shows the results from the model showing the number of traps, the number of animals trapped and the time to eradication with current trapping effort, and an increase in the number of traps to 50 per acre or 100 traps per acre.

As discussed above, under current trapping 3 sites are predicted to achieve eradication; Bird in the Hand Pool (2020), Rookery Reservoir (2022) and Thornhill (2020). With an increase to 50 traps per acre, it has been predicted that all sites would achieve eradication, and those sites where eradication had already been predicted under current effort would achieve eradication quicker (e.g. eradication at Rookery Reservoir by 2021). However, in some cases this would result in a sizable increase in the number of traps required e.g. at Yeadon Tarn 954 traps would be needed. A similar pattern was observed with a further increase of the number of traps to 100 per acre, with a minimum time to eradication of 2018 at Thornhill Road Pond.

Table 1. Number of traps, number of crayfish removed and timescale for eradication with 1) current trapping levels maintained, 2) 50 traps per acre and 3) 100 traps per acre. NAs represent scenarios where the crayfish is still predicted to be present in 2031.

Number of traps maintained					50 Traps per acre			100 Traps per acre		
Site	Traps	Traps per acre	Trapped	Eradication	Traps	Trapped	Eradication	Traps	Trapped	Eradication
Bird in the Hand Pool	40	46.511	461.6195	May 2020	43.0	463.2116	May 2020	86	477.5169	May 2019
Hatfield Forest Lake	20	1.761	39302.4664	NA	568.0	47460.2072	May 2022	1136	52869.8255	May 2021
Rookery Reservoir	50	27.322	3356.4556	Jun 2022	91.5	3509.8894	May 2021	183	3821.8839	Apr 2021
Starmount Fishery	30	11.858	19091.4549	NA	126.5	5104.6552	Jun 2021	253	4487.3673	May 2020
Thornhill Road Pond	20	29.851	193.4717	May 2020	33.5	186.5640	May 2019	67	188.0339	May 2018
Yeadon Tarn	50	1.310	92374.5381	NA	954.5	79870.3606	May 2022	1909	88911.9237	May 2021

An estimate has been provided of the number of site visits that would have to be made under each trapping regime for eradication to be achieved (see table 2). As more traps are used less visits are required to achieve eradications, but the amount of effort to empty all the traps would increase. To represent the increase in effort required to achieve eradication at each site the number of traps has been multiplied by the number of visits (see figure 13). This provides a proxy for the amount of effort needed to eradicate the population. As can be seen, the amount of effort required to eradicate crayfish populations from large bodies of water (e.g. Hatfield Forest and Yeadon Tarn) is very high, especially in comparison to small water bodies.

Table 2. Number of traps and visits required to achieve eradication under different strategies

	Number of traps maintained		50 Traps per acre		100 Traps per acre	
Site	**Traps**	**Visits**	**Traps**	**Visits**	**Traps**	**Visits**
Bird in the Hand Pool	40	226	43	226	86	174
Hatfield Forest Lake	20	NA	568	331	1136	279
Rookery Reservoir	50	335	92	279	183	273
Starmount Fishery	30	NA	127	283	253	226
Thornhill Road Pond	20	231	34	174	67	122
Yeadon Tarn	50	NA	955	331	1909	279

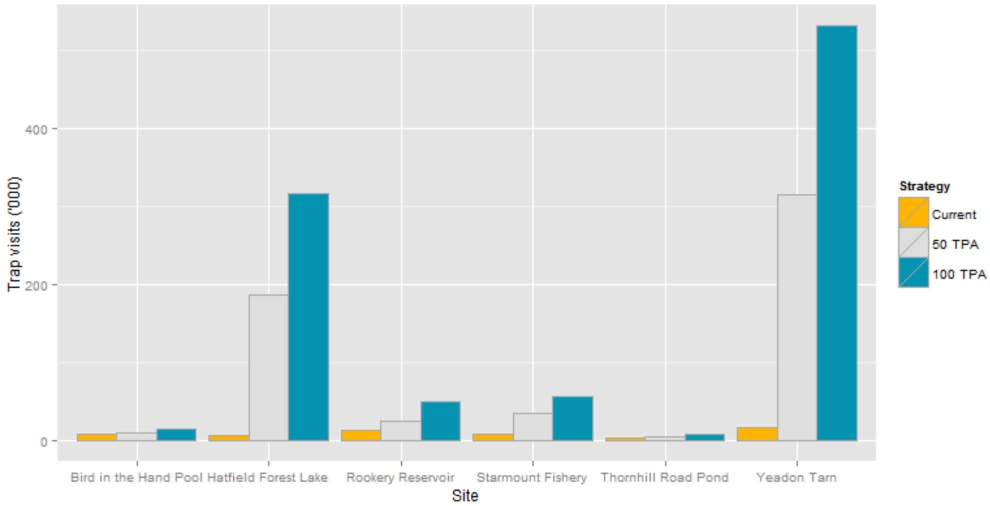

Figure 13. Number of traps multiplied by number of site visits required for eradication in each of the three strategies.

Conclusions

- The population model was used to determine the effects of the continuation of trapping on the crayfish population at all of the study sites.
- Under current effort eradication was estimated to be possible at 3 of the sites, Thornhill Road Pond, Bird in the Hand Pool and Rookery Reservoir. These sites are smallest in size and have the highest trapping density.
- In the case of Bird in the Hand Pool and Rookery Reservoir trapping had been previously conducted at the sites in the previous 3 years, therefore the population had been depleted as a result of previous efforts before this study began.
- Thornhill Road Pond population is just establishing and therefore may be easier to remove as a result.

- With an increase in trap numbers (to 50 and 100 traps per acre) eradication was estimated as possible at all sites, with the amount of time to eradication decreasing with the more traps being used.
- With an increase in the number of traps being used the number of visits required to achieve eradication decreases, but the effort required to empty the traps increases. At large bodies of water, considerable effort would be required to achieve eradication using the trapping methods used in this study alone.
- To try and relate this to time spent, each site was asked to estimate the amount of time spent on the project per week (see Annex 9). For example, Yeadon Tarn, which deployed 50 traps as part of this study, estimated the time to empty all the traps to be approximately 8 hours. To check and empty the equivalent of 50 traps per acre at Yeadon Tarn will take just under 153 person hours per week (assuming a linear relationship between the number of traps and time spent).

7. Alternative trapping scenarios

Given the significant levels of effort required to potentially eradicate a population of signal crayfish from a water body, alternative trapping scenarios were investigated using the population model where low intensity trapping was conducted. As already discussed, low level intensity trapping is unlikely to result in the eradication of a population, but provides an indication of the level of control that can be exerted on a population. In total 4 different scenarios were examined:

1. Where trapping was conducted at low intensity (between 1 and 10 traps per acre) with traps being emptied once per week throughout the year.
2. Where one summer of intensive trapping (50 traps per acre emptied once per week) was conducted between May and August, followed by low intensity trapping (between 1 and 10 traps per acre) with traps being emptied once per week throughout the year.
3. Where two summers of intensive trapping (50 traps per acre emptied once per week) was conducted between May and August, followed by low intensity trapping (between 1 and 10 traps per acre) with traps being emptied once per week throughout the year.
4. Where low intensity trapping (between 1 and 10 traps per acre) was conducted between May and August each year, with traps being emptied once per week during this period.

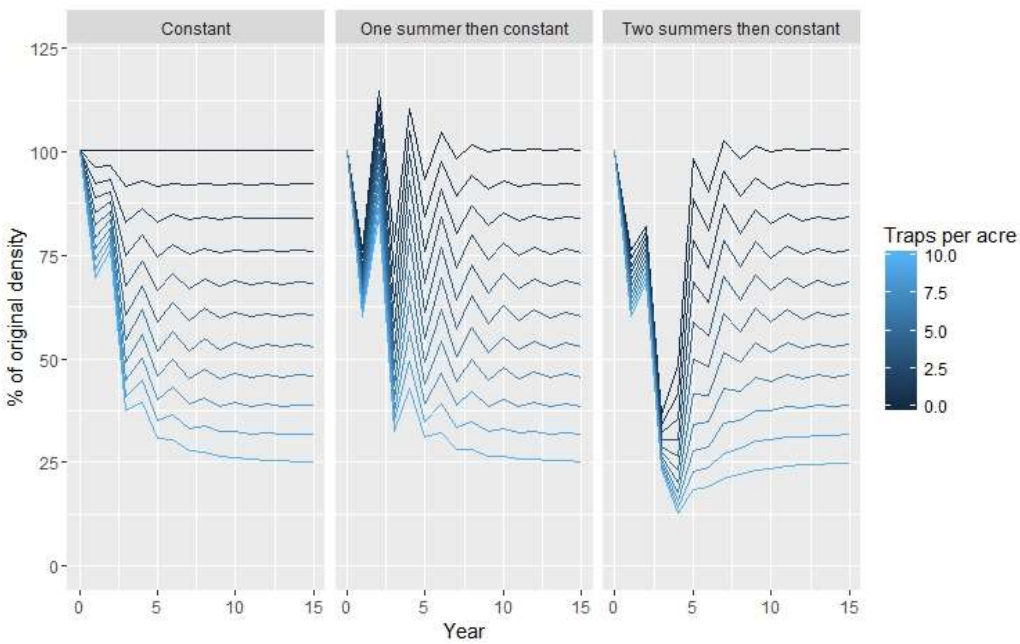

Figure 14. Predicted percentage of remaining crayfish population in response to varying degrees of trapping pressure (0 to 10 traps per acre), (left graph) when effort remains constant (traps emptied once per week throughout the year), (middle graph) where one summer of intensive trapping (50 traps per acre emptied once per week between May and August) precedes constant trapping, and (right graph) where 2 summers of intensive trapping precedes constant trapping.

Figure 14 shows the level of effects of i) constant trapping, ii) one summer of intensive trapping followed by constant trapping and iii) two summers of intensive trapping followed by constant trapping on a simulated crayfish population. Constant trapping, even at relatively low trap densities (10 traps per acre) provides a good level of control with the population size decreasing by 75% after 10 years. Even with as few as 3 traps per acre, a 25% decrease in the population size is still observed. When preceded with one or two summers of intensive trapping the same level of control is achieved, but in slightly less time. The recovery rate of a crayfish population when trapping is stopped or effort is decreased can be observed in the middle and right hand graph of figure 14, where in only a few years a population will return to its original density. This further highlights the need to continue trapping once started. In the middle graph of figure 14 (one summer then constant), the population recovers and then exceeds its original density. This is a result of the reduction in the density dependant effect on recruitment and juvenile survival, causing an increasing in the number of small crayfish in the population.

Figure 15 shows the effects of varying degrees of trapping pressure on a simulated crayfish population where trapping is conducted during the months of May to August each year, with traps being emptied once per week. The level of population suppression is much less with trapping only conducted between May and August, with approximately a 35% reduction in population size when deploying 10 traps per acre, in comparison to a 75% reduction when traps were deployed all year round (figure 14). The population control is reduced with a reduction in the number of traps deployed.

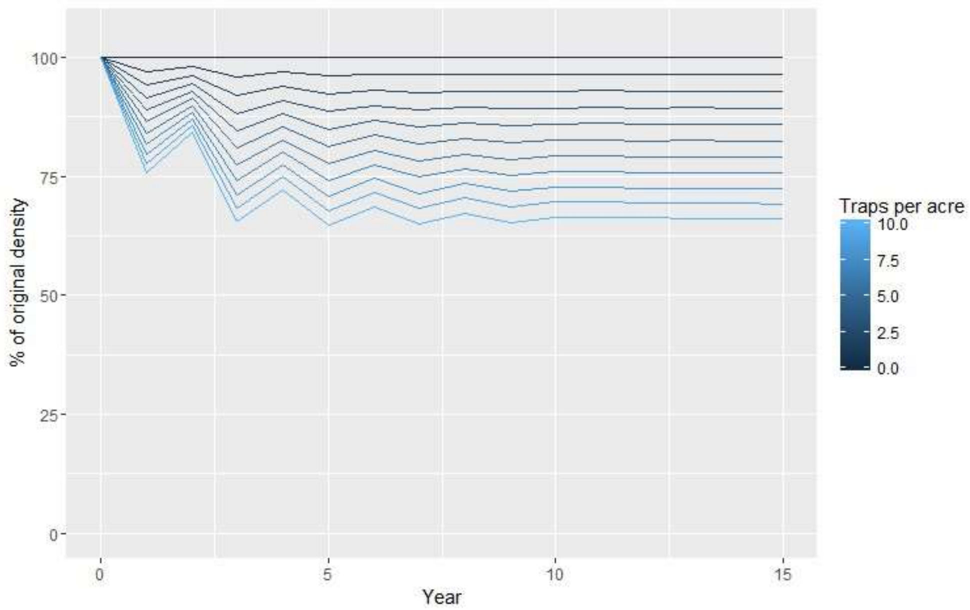

Figure 15. Predicted percentage of remaining crayfish population in response to varying degrees of trapping pressure (0 to 10 traps per acre), where traps are emptied between May and August once per week through the period.

Conclusions

- Intensive trapping sustained over a long period with a view of eradicating a population may not always be a viable option, therefore alternative low level trapping has been investigated with the aims of controlling a population and a level where it low longer poses the same degree of issues.
- Periods of intensive trapping were simulated for one and two years proceeded by low level trapping to examine if this was a viable management approach.
- With constant low intensity trapping all year round a population can be substantially controlled, potentially reducing the size by 75% over a 10-year period if 10 traps per acre are emptied once a week. Populations size can be decreased by about 50% with 6 traps per acre.
- One or two summers of intensive trapping preceding the constant low level trapping marginally decreased the time spent to reach a point of new equilibrium in the population.
- With one summer of intensive trapping, the population responded, once trapping pressure had been removed or decreased by exceeding its original density before returning to equilibrium. This is possibly in response to a decrease in the level of predation of juveniles and suppression of reproduction at high densities, which is not managed by further trapping.
- With 2 summers of intensive trapping the population does not exceed its original population density with a reduction of trapping pressure, but recovery of the population is clearly observed where trapping pressure is reduced.
- With continuous summer trapping, between May and August, so a level of control can be achieved, but much less than when trapping is constant throughout the year. With removal of this pressure it is likely that the population will recover as observed previously.
- Low intensity trapping does present a viable management option for the control of a crayfish population where a reduction in the density of crayfish in the water may elevate issues that they cause. It should be noted however, that if trapping was to stop then the population would return to its previous density.

8. Alternative theoretical treatment scenarios

This report has primarily focused on the potential of trapping to reduce or eradicate signal crayfish populations. The following sections describe other potential control methods; in particular male sterilisation and the use of a chemical attractant and biocide. The following models use the parameters (e.g. trap capacity) found in previous sections, and were run for a theoretical site one acre in size, where trapping/sterilisation/bait replenishment occurred on a weekly basis. These models assume that the treatment regime begin in May 2016.

Male sterilisation

Male sterilisation has been achieved under laboratory conditions by removal of the male gonopods, effectively rendering the male incapable of successfully being able to deposit stermaophores onto the female during the mating process, and therefore fertilise eggs. Male sterilisation was simulated so that trapped males were sterilised and replaced whenever they were found in a trap. These males were then able to “mate” with females, reducing the chances of the female mating with other, non-sterilised males. Other crayfish caught (i.e. females) were removed as with a normal trapping programme. The recovery rate of sterile males (i.e. regrowth of gonopods to a functional size) is unclear. Therefore, models were run with and without a rate of recovery from sterilisation, for 10, 50 and 100 traps per acre, and compared to the equivalent trapping models. The rate of recovery was set so that any sterilised male may revert at any time over a 3-year period with all animals recovering after 3 years. While laboratory trials have indicated that there is likely to be some recovery it will not be as quick as described in the model, as is likely to take a minimum of 3 years, however, this scenario was used as a worst case scenario.

The results are plotted in figure 16 and summarised in Table 3. Notably it appears that a relatively low density of traps (10 per acre) would eradicate the crayfish by 2023, but only if sterilisation is 100% effective, with no recovery. With a 3-year recovery period, or trapping alone, the populations persist beyond 2030 – albeit at a reduced density. Increasing the trapping density to 50 and then 100 reduces the estimated time to eradication to 2019, though the benefit of increasing the trapping density from 50 to 100 only brings the removal of the crayfish population approximately 2 months earlier; these diminishing returns are due to the presence of juvenile, un-trappable stages of the population.

In all the scenarios studied, sterilisation with no recovery shows more favourable results that trapping alone. When recovery is included, however, the time to eradication increases. As can be seen in the plot, this is because sterilised males are immune to trapping (i.e. they are returned to the water if trapped rather than being removed), and a small but significant proportion of these crayfish recover, allowing the population to persist for longer. This highlights the importance of optimising the sterilisation procedure.

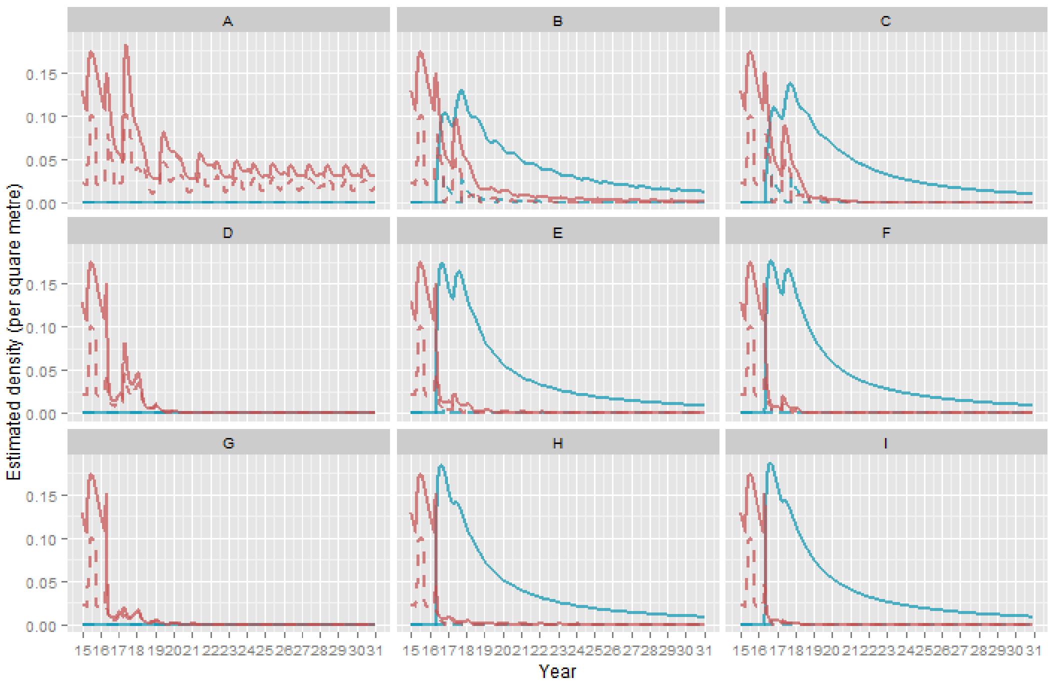

Figure 16. Projected population densities with and without male sterilisation (scenarios described in table). Red lines are un-sterilised densities and blue lines are sterilised. Dashed lines represent females and solid lines represent males. Trap density increases from top to bottom, while the left hand column shows trapping only, the middle column shows sterilisation with a 3-year recovery period, and the right column shows sterilisation with no recovery.

Table 3. Trapping and sterilisation simulation results. Models were run with 10, 50 and 100 traps per acre, with and without a recovery rate from sterilisation.

Scenario	Traps per acre	Sterilisation	Recovery rate (annual)	Trapped	Eradication date
A	10	FALSE	0.0000000	12395	NA
B	10	TRUE	0.3333333	3061	NA
C	10	TRUE	0.0000000	2219	September 2022
D	50	FALSE	0.0000000	7693	April 2023
E	50	TRUE	0.3333333	3323	January 2031
F	50	TRUE	0.0000000	2471	May 2019
G	100	FALSE	0.0000000	5822	April 2022
H	100	TRUE	0.3333333	2969	February 2030
I	100	TRUE	0.0000000	2147	March 2019

Biocide

An 'attract and kill' biocide delivery mechanism is being developed by Cefas and the crayfish population model was used to determine its potential success at removing a population. The delivery mechanism consists of a feeding station containing a bait that crayfish find attractive. Within this bait is a biocide, lethal to crayfish if any is consumed. In relation to modelling this control method, it is assumed that the bait is equally attractive, available and palatable compared with other available food sources. Practically speaking this means that the bait is evenly distributed and available to all meta-populations, and that individuals travel widely enough that they will come into contact with the feeding stations soon after they have been placed. Within the model two variables were examined, the number of lethal doses and the time between the biocide being replaced, as the amount of available biocide within the population will limit how quickly the population is removed. The feeding rate itself varies according to the amount of bait remaining at each time point, the density of live crayfish, and the relative abundance of alternative food sources. The biocide is assumed to be stable enough that the dose and its efficacy will not decline between bait replenishments.

In the model simulations, the bait was added at a variety of intervals. All crayfish stages were assumed to feed at the same rate, and experienced the same mortality rate per unit of bait consumed. To provide an upper estimate of the doses of biocide required for eradication, it is assumed that each crayfish weighs 100g and consumes 1% of its bodyweight per day.

In the simulations different volumes of spiked bait were added at weekly, fortnightly, monthly and quarterly intervals (table 4). It was assumed that the bait was consumed only by crayfish, and that the feeding rate of the bait was proportional to the ratio of bait to other resources (assumed adequate to sustain a population of 10 crayfish m^{-2}). The results show that increasing the volume of biocide added provides much better results than increasing the frequency of replenishment – though this assumes there is no leaching, decline in efficacy or consumption by other species (see figure 17).

Table 4. Time to eradication using a biocide attract and kill delivery mechanism with varying number of doses of biocide being introduced with variable times between replenishment of the biocide.

Days between replenishments	Dose per m^2	Eradication
7	0.5	NA
14	0.5	NA
30	0.5	NA
91	0.5	NA
7	1	NA
14	1	NA
30	1	NA
91	1	NA
7	5	June 2017
14	5	June 2017
30	5	Jul 2017
91	5	Aug 2017

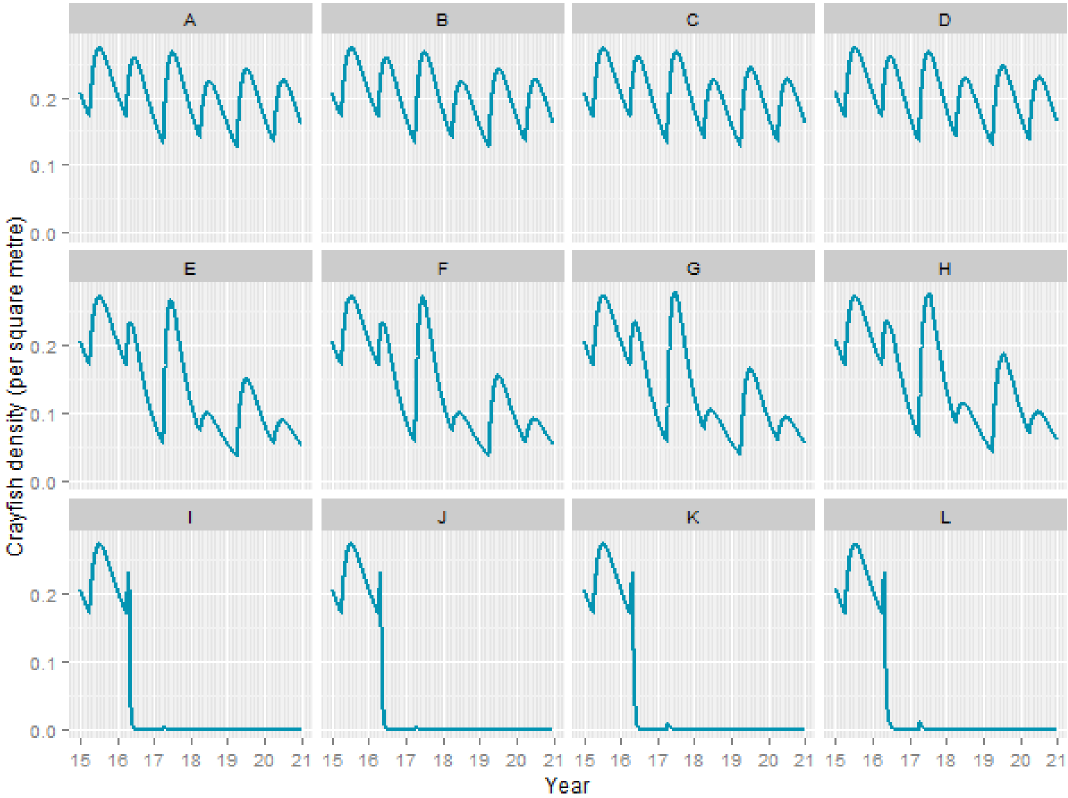

Figure 17. Time to eradication using a biocide attract and kill delivery mechanism with varying volumes of biocide being introduced with variable times between replenishment of the biocide. From Left to right graphs represent- weekly, fortnightly, monthly and quarterly bait replenishment, with graphs A-D showing simulations for 0.5 doses of biocide per m^2 E-H 1 and I to L 5doses per m^2.

Treatment combinations

To determine the efficacy of combining treatments, scenarios were run with differing levels of trapping, sterilisation and biocide treatments. The values used are provided, along with the number of trapped crayfish and date of eradication (defined as the last day the trappable population is in excess of one animal per acre) in table 5. The results are plotted, with and without male sterilisation, in figure 16 and figure 17 respectively.

Table 5. Table showing the date of eradication of the modelled population where different combinations of control methods were applied, there were trapping (and increasing trap numbers) sterilisation (yes or no) biocide and the number of doses per m² (either 0, 1 or 5).

Code	Traps per acre	Sterilisation	Biocide	Doses	Number of trapped crayfish	Date of eradication
A	10	✓		0	2212	Oct 2022
B	10			0	12382	NA
C	50	✓		0	2400	Jun 2019
D	50			0	7267	May 2023
E	10	✓	✓	1	1916	Jul 2022
F	10		✓	1	3004	Jun 2025
G	50	✓	✓	1	2352	Apr 2020
H	50		✓	1	4107	Mar 2022
I	10	✓	✓	5	78	Jun 2017
J	10		✓	5	78	Jun 2017
K	50	✓	✓	5	296	May 2017
L	50		✓	5	298	May 2017

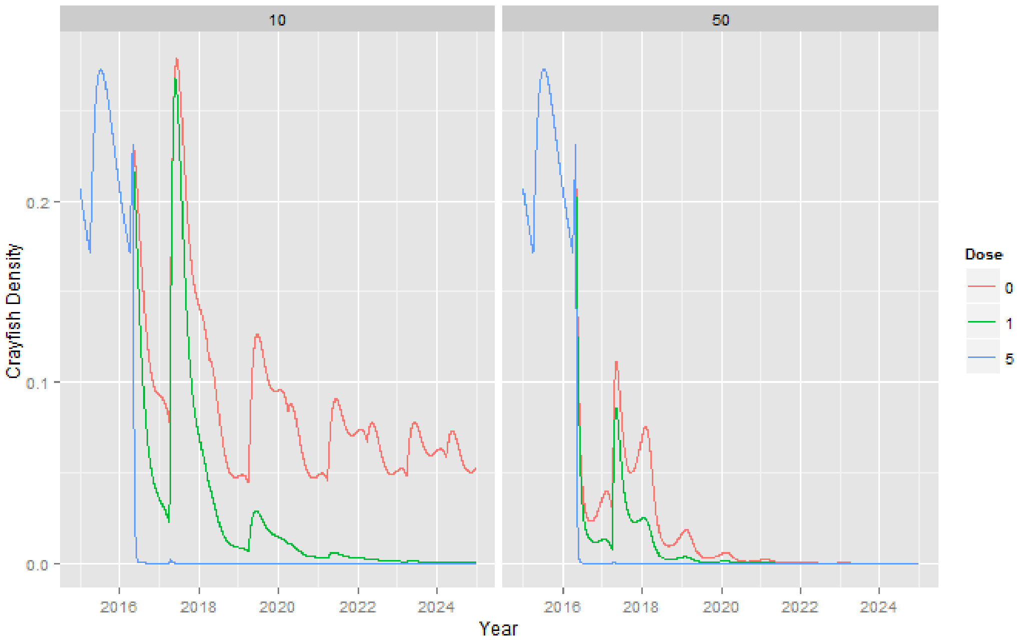

Figure 16. Crayfish density plotted against time; for 10 traps per acre (left) and 50 traps per acre (right) with no sterilisation and varying doses of biocide (0, 1, and 5 per m²).

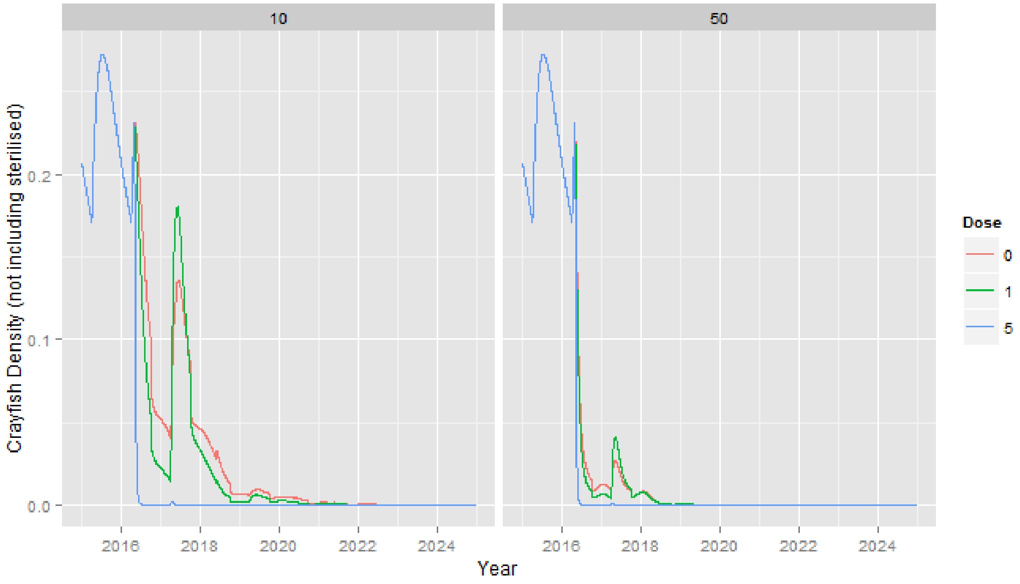

Figure 17. Crayfish density plotted against time; 10 traps per acre (left) and 50 traps per acre (right) - with male sterilisation (100% efficacy and no recovery) and varying doses of biocide (0, 1, and 5 per m²). Sterilised individuals not included in the density.

Conclusion

- Alternative methods of control were examined to determine their relative effectiveness under simulation compared to trapping. Male sterilisation and the use of biocides as potential control methods were examined.
- An annual recovery rate for male sterilisation was included to account for regrowth observed in laboratory trials.
- With no recovery rate sterilisation was very effective, even when a low (10 per acre) number of traps were used, eradication was achieved by 2022, while without sterilisation (i.e. trapping alone) eradication was determined not to be possible.
- With an increase in trap number, and therefore the number of males sterilised, the time to eradication decreased to a minimum of March 2019 when deploying 100 traps and with no recovery of sterilised crayfish.
- The effects of an 'attract and kill' biocide delivery mechanism (currently being developed by Cefas) was modelled.
- With a low number of doses per m^2 of the biocide eradication was not achieved, but with 5 doses per m^2 eradication was achieved rapidly (by June 2017).
- Changes in the replenishment rate of the biocide had little effect on time to eradication.

- When a combination of the control methods was simulated (trapping, sterilisation (with no recovery rate) and biocide control) eradication was achieved, in all but one scenario (code B on table 5) where only trapping was applied at a level of 10 traps per m^2.
- Male sterilisation and trapping together achieved eradication quicker than trapping alone.
- Biocide treatment with only 1 dose per m^2 in combination with trapping achieved eradication more effectively than trapping alone, but was less effective than trapping and male sterilisation together.
- When biocide treatment with only 1 dose per m^2 was combined with trapping and sterilisation there was little marked difference to time to eradication compared with trapping and sterilisation.
- When using the biocide treatment at 5 doses per m^2 there was no marked difference in time to eradication between using the biocide alone (table 4) or in combination with other control methods.
- These results suggest that biocidal control should be deployed in isolation at 5 doses per m^2 and should not be considered for deployment at a lower dose density.
- Sterilisation in combination with trapping is potentially a viable means of increasing the effectiveness of a trapping programme, although more work is required to determine the actual recovery rate of the sterilisation process used in this model.
- Biocidal control at the higher dose rate was the most effective means of control estimated to result in eradication within a year of deployment, however there are a number of assumptions made in relation to the attractiveness and therefore the efficacy of this method which would still need to be determined.

9. Developing a trapping programme

In many cases the removal of crayfish by trapping (or other means) is controlled, and requires permission from the authorities. For the purpose of making this section applicable to a number of scenarios specific authorities are not mentioned, but before commencing any trapping or other actions with a view of controlling a crayfish population, irrelevant of where the programme is to take place, it is imperative that you talk to the appropriate authority to ensure that any activities are undertaken legally. This outlined approach is based on the results from this work alone, and is therefore a combination of field data and modelling results. Following these steps will not guarantee the eradication of the population being targeted, but they should be used to help formulate an approach. The following is a step by step process to aid in the development of a trapping programme:

1. *Identify the problem population.* The extent of the population needs to be understood. This is important as any control programme needs to affect the whole population. It is advisable to contact your local relevant authority to discuss the population, what is being planned and the legal requirements before taking any further action.
2. *Are sufficient resources available?* If only trapping is to be used, ideally at least 46+ traps should be set per acre of water and emptied at least once per week for 52 weeks of the year for multiple years (7+) to achieve eradication. Ensuring that there are sufficient resources available to purchase traps, bait and empty them is important. Control and/or eradication will be a long term process and therefore commitment is required by those undertaking the work.
3. *Health and safety first.* It is imperative that all measures are taken to ensure the safety of all those undertaking any trapping exercise. Even setting traps from the bankside can be dangerous and an appropriate assessment of the potential risks needs to be conducted before any work is conducted.
4. *Prevent further immigration.* Any potential sources of animals entering the target population needs to be identified and stopped or limited as much as possible, otherwise control/eradication will be impossible.
5. *Be mindful of all water users and water user engagement.* When setting up a trapping programme be mindful of all of the water users and how people may interact with the traps as well as potentially aiding in trap emptying and setting. Traps can cause snag and trip hazards so should be set away from where people will be using the water, especially if entering the water body. People are curious and often care about the water body that they use. Ideally all should be informed of the plan, what it hopes to achieve, how it will potentially affect them,

the time scale the work is likely to be undertaken for, the potential benefits and how they can contribute to the programme.

6. *Setting and emptying traps.* Traps should be set so that all of the population will be affected, although this may not be possible due to constraints due to water use or accessibility. At the least, traps should be distributed around the perimeter of the water body as this is likely to encompass much of the suitable habitat.
7. *Trap all year round.* More animals will be trapped during warmer weather, but it is the trapping during the winter and autumn that can have the biggest impact on a crayfish population as this is when the females carrying eggs are observed in the population. The removal of females carrying eggs has a huge impact on recruitment.
8. *Collection of data.* Ideally the number of animals in each trap, the gender of each animal and their size should be recorded. This information is useful in understanding how the population is responding to the trapping. Collection of data in relation to other related observations such as the number of fish fry, bait being taken by crayfish from anglers or knocks on line can also give some indication of how effective the trapping programme is.
9. *Biosecurity and animal disposal.* Ensuring that there is no risk of transferring crayfish or their diseases to other waters is of utmost importance. Do not transfer traps or equipment between bodies of water. All animals removed should be destroyed on site, none should be taken off site live or sold unless under specific cases. The Check, Clean, Dry guidelines should be followed http://www.nonnativespecies.org/checkcleandry/index.cfm.

10. Discussion

The work presented within this document was conducted with a view to providing insight into methods of controlling and eradicating populations of signal crayfish in enclosed bodies of water, primarily through physical removal in the form of trapping, however, other methods of control/eradication have also been examined. The project was conducted specifically to meet objectives under the Water Framework Directive in relation to the impact of invasive non-native species, with the aim of providing guidance on how a programme of trapping with the goal of controlling or eradicating a population of signal crayfish could be established and run. The report has been structured with a view to make the large amount of data and information generated during the project accessible to a wide range of people, including managers of waterbodies, policy makers, scientists and stakeholders alike.

At the end of the project the manager of each site were asked a range of questions in relation to how they felt the work had gone, what they would have done differently, the perceived impact that the trapping has had on the site, and if they would continue with the trapping after the end of the project. These questions and the answers from each site are provided in Annex 9.

The success of the project relied heavily on volunteers, who conducted the trapping in a citizen scientist format. The volunteers made this project possible and allowed for a broad range of sites to be used, providing a wider view of the effects of trapping on enclosed crayfish populations, in comparison to studying one site in isolation. The continued hard work, dedication and input of the volunteers has been invaluable, providing a clear insight into the practicalities of conducting a programme of work with the aim to control and eradicate a crayfish population by members of the public.

While all of the sites agreed to take part in the study before work commenced, all volunteers were exemplary in their continued effort and dedication to the project. The enthusiasm for the work shown by the volunteers certainly helped in gaining universal support from angling club members, landowners, other water course users and stakeholders (see Annex 9), and therefore the continuation of the work. The activity of the volunteers has also helped to raise awareness of the issues surrounding invasive crayfish, and non-native species as a whole, from a broad range of society including city council members, anglers, recreational sailors and school children (see Annex 9). The project has helped to illustrate that while there are complexities with organising citizen scientists, the quality of the results and the volume of work which can be achieved far outweigh any problems, or at least those that arose during this project.

In the majority of cases the sites did not experience any issues relating to the running of the programme, especially at the sites where a clear benefit has been observed as a result of the trapping, such as an increase in juvenile fish being observed or a decrease in the crayfish being a pest to anglers (see Annex 9). All sites kept members of the associated angling club informed which in turn maintained interest in the project.

Benefits of the work varied between sites, from environmental changes such as reduced bank erosion and increasing juvenile fish numbers, to changes in overall management strategies at the water in response to the crayfish population decline (see Annex 9). In addition, all sites observed a decrease in the problems crayfish caused anglers, demonstrating that the trapping also has a positive impact on the sites as an ecosystem service. No significant impact of the trapping itself on the environment was observed by the volunteers, all reported some by-catch, but these tended to be fish that could be easily returned live to the water. On two occasions mammals were caught: a rat and a mink (see Annex 9).

When asked their opinion concerning the modified traps (see Annex 9), most site managers were of the opinion that they did not work and were more difficult to use as a result of the modifications, especially the meshing. While not as successful as hoped, the modifications do provide an interesting insight into how trap modifications could improve the efficacy of current trap designs. With some refinement of the modifications made, the modified traps could be used to increase the efficacy of trapping further.

The results from the project suggests a likely minimum effort of trapping required to achieve eradication, with a minimum of 46 traps per acre being deployed and emptied at least once per week all year round and deployed for approximately 7 years if using trapping alone. The model demonstrates that with an increase in trapping effort eradication is made more possible over a shorter time period, but this would result in significant demands on resources. Other means of increasing the effectiveness of trapping, or a combinations of methods would have to be used to tackle populations in larger bodies of water, purely down to the resource demand required otherwise.

In addition to the use of traps to eradicate a population, for which a high intensity of trapping would be required, the effects of less intensive trapping was also investigated. While low level trapping alone would be unlikely to achieve eradication, it did help to suppress a population, which may be viewed as sufficient in some cases to reduce the impact of the signal crayfish. Recovery rates of the population were, however, very rapid and any such control programme would have to be implemented indefinitely.

In addition to trapping the other methods examined are still very much in development, with the only meaningful data available for either of the methods being from laboratory studies, however, the population model does present interesting information suggesting that their further development would be key in control/eradication of crayfish populations. The population model presents a useful tool by which the efficacy of control methods can at least be examined in cost effective and environmentally sound means, before any field trails are conducted.

Four of the five sites that finished the study could see a clear benefit to the trapping. Thornhill was the only site that was discouraged, but this may be due to the establishing nature of the population. All of the sites have said that they wish to continue with trapping either at the same trapping density or changing it slightly. Some sites are intending to examine other means of control, such as the introduction of predatory fish to help with the management of the crayfish (see Annex 9). All sites stated that they would be prepared to take part in further studies if requested.

This study has presented evidence that trapping could eradicate populations of crayfish under certain circumstances. However, eradication has still not been achieved via trapping, and if it was to occur would require further long term investments. While the trapping protocol put together for the sites was based on what was considered achievable and practical for citizen scientists, commercial trappers may have the means and resources available to deploy many more traps and empty them more frequently, possibly reducing the time to eradication considerably. There would, however, have to be incentive for commercial trappers to remove small animals and to continue trapping once the numbers being caught start to reduce.

While this work may go some way in addressing the common view that trapping will not eradicate a crayfish population, the amount of effort required would indicate that in most cases this is not a tenable means of eradication on its own, especially if there is no commercial incentive to trap smaller animals or to go beyond the point of diminishing returns. The further development and testing of other methods of control, such as male sterilisation or introducing predatory fish, to enhance trapping efforts, new trap designs to increase efficacy, or standalone methods such as ‘attract and kill’ biocidal control, are therefore essential to enable citizen scientists to eradicate crayfish populations more effectively.

Appendix
Annex 1. The trapping of crayfish

The effect of trapping on crayfish populations depends on several factors, including environmental variables.

- Seasonal changes have been reported in the distribution and abundance of crayfish caught in traps (Miller & Van Hyning 1970; Klosterman & Goldman 1983). Changes in trap catches (kg/trap) has been attributed to temperature fluctuation combined with the moulting period (Shimizu & Goldman 1983; Lowery & Holdich 1988). In Oregon, it has been found that catches in winter are generally low due to the decrease in feeding rate with decreased water temperature causing animals to become quiescent (Miller & Van Hyning 1970). Although *P. leniusculus* populations generally have a stable sex ratio of 1:1, there are seasonal differences in the catches based on sex (Miller 1960). Spring catches are more biased towards males, but total catch may be generally low because the males are in their moulting period. Berried females are reluctant to enter traps (Abrahamsson 1971; Mason 1975; Kirjavainen & Westman 1999), but are often caught subsequent to the hatching period, when they aggressively seek food to replenish reserves lost while carrying eggs (Lewis 1997). Both genders are caught in increasing numbers during summer months as they become more active and the breeding period when both sexes are more active. Despite this, catches consist of between 0 and 50% females (Cullen et al. 2003), but rarely exceed more than 20% females.
- How catch composition may vary with exploitation of a population over time has not been explored. Trapping is often considered to be inherently biased to the removal of dominant large adult males (Holdich et al. 2006). However, this bias may not be a function of trapping per se, but the type of traps used, and the use of traps with smaller entrances may be biased in the opposite direction. The removal of the dominant (large) males from a population may lead to reduced pressure on juveniles giving rise to even larger populations (Gherardi et al. 2011), but will also result in changes in catch composition. This was observed in populations of *Astacus astacus* where the removal of larger animals reduced the level of competition on smaller animals resulting in the development of much denser populations (Skurdal & Qvenild 1986), although stunted growth may be a result of limited resources rather than over exploitation (Skurdal & Qvenild 1986). Several trapping programmes on riverine systems have found that removal of large adult males from one section of the river acts like a drain on neighbouring areas (both from up and down stream), with large adult males moving into the available space formed by the trapping (Ibbotson et al. 1997; Holdich et al. 1999; Moorhouse

& Macdonald 2010). It is thought that the removal of females may result in feedback mechanisms resulting in the production of more eggs and maturation at a lower size by the remaining adult females (Holdich et al. 1999).

Several studies have examined the potential for trapping to control and/or eradicate with varying degrees of success and subsequent conclusions:

- Bills & Marking (1988) conducted intensive trapping in the USA on a population of *Orconectes rusticus* over a six-week period. Although the trapping programme failed to remove smaller animals, due to the design of traps used, the population was significantly suppressed. In a similar study, Roqueplo et al. (1995) trapped a population of *Procambarus clarkii* in France. Modified traps allowed the removal of a larger range of sizes, resulting in suppression of the population, but not eradication. Similarly, Frutiger et al. (1999) conducted a trapping programme in 1997 on a population of *P. clarkii* in Switzerland. The programme resulted in the temporary reduction of total population size; however, evidence suggested that removed crayfish were replaced in a short time by young animals.
- Several studies have also been conducted in England with similar effects (see papers by Holdich). Rogers et al. (1997) reported a trapping exercise using 'Trappy' traps where it was estimated that the population was reduced by more than half. However, despite a reduction in the number of larger animals, smaller animals were unaffected. The majority of these studies concluded that trapping is effective at reducing total population size, and therefore could be used to potentially control crayfish, but not eradicate.
- Another study (Peay & Hiley 2001) concluded that trapping was wholly ineffective as a control method. However, the study conducted by Peay & Hiley (2001): i) used a comparatively low intensity of trapping; ii) was conducted over a short time period; iii) did not mitigate the effect of migration into the area being trapped and iv) the whole population was not susceptible to the methods applied when compared to other referenced studies.
- West (2010) reports on a significant trapping exercise that has been conducted since 2001 and is still in progress on the River Lark, England. The project has: i) refined the types of traps used; ii) used a range of trap styles to capture a wider range of sizes; iii) undertook trapping upstream of the control area to reduce migration and iv) has been conducted for 9+ years. Although intensity of trapping has varied throughout the study, there has been a total reduction of 70% in the catches. This has resulted in observed recovery of the immediate ecosystem, such as river banks and fish populations.

- Another long term trapping programme (1999 to present) on the River Clyde in Scotland has seen a significant reduction in total numbers caught (from 10,625 in 2001-2002 to 5,335 in 2006-2007) with the same trapping intensity (Reeve 2004). This project has used 'trappy' traps for the whole period and a relatively low trap density. However, the average size of the crayfish being caught is smaller and the animals are becoming sexually mature at a smaller size, possibly as a result of the trapping. This could be an important issue to consider when determining the effects of a control or eradicate programme on a crayfish population.
- Extensive work has been conducted on controlling *P. leniusculus* in Loch Ken, Scotland (Ribbens & Graham, 2009). Loch Ken is currently a unique situation in the UK, being the largest still water body of water (9 miles long) containing crayfish. Other methods of control, such as the use of pesticides, would be impossible in a water body of this size, therefore trapping was investigated. The study investigated a variety of trap types suitable for use in such an extensive body of water, in addition to an intensive trapping period to determine feasibility. Trapping trials found prawn creel traps to be most effective given the scale of work (>400 traps being placed every 24 hours), with the traps being suitable for hydraulic lifting and self-shooting systems. Although difficult to assess trap effectiveness when trapping in-situ, all the traps tested (prawn creels, pyramid traps, cylinder traps, fyke nets and homemade barrel traps) caught similar length profiles while the prawn creel retained the greatest numbers. During the 56-day intensive trapping approximately 450 prawn creels were set every 24 hours. Although only part of the water (and therefore population) was trapped, it is estimated that 659,300 animals were removed. More male crayfish than females were caught at the beginning of the trapping period, while by the end the sex ratio of catches had become more balanced, with the size of the male animals being caught reducing during this period. There was also a reduction in the mean number of crayfish caught per trap over the trapping period suggesting a reduction in the population. Despite being an extensive project, for the size of the body of water this was a trial with some interesting insight in how trapping may alter population structure.

Annex 2. Commercial trapping of crayfish

As part of the project and in order to gain a better understanding of crayfish trapping and the commercial sector a day was spent in the field with a commercial trapper who arranged a visit to a crayfish processing plant, a visit to the holding facilities of a crayfish trapping team and the lifting of his own different types of traps in and around London. Commercial trapping all involves the wild harvest of live animals and their transportation to a holding facility for depuration. Animals are then either sent live to consumers in the UK, to other EU Member States or are processed before being shipped. This short summary of trade focuses on the gathering of live animals for the commercial trade, and the processing of animals.

As *P. leniusculus* has spread across England the number of trappers and commercial value of the sector has risen and this has now led to some larger processing plants becoming established. Historically the trade focused on live trade, but this has recently changed to a processed product. The unit visited in Oxfordshire has recently invested approximately £500,000 in processing and packing equipment and now exports in the order of 48 tonnes of processed product to Sweden and 18.3 tonnes of live product to Finland per annum, in addition to supplying markets in France, Russia and some smaller markets in the UK.

The plant is supplied by teams of trappers whose busiest period is a window of three months (June – August) leading up to the Scandinavian summer holidays in order to supply this market. This is currently where the large demand is and fits with the time of year when the crayfish are most active and easiest to catch. This results in the processing plant working long hours to make the most of this window of opportunity. However, commercial trapping does take place throughout the rest of the year, but not to the same extent. It is considered that other market areas are growing and developing resulting in an increased demand for crayfish.

The trapper made the point that there are many within the industry that wish to be regulated and have a stamp of approval legitimising their business and demonstrating compliance with the law. This has resulted in the establishment of the National Institute of Crayfish Trappers (NICT) that is attempting to get crayfish trapping organised and working to develop codes of conduct. During discussions with the trapper it was stressed that most trappers are not motivated by seeding or stocking other waters as this represents a longer term return of 10 years to build a good adult stock. In addition, concern was expressed that at present anyone can get a licence for any number of traps and it was felt this was an area that required more stringent control.

In general terms, crayfish are removed from a body of water by a trapper, and then taken directly to the processing unit or to a centralised holding facility and then to the processing unit. Not all trappers supply a processing unit, such as the one visited, with some trappers selling their product directly themselves.

When the Crayfish arrive at the processing plant they are held in depuration systems for purging before cooking, processing and packing for export (see figure 1 below).

Figure 2. Images from the crayfish processing plant, showing the a) cooking and b) packing equipment, in addition to c) the packaging itself.

During a visit to a crayfish holding unit (a disused trout farm) opportunity was provided to both look at the stocks being held and discuss with the trappers their findings. Stock held at the time of the visit consisted predominately of larger mature specimens that were estimated by trappers to be upwards of 8 to 10 years old. The trappers were keen to emphasise that they also remove smaller animals which are traditionally below market size and markets are being developed for these. The various merits of different types of traps were discussed and the modifications used by the trappers. Modifications used included the opening up the mouth of the trap (while staying within the maximum limits set to avoid unwanted by-catch) and using a system of inward pointing cable ties to stop the crayfish (of all sizes) exiting the traps. Opening up the aperture has been driven by the fact that at some sites the maximum size of the crayfish being caught was up to 220g in weight. At other sites sizes in excess of 250g have occasionally been reported. The commercial trappers confirmed that crayfish of this size would not be able to enter the standard 'trappy' traps' entrance and that their modifications have proven to both extract larger specimens and provide better retention of all sizes. This could potentially be enhanced further by reducing the mesh size of the traps.

When emptying the traps set by the trapper on the previous evening it was demonstrated how effective fyke nets can be. One double ended fyke net set in a small lake in the Cotswolds caught a bucket of crayfish in each end. Another example was provided where a chain of 'trappy' traps had been set down the river Thames in an area that had been trapped consistently for six years. Each trap on the chain still caught up to 4 crayfish but because it is a river new crayfish keep moving in from beyond the trapping zone (as the whole population is not trapped). The trappers would like to carry out more work using both fyke nets and traps in combination, but this currently needs special permission, in addition to fyke nets requiring some expert skills to set, in addition to being set within the water rather than from the bank.

At one site that was trapped consistently over four years the catches were quoted as dropping from

Figure 3. Showing a) a line of 'trappy' traps being pulled b) a fyke net being pulled and c) part of the catch from a fyke net.

1.8 tonnes to 1.2 tonnes, to 365.3 kilos to 65.4 kilos on a year by year basis. The trappers also thought that once this had been achieved the population doesn't recover quickly.

One interesting observation from some of the commercial trappers is that the best catches are influenced by the moon and atmospheric pressure with best catches being on the nights approaching full moon. They also thought that at other times catches were made up of smaller sized crayfish and crayfish with missing claws and this was area for further research. As a general rule of thumb commercial trappers estimate there are usually 20 crayfish per kilo. Consequently, a catch of 20,000 would equate to 1 tonne of catch.

Annex 3. Site selection criteria and description

In order to select sites for the project from across England to take part in the trapping programme trials a check list of desirable qualities was drawn up. Contact was made via the Angling Trust (AT) to sites that were AT members and thought to be likely candidates. The criteria for the sites to be selected included: i) full buy in from stakeholders'/land owners'/land users and volunteers; ii) the presence of a signal crayfish population; iii) no trapping has been previously conducted at the site (preferred); iv) the site is still (lentic) water preferably with no in or out flow; v) limited access to non-members; vi) background to the site is available; and vii) easy bank access and low flood risk.

Following initial selection of possible sites further assessment of the sites was conducted to determine suitability. These visits were conducted by Cefas and the Angling Trust to discuss with site operators/owners the nature of the work and to establish the final sites to be used in the study. At the site visits the following questions were asked and data recorded.

1) Have the given criteria all been met?
2) How many volunteers are available?
    a) Are they available to provide assistance all year round?
    b) Can they provide assistance up until the end of the project (March 2015)?
    c) How much time can they commit to the project?
    d) Are they prepared to work sometimes independently?
3) Can data be submitted to Cefas (either by mail or electronically) on a monthly basis?
4) How large is the site?
5) How long have signal crayfish been present at the site?
6) Has there been previous attempt to trap or control the crayfish population?
7) How soon can the site start trapping?
8) Are there means by which the site can dispose of crayfish (without selling them)?

Information was collated and the most suitable sites selected. Although these criteria were ideals, no site could meet all of them. One site was dropped from the study after showing reluctance to commit to the long term trapping programme. However, an additional site was added to the list following recommendations from the Environment Agency. This provided contingency in the case of a site dropping out of the process.

Bird in the Hand, Hilderstone, Staffordshire.

Site description

This is a well maintained small coarse fishing lake situated in a rural area outside of Stone in Staffordshire run by Creda Redhouse Angling club. It is fed by a small spring and three run off drains with the bottom of the lake being clay based. The fishery was originally built as a trout lake but now contains fish typical of a mixed coarse lake. The club conducts angling matches on the water but it is not considered a heavily stocked water.

The site has easy access and good safety facilities with gently sloping grassed surrounds. The site is restricted to members only and is fairly secure and well policed but does have a footpath running through it. There was no memory of the water ever having flooded. The club does not own the water but leases it from the landowner who has just constructed a new lake (not yet filled) adjacent to the site. The close proximity of the new water was discussed in terms of crayfish movement and it was concluded that prevention of movement across this distance with an outlet running directly into the new pond would be very difficult. The water is currently classified as online whereas the adjoining lake is classified as offline. There is concern that fish health checks on the adjacent water (if they happen) will not be as stringent, and could risk undermining fish health at the Bird in the Hand site and the effectiveness of this project. However, this discrepancy is currently being discussed with the Environment Agency.

History of signal crayfish at the site

The signal crayfish population have been present on site for an estimated 30 years. It is thought that they were introduced at the same time as the site was dug and put there to supply the local pub. Some previous trapping has been carried out since 2008 consisting of 12 traps increasing to 21 in 2010 for which some data was supplied.

Impact of signal crayfish on the site

When asked about their observations of the effects of the crayfish they thought that there had been a decrease in fish fry and smaller fish (C1s or C2s). Roach have generally declined along with other small species. They had also noticed odd burrows in the bank but it was difficult to say if undercutting was caused by the crayfish or wave action. This is in addition to bait being taken and fishing lines being knocked by crayfish.

Methodology and trapping process

The club has many members who were interested in the project many of whom were retired but the core work was to be carried out by a regular team of three. The numbers of traps positioned was set at 40 which was the maximum that the club felt it could manage for the duration of the project. No traps were placed on the small island in the centre of the lake due to safety and logistical reasons. The club set themselves up very well with a specially designed trolley for sampling purposes. All 40 traps have been sampled twice per week.

Biosecurity and animal disposal

A system was already in place for disposal of the crayfish on site whereby they either crushed and buried them or cooked them in the clubhouse for members. The cooking of crayfish by club members is a regular club social event.

Data recording and submission

Data was recorded manually as all the traps were emptied twice per week. This was then copied and posted to Cefas.

Hatfield Forest Lake, Bishops Stortford, Essex.

Site description

The lake is situated within an area of ancient woodland owned and managed by the National Trust. It is approximately 11 acres in size and is fed purely from forest run off water. Hatfield Forest is also an SSSI and an NNR. The lake is generally fairly shallow sloping to 12ft at the deepest point. It has a nature conservation area at one end and is surrounded by paths used by walkers and bird watchers. There are duck feeding areas used by families and a café/restaurant situated close by. While there is open public access the site is closed during the night and well policed during the day. The angling pressure on the site is very light with only a limited number of tickets and memberships available through the National Trust. The lake is known as a superb carp water, but is not advertised as such by the small number (12-15) of anglers who fish the lake. The anglers have voluntarily chosen to implement a close month, to reduce fishing pressure on the carp. There is very little risk of flooding affecting the lake. Any overflow or spillage through the outflow settles into the forest and soaks away.

History of signal crayfish at the site

The site is not sure exactly when the signal crayfish arrived within the lake but they believe it to be in the order of 10 years ago. There is some run-off from the lake that enters the River Basin, so this is a possible entry route. Alternatively, crayfish were apparently seeded in lakes at a property on the entrance road to the site in the 1980s (intended for farming). Some small scale trapping for food is believed to have taken place a few years ago.

Impacts of signal crayfish on the Site

The site has developed an extensive network of volunteers and students working on the project. A significant amount of interest has been developed at the site for the project. Survey work has been completed by naturalists at the site. This information will be made available separately once finalised. Although no specific comments had been made by anglers on line knocking and bait removal by the crayfish, it is suspected that they crayfish have had an impact on fish recruitment.

Methodology and trapping process

The team at the site has been led by a volunteer warden who is a retired engineer. They applied a very rigorous and methodical approach to the project and have also had MSc & PhD students use the site as part of their studies. This has provided both valuable labour, students with relevant experience and additional information relating to the site which would not have been collected otherwise. The traps were laid out and coordinates taken across the lake with the site preferring to access the traps by boat rather than disturb too much vegetation. A total of 20 traps were deployed around the perimeter of the lake (see figure 16). The site was very innovative in developing a type of marker float for the traps that prevented the fisherman from getting their lines tangled (Figure 17).

Biosecurity and animal disposal

As a National Trust site there was already a system in place for disposal of fallen stock within Hatfield forest which was utilised for this work.

Data recording and submission

Data was initially recorded manually as all the traps were emptied. This was then transferred onto a master spreadsheet and periodically emailed to Cefas.

Rookery Reservoir, Bordon, Hampshire.

Site description

This water is one of a series of waters owned and managed by Oak-hanger Angling club. The water was originally used as a trout lake but now contains a typical mix of coarse fish species. It has a fairly consistent depth of 6 – 7ft and has a fairly light fishing pressure with typically 6 or 7 people fishing the water each day in the autumn. The lake has a good population of big roach. The lake is closed for 1 ½ months from March to the end of April, to give the fish a 'break'.

The reservoir is sheltered by large trees and is very secure, member only water with chain fencing around the perimeter. The lake is dug into the water table and has no inflow or outflow. There is an overflow but this is very rarely in use and the reservoir has never flooded in living memory. There is good access around the reservoir with prepared angler swims.

History of signal crayfish at the site

The site is reported to have a large population crayfish present and it was thought that they appeared approximately 10 ago. There has been some previous trapping carried out about 3 years ago with 1.5 tonnes of crayfish being taken out by commercially trappers.

Impacts of signal crayfish on Site

The fishery manager thought that there were holes and damage to the banks. The fry population seemed to be low and crayfish have been observed predating on fish. The main problem was the anglers being plagued by signal crayfish taking their bait and knocking lines.

Methodology and trapping process

A large team of volunteers was put together and were given different shifts to check the traps. A total of 50 traps have been deployed at the site (figure 20). The sampling teams were to check the traps weekly but split into two lots of 25 traps each. The teams were provided with labelled buckets, ID cards, measuring plates and instruction.

Biosecurity and animal disposal

The project team crushed the crayfish and then incinerated the carcases on site.

Data recording and submission to Cefas

Data was initially recorded manually as traps were emptied and reset. This was then transferred onto a master spreadsheet and emailed into Cefas on a monthly basis up until the point where the fishery manager changed and the club was re-organised.

Starmount Reservoir, Radcliffe, Borough of Bury.

Site description

Starmount is one of a small group of stone based reservoirs that is run by Radcliffe Angling club. The lake has stone lined sides then an evenly sloping stone lined bottom reaching a depth of 18ft with a flat bottom. There is no inflow and the outflow is rarely in use and is blocked with chicken wire. There was thought to be a very low flood risk. The site is open to the public with easy footpath access all around the site.

History of signal Crayfish at the site

The site thought that the signal crayfish had appeared in the last 3 years. Trapping has been taking place in some adjoining lakes but only a couple of test traps had been set in the main larger reservoir. The water is clear with crayfish being easily visible in the margins. Divers in the lake have reported not seeing crayfish in the deeper flatter areas.

Impacts of signal crayfish on the Site

The only impact noted was on the nuisance effects on Anglers whilst fishing.

Methodology and trapping process

Thirty traps were positioned around the lake. This was thought to be the maximum number that the club could manage.

Biosecurity and disposal of animals

The project team crushed the crayfish and then incinerated the crayfish on site.

Data recording and submission to Cefas

Data was initially recorded manually as traps were emptied and reset. This was then transferred onto a master spreadsheet and emailed into Cefas periodically.

Thornhill Road Pond, Dewsbury, borough of Kirklees.

Site description

This site consists of a small concrete and stone sided pond situated amidst an industrial area. The pond itself is beside the river Calder but is at a much higher level with all the surrounding development. The water is stocked with a typical mix of coarse fish and is run by Dewsbury Angling Club. The pond is only fed by gutter water from the surrounding industrial area and the outflow has a valve and a large drop to the river below. It was felt that there was very low risk of flooding at that height. The site has secure access for members only via locked fencing. Whilst the pond structure is beginning to age and crack there remains good access all around the site for anglers and trapping teams.

History of signal Crayfish on the site

Club members have no memory of catching or seeing any signal crayfish on site from 1992 until 2012.

Impacts of signal Crayfish on the site

As the crayfish had only just arrived it was felt it was too early to say what impact they have had. The site was not sure if the carp were breeding, however, they would necessarily breed every year anyway.

Methodology and trapping process

Introductions to the club were made via the Environment Agency. Before trapping could begin or licences be issued, a management plan was submitted by the club to the Environment Agency. This covered policies and procedures to be followed during the trapping operations. The site begun with 10 traps, which was increased to 20 shortly after the start of the project.

Biosecurity and animal disposal

Due to the sites northerly location and being in an area where crayfish are fairly recent arrivals the Environment Agency developed a management plan with the site to document the processes to be followed. All captured crayfish were disposed of in accordance with the management plan. This involved crushing and incineration on site and disinfection of the tubs and bins.

Data recording and submission

Data was initially recorded manually as traps were emptied and reset. This was then transferred onto a master spreadsheet and emailed into Cefas periodically.

Yeadon Tarn, Leeds, Yorkshire.

Site description

Yeadon Tarn is a large shallow water body situated between residential areas and Leeds airport. It is used by multiple interest groups including sailors and kayakers, model boat owners, walkers, nature conservation, bird watchers and fisherman. The lake is filled with land drain water only (but none from the Airport) and has an outflow with a 3ft drop to a drain.

It has zonal areas for each interest group and there is an active group that meets to discuss managerial issues. Recreational activities tend to take place at one end while there is a nature reserve at the other. The margins are surrounded by many large stones which act to reduce the impact of wave erosion. The public have access around the lake at all times.

History of Signal Crayfish on the site

The site first saw crayfish skeletons appearing approximately 5 – 6 years ago. It's is not clear how they arrived at the reservoir. It was questioned if they could have arrived as eggs on keep nets but this was thought very difficult to establish.

Impacts of Signal Crayfish on the Site

The crayfish have become a major problem for the fishermen due to the nuisance effects on their baits. There is some undercutting of banks but it is unknown if this is due to crayfish damage or wind and wave erosion. There appeared to be a lack of fry and small fish, mainly carp. After one year there appeared to be more fry, however extra spawning habitat was added to the backs of the wave baffles.

Methodology and trapping process

Due to the large size of the water the team opted to begin with a full 50 traps situated primarily around the perimeter of the lake, but with some situated with the nature reserve where the water it shallow. No traps were set along the dam edge or near to boating areas to avoid disruption with recreational activities.

There was initially some concern among the users as to what the traps involved and how they worked and associated safety issues. This was resolved by setting up a meeting with the user group and demonstrating the traps and how they would be tethered. Eventually, the sailing club supported the project and have offered the use of a boat.

Biosecurity and animal disposal

Due to the sites northerly location and being in an area where crayfish are fairly recent arrivals the Environment Agency developed a management plan with the site to document the processes to be followed. All captured crayfish were disposed of in accordance with the management plan. This involved crushing and incineration on site and disinfection of the buckets and tubs.

Data recording and submission

Data was initially recorded manually as traps were emptied and reset. This was then transferred onto a master spreadsheet and emailed into Cefas periodically.

Annex 4. Laboratory testing of trap types to be used in field trials.

The trapping of crayfish is normally conducted using cylindrical funnel traps, these are commonly referred to as Swedish ‘trappy’ traps, and are the most common trap used in European crayfish fisheries (Fjälling 1995). A number of other traps have been used and tested in a variety of different trials (Bean & Huner 1979; Westman et al. 1979; Fjälling 1995; Campbell & Whisson, 2000). One of the main drawbacks of most of these trials when considering their use in the control/management of populations is that they are based primarily around the commercial exploitation of populations. There are a number of factor found to be important in relation to trap effectiveness:

- Trap retention is a key feature of trap functionality for control/management purposes. Westman 1991 found retention an issue with the majority of traps used in a test of trap efficacy, with animals being able to enter and exit some trap designs at will. Modification of the entrance to crayfish traps to a slit-like aperture was reported to increase retention considerably (Westman 1991). Morgan et al. (2001) modified funnel traps by introducing a ‘T’ junction that animals have to enter the trap through. This modification improved trap efficiency and reduced the number of fish caught.
- One common feature of traps used in commercial fisheries is that the mesh size is big enough to allow the escape of animals that are below a commercial size. The retention rate of traps has been improved by decreasing the mesh size of the traps (Peay & Hiley 2001). Unmodified ‘trappy’ traps will catch animals of 35-70mm carapace length, while traps that have a reduced mesh size will trap considerably smaller animals minimum 18mm according to Wright & Williams, 2000.
- Traps with a large internal ‘volume’ have been reported to have both the best yield (catching the most animals in total) and the best retention (Bean & Huner 1979; Fjälling 1995; Campbell & Whisson, 2000). The increased volume of the traps may negate the prior occupancy effect of deterring smaller animals from entering a trap as the additional volume makes encounters less frequent. The additional volume may also improve retention as it will make relocating entrances by animals, once in the trap, more difficult.

A short laboratory based study was conducted to assess the relative efficacy of three crayfish trap types. The laboratory trial results were to be used to inform on the most suitable trap type to be used in field trials and the development of best practice guidance for trapping invasive crayfish populations in enclosed water bodies. The trap types were selected based on the following criteria:

- Robust - traps need to be able to withstand prolonged periods of submersion throughout the year, with regular (at least weekly) handling. Some nylon traps, or trap types with zips can snag and break easily and therefore were avoided for this study.
- Easily deployed – for the development of management plans which are accessible to a broad range of people, the equipment required for implementation should ideally not require any specific training or relevant qualifications, therefore use of the method had to be accessible to all.
- Safe to deploy – traps ideally should be safe to deploy at all times of the year. Entering into a water body to deploy traps is a health and safety risk which should be ideally avoided, ruling out the potential use of fyke nets.
- Readily available – to control a population of crayfish large numbers of traps may be required, therefore the trap design needs to be readily available for purchase.

A variety of methods and types of traps were examined as part of the traps selection process for this study, including fyke nets, a range of cylindrical traps, a variety of homemade traps used during various studies and trap types used in the marine crustacean fisheries.
Based on the criteria it was decided to use bankside deployed baited cylindrical crayfish traps for the field trials. These are easily deployed by all age groups, require no training and are comparatively safe to use. There are a range of crayfish traps available commercially that meet this description
There are a number of commercial traps that were made from nylon netting on a coiled wire frame: due to concerns of durability these types of trap were not used. Despite a number of comments on how effective fyke nets were at attracting crayfish, deployment required entering into the water and requires considerable physical effort to remove when full of crayfish, therefore fyke nets were excluded.
Three trap types were shortlisted for comparison by laboratory based trials. These were the Swedish 'trappy' trap deluxe, minnow trap, the Swedish 'trappy' trap and the (see figure 3 below). Laboratory

Figure 4. Trap types selected for testing (from left to right) 'trappy' trap deluxe; Minnow trap; and standard 'trappy' trap.

trials were conducted to assess how effective these traps were at: i) attracting crayfish; ii) retaining crayfish and if: i) time of deployment; ii) comparative population density iii) gender or iv) size of animal effected either retention or attractiveness.

Materials and methods

Animal husbandry

Approximately 1,700 signal crayfish (*Pacifastacus leniusculus*) were collected and brought to Cefas Weymouth laboratory in November 2012. The animals were of mixed size and age. These animals were acclimatised for 1 week and experiments conducted in November and December of the same year. Stock populations were held in two 300L tanks containing ‘hides’ (section of UPVC plastic tubing) and maintained at 12ºC with constant aeration. The animals were fed twice a week on potato and carrot mix, feeding was avoided on experimentation days.

Experimental design

All experiments were conducted in large 900L experimental tanks. During all experiments hides (UPVC plastic drainpipe) were available for the animals in the experimental tank. Hides were provided for animals at a ratio of 2:3, each hide was approximately 15cm long with a 10cm diameter, each providing room for one or two animals to hide. The sex, carapace length and additional observations (e.g. missing limbs) were recorded for each animal before it entered the experimental tank. Three types of experiment were conducted:

- trap attractiveness- examining how many animals moved into a trap from outside. In these experiments crayfish were placed into the tank and left to acclimatise. A baited trap was then placed into the centre of the experimental tank. After a set period the number of crayfish inside and outside of the trap were recorded.
- trap retention (trap effectiveness) – examining how effective the trap is at keeping crayfish in. In these experiments a set number of crayfish were placed into the trap and the trap then placed in the centre of the experimental tank. After a set period of time the number of crayfish inside and outside of the trap were recorded.
- prior residency – examining whether the size of the fist animal entering a trap will alter the subsequent catch composition or size. Crayfish were placed into the tank and left to acclimatise. A trap containing either a large male or female crayfish that had been marked for identification was placed into the middle of the tank. After a set period of time the number of crayfish inside and outside of the trap were recorded. Prior residency experiments were

conducted only overnight (15 hours), with the deluxe 'trappy' trap and with the lower density of animals.

All traps were baited using a standard commercially available bait box filled with 25g (±5g) bacon (except where empty bait boxes were used as a placebo).

Three commercially available trap designs were used in the laboratory trials:

- the Swedish 'Trappy' trap (refereed to here as 'trappy trap normal' or TTN),
- the 'Trappy' trap deluxe (TTD)
- THE minnow trap (MIN)

Initial experiments examined the trap attractiveness of the 3 trap types in relation to time of day. Four different time slots were compared; these were:

- In the morning, referred to as AM with a duration of 3 hours.
- In the afternoon, referred to as PM with a duration of 3 hours.
- During day light hours, referred to as DAY with a duration of 7 hours.
- During darkness, referred to as NIGHT with a duration of 15 hours.

All of these experiments were run at low (15 animals per experiment) density, with 3 repetitions of each. Data was normalised to account for the different duration of the time slots, and significantly more animals were trapped during darkness than at any other time of day. Based on the resulted from these experiments, high density (30 animals per experiment) experiments were run during darkness (i.e. NIGHT time slot) only.

Prior residency experiments were all run during darkness and at high density (30 animals per experiment).

Results

Since high density experiments were run only at night, these results were analysed separately; first the impact of timeslot, trap, sex and length were investigated, using only the low density data. The data corresponding to night experiments was then extracted and used to investigate the impact of crayfish density.

Trap attractiveness

Data was examined for the trap attractiveness experiments, comparing total count of animals per time slot. Analysis was conducted using a logistic regression. Figure 4 shows the total count of animals caught per trap per time slot. Trappy trap deluxe (TTD) and trappy trap normal (TTN) caught significantly more animals during AM and NIGHT time slots in comparison to minnow traps (MIN). All traps caught more animals during the NIGHT time slots that the other time slots tested (these were all significant difference when comparing NIGHT with the other times slots respectively for each trap type). TTN caught significantly more crayfish during the PM time slot that either TTD or MIN. MIN traps caught more animals during the DAY time slot, but this was not significantly different from numbers caught in both TTD or TTN. Even with the normalisation of data to account for the different duration of time slots traps caught animals more effectively during the NIGHT time slot. This clearly demonstrates that traps operated most effectively during darkness, this is likely to be a result of animals being more active during darkness. No statistical different was observed when timeslot was compared to total count of gender caught per trap type.

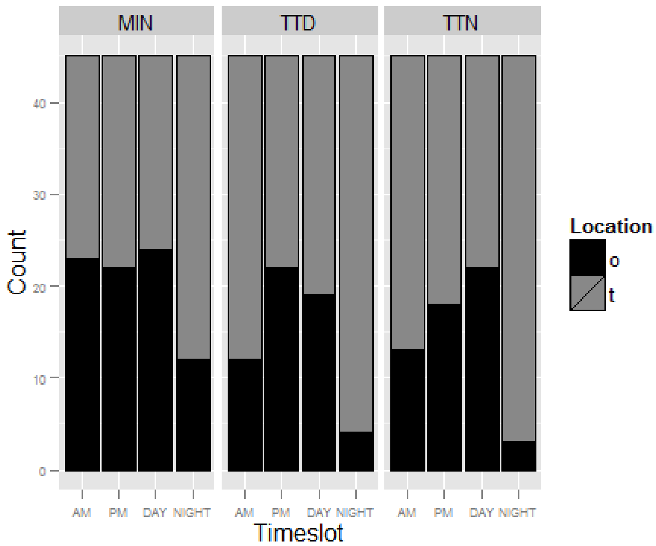

Figure 4. Total number of crayfish trapped (t) in grey and those not trapped or outside of the trap (o) in black for minnow trap (MIN) trappy trap deluxe (TTD) and trappy trap normal TTN for 3-hour trapping periods (AM and PM) 7 hour (DAY) and overnight for 15 hours (NIGHT).

The total number of crayfish caught per trap was examined. Significantly more animals were caught in TTN and TTD than in the MIN trap. There was no significant difference between genders and the counts of each in the different trap types. Figure 5 shows the total number of animals caught per trap type.

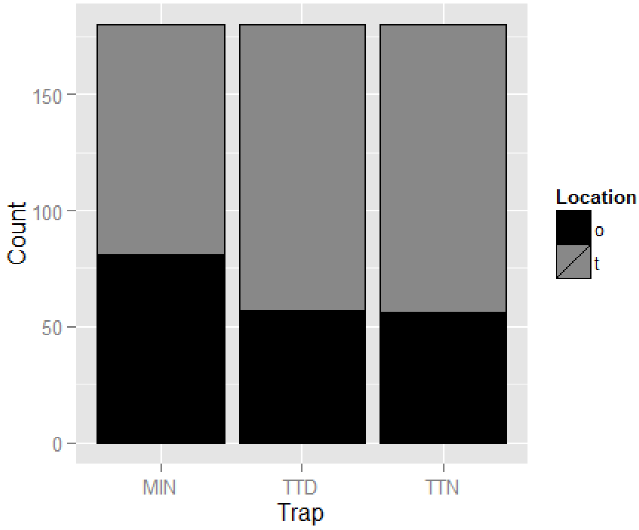

Figure 5. Total number of crayfish trapped (t) in grey and those not trapped or outside of the trap (o) in black for minnow trap (MIN) trappy trap deluxe (TTD) and trappy trap normal (TTN).

Figure 6 shows the total number of crayfish caught per trap type plotted against carapace length (which has been categorised into 0.5 cm intervals). TTD caught significantly more animals in the 3.5 to 3.9 cm and 4.0 – 4.4 cm size categories than the other trap types. MIN caught significantly less in the 4.5 – 4.9 cm categories and higher than the other trap types. TTN caught significantly more animals in the 5.0 – 5.4 cm size category, while TTD caught more 5.5- 6.0 cm crayfish, but this was not significantly different to TTN.

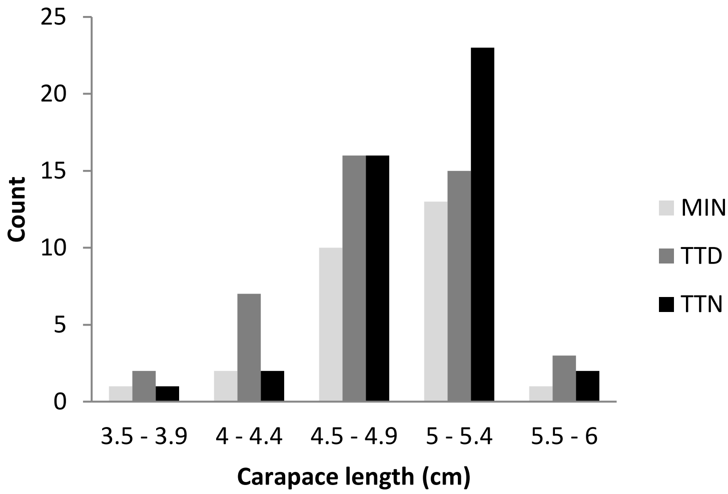

Figure 6. Total number of crayfish caught during trap attractiveness trails per trap type minnow trap (MIN) trappy trap deluxe (TTD) and trappy trap normal (TTN) plotted against size category.

When comparing numbers caught between low (15 animals per experimental tank) and high (30 animals per experimental tank) densities there was no significant difference.

Trap retention

A logistic regression was used to analyse the data. Gender and density (of animals in the trap) had no significant impact on numbers retained in comparison to those that had escaped. The number of animals retained as not effected by the amount of time the animals were left in the trap, apart from with MIN where more animals escaped over 15 hours than over 3 hours. There was a significant increase in small (3.5-3.9 cm) animals escaping from all traps types than other size categories. Figure 7 shows the proportion of crayfish retained per trap types. While there was no significant difference between the TTD and TTN trap types, MIN traps retained significantly fewer animals.

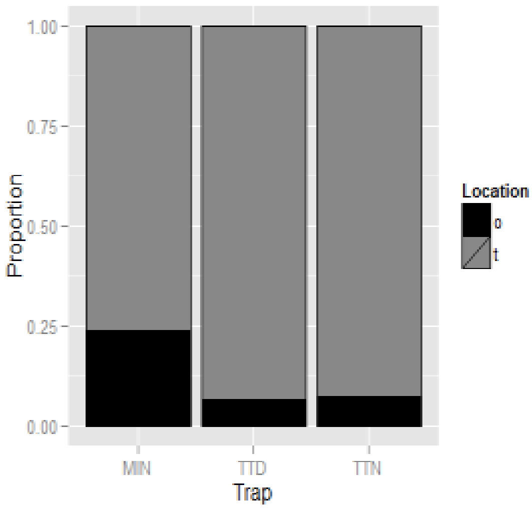

Figure 7. Proportion of crayfish retained during the night time slot within traps (t) in grey and those not retained or outside of the trap (o) in black for minnow trap (MIN) trappy trap deluxe (TTD) and trappy trap normal (TTN).

Prior residency

A logistic regression was used to analyse the data collected in relation to prior residency. There was no significant difference in catch composition (gender and animal length) in relation to the gender of the initial residence. However, fewer animals entered the trap containing large males than large females, although this result was not significant.

Discussion

Trapping

In all cases TTD and TTN were significantly more effective at trapping crayfish in comparison to MIN, with very little difference between the two trap types. Differences between TTD and TTN were observed in the length of animals caught, with TTD capturing more small and large sized animals than TTN, however, TTN caught more medium sized (5.0-5.4cm carapace animals) than TTD.

The gender of catch composition did not alter between the 3 trap types tested. Although more males were caught in trials using all of the trap types, this was not significant. The ratio of females to males within the population used was 1:1.11. This is comparative to sex ratios from wild populations. Traditionally trapping is thought to be inherently biased to the removal of adult males, which tend to be the larger animals within a population. With more repetitions the male bias is likely to become more pronounced.

The test results suggest that larger males (6cm+ carapace length) are proportionally less likely to be trapped. This is supported by evidence provided by commercial trappers (see Annex 1). One reason for this may be the limited aperture size making ingress difficult for larger animals. Commercial traps work around this problem by modifying traps increasing aperture size.

No significant difference was observed between trials conducted during the morning (AM) or afternoon (PM). There was also no significant difference observed between morning (AM 3 hours) and afternoon (PM 3 hours) trials and trials conducted throughout the whole day (DAY 7 hours), even when data was normalised to account for differences in the duration of trials. Trials conducted over night (NIGHT 15 hours) showed a significant increase in animals caught (even when adjusted for duration). This clearly shows that it is best to trap during dark i.e. over night.

There was no significant difference in trap attractiveness with density of animals. This may be as a result of the densities used and the threshold point where density does have an impact on trap efficiency not being reached. Crayfish population density will affect the efficiency of traps, but this will be dependent on the retention of animals in the traps, and therefore the carrying capacity of the different trap types.

Retention

All traps failed to retain small (3.5-4.9 cm) animals, although TTD retained the most (not significant). MIN traps failed to retain the most animals, even with large animals escaping over time. The relative poor retention of MIN traps may be a result of the comparatively small 0.45m^3 chamber size in comparison to 0.063m^3 for TTN and 0.083m^3 for TTD. Although there was no significant difference between TTN and TTD, TTD traps did retain more small animals. This may be due to the smaller mesh size of TTD traps in comparison to TTN.

There were no significant differences observed as a result of stock density. Again this may be due to the threshold density not being surpassed within the experiments.

Prior residency

No significant difference was observed with prior residency of either a male or a female. Although traps containing a large male prior residence did trap slightly fewer animals, this result may become more pronounced with more repetitions. This may be due to a lack of size differentiation between the animals in the test population. It may also be that it is not the effect of a single animals that prevents other (smaller) animals from entering the trap, but a combination of a number of large animals in the trap.

Conclusion

From this work there are some clear conclusions that can be drawn that will aid in the development of a trapping programme:

1) Trapping at night is far more effective than trapping during the day.
2) Minnow traps performed poorly in comparison to the other traps designs.
3) There was little difference between the 'trappy' trap designs, although the deluxe version was better at trapping and retaining a greater size range.

Trap type selection for field trails

Within the experiments the standard (TTN) and deluxe 'trappy' trap (TTD) designs performed most effectively. Although the TTD did catch a broader range of size categories. Other parameters of the traps were compared such as mesh size, volume and ease of use.

The TTN had a diamond mesh size with a diameter of approximately 3.5cm, and a volume of 0.063m^3. In comparison the TTD has a rectangular mesh (3.5x1.3cm), a volume of 0.083m^3. This means that the only animals with a diameter of 1.3 cm can escape through the mesh of a TTD in comparison to a TTN and that TTD traps have a greater volume to retain a greater number of animals. In addition, TTN traps were difficult to use due to the funnel attachments to the main body of the trap. In contrast TTD had a single flip top lid, which was easy to use. The TTD trap was more rigid and could also be stacked, while the TTN was relatively flimsy and could not be stacked. It was therefore decided to use the deluxe version of the traps for further field trials.

Annex 5. Experimental design in relationship to citizen science projects

The experimental design was discussed within the scientific team at Weymouth but it soon became clear that what could be achieved at each site would vary between sites depending on factors such as availability of labour, size of the water, the number of traps to be positioned and the time required to record and process the data and deal with the captured crayfish. It was recognised that if teams were asked to provide several hours per day checking traps every day of the year for a prolonged period then the project would most likely fail due to volunteer fatigue.

It was realised that a practical approach had to be taken in setting the workload at a level the volunteer groups felt comfortable and realistic for them to achieve. Therefore, the number of traps, where they were placed, how frequently they were checked and what information was to be gathered was dictated by the clubs to a degree while being guided by Cefas staff. While this may have limited the amount of information ideally gathered for work of this nature, it ensured the work would continue throughout the life-time of the project and that the information obtained was reliable. While data gathering was normalised as much as possible across the sites, trap numbers, frequency of checking and placement varied, providing different trapping intensities and catch per unit effort across the six different sites. The type of bait used was also discussed and the implications of this on the time taken to set traps, the cost to the project, the ease of use, the availability of supply and the consistency and comparability between sites and the biosecurity risks. It was decided that the most convenient and consistent method would be the use of cat food pouches readily available from supermarkets. A particular brand was not deemed essential for the project, although this may have some bearing on catch rates it was impossible to standardise.

It was decided to request volunteers to collect relatively simple information from the trapping exercise, ensuring robustness and confidence in the data, rather than the process of collecting the information taking overly long, complicated or prone to errors. Therefore, information collected for each catch was limited to recording total catch number, the sex and length category of each animal along with if the females were carrying eggs. It was felt that this information would be sufficient to be able to inform the population model and determine the relative effectiveness of the trapping process when applied with differing degrees of effort. The use of size categories was used instead of actual total length or carapace length to ease the process of collection. Size categories used were small (0-4cm body length), medium (4-6cm body length) and large (6+cm body length). Any by catch was also recorded. This information was submitted to Cefas by the clubs normally on a monthly basis although this did vary.

Each club was requested to place out as many traps as they could deal with and empty the traps as frequently as they could while maintaining consistency. Each trap was individually marked for recognition and trap locations recorded and marked on maps provided by the clubs. Traps remained in the same location for the study period, or moved short distances from these locations, e.g. during angling competitions, so the maps provide an approximation of the locations.

Biosecurity and crayfish trapping

When dealing and handling live crayfish as part of a research project there is still a small risk of accidental transfer of either the alien crayfish themselves or crayfish plague (*Aphanomyces astaci*) on equipment or by the volunteer trappers themselves. However, this can be fairly easily mitigated against by the clubs by either ensuring that the captured crayfish are culled and disposed of safely and securely on site and ensuring that no equipment is to be moved off site.

These issues around biosecurity, culling and disposal of captured crayfish were discussed at an early stage with all volunteers and simple solutions put in place for most of the sites. For two of the most northerly sites where trapping is not generally accepted, a higher level of biosecurity was put into place. This involved the site having close liaison with Environment Agency officers and the development of a management plan that documented how disposal of carcasses would be carried out and how the disinfection of equipment would take place.

Annex 6. Summary table.

	Bird in the Hand	Hatfield Forest	Rookery	Starmount	Thornhill	Yeadon tarn
Angling club	Creda Redhouse AC	National Trust Ticket	Oakhanger AC.	Radcliffe AC	Dewsbury AC	Aireborough & district AC
NGR Reference	SJ95863623	TL54091991	SU77013771	SD75650870	SE24042072	SE21504147
LFMD Reference	EW046-W-510	EW046-S-766	EW011-U-252	EW025-K-750	EW067-H-347	EW016-F-411
Trapping Reference	C/CM/230920 13/K9	C/NE/2309201 3/K6	C/SP/2309201 3/K8	C/SO/1510201 3/K4	C/RA/1510201 3/K5	C/RA/2309201 3/K7
Acres	0.86	11.36	1.83	2.53	0.67	19.09
Bank Perimeter	476m	993m	606m	478m	179m	1139m
Average depth	1.5m	1.8m	1.8m	Sloping to 5.5m	1.8m	1.2m
Deepest point	2.5m	3.5m	2.1m	5.5m	3.3m	1.2m
Crayfish Presence	30 years	10 years	10 years	3 years	1 year	6 years
Previous Trapping	Yes, since 2008. Historical data	Some small scale many years ago	3 years ago (1.5 tonnes taken)	Only a couple of test traps	None known	None known
Water source	Spring fed + 3 run off drains	Forest run off only	None	None	Gutter water	Land drains
Outlet	Wire screened to new fishery lake	Outflow to forest drains /soaks away	None	Outflow blocked by Chicken wire rarely in use.	Outflow with valve and large drop to river.	Outflow / overspill with 3ft drop
Flood risk	Never in memory	Very low risk	Never in memory	Low risk	Low risk	None
Fish species	Carp, roach, rudd, tench, bream, ide, perch, chub, crucians, gudgeon.	Carp + ?	Carp, bream, perch, pike, dace, rudd, roach, tench & crucians.	Carp, chub, bream, crucians, perch, roach, gudgeon, tench, pike.	Carp, rudd, roach, perch, bream, chub, tench, orfe, golden orfe, crucians	Carp, roach, perch, bream, tench, gudgeon, golden orfe, rudd, crucians, koi.
Number of Traps	40	20	50	30	10 then 20	50
Collection	All twice a week	All once per week	Half twice a week (25 then 25)	Once per week	Once per week	Once per week in two sessions - (25 then 25)

Annex 7. Trap modifications.

Modifications were made to traps with the view of increasing retention of smaller animals, while increasing the accessibility of larger animals. Based on comments from commercial trappers and those conducting the trapping at the trial sites 3 modifications were made:

1. The traps were covered in stocking material (see figure 8) to reduce mesh size with a view of increasing the retention rate of small animals, this included the funnels at either end of the trap.
2. The entrance to the traps were increased (while staying within the legal limit) with the aim of increasing the accessibility of the trap to larger animals.
3. Again with the view of increasing retention, especially in light of the increased entrance diameter, zip ties where placed around the entrance of the trap facing into the trap.

Figure 8. Deluxe trappy trap covered in stocking material, also the zip ties coming off from the funnel can be observed.

Figure 9. Increased trap entrance diameter, also zip ties added to limit mesh size on the funnels, zip ties can also be observed internal to the trap.

Trap modifications were applied to half of the traps used at the trails sites. Modifications were made to alternate traps during the trapping period between April 2015 and April 2016.

Annex 8. Exploratory data.

Site name	Traps per acre	Estimated year of population establishing	Change in proportion of small crayfish	Change in proportion of female crayfish
Bird in the Hand Pool	46.511	30	0.446 – 0.999; $p < 2 * 10^{-16}$	0.143 - 0.044; $p = 8.82 * 10^{-10}$
Hatfield Forest Lake	1.761	10	0.050-0.631; $p < 2 * 10^{-16}$	0.424 - 0.463; $p = 0.0482$
Rookery Reservoir	27.322	10	0.0254 - 0.175; $p < 2 * 10^{-16}$	0.412 - 0.475; $p = 0.0375$
Starmount Fishery	11.858	3	0.414 - 0.515; $p = 0.00128$	0.304 - 0.476; $p = 1.83 * 10^{-8}$
Thornhill Road Pond	17.910-29.851	1	0.227 - 0.125; $p = 0.193$	0.282 - 0.362; $p = 0.397$
Yeadon Tarn	1.310	6	0.047 - 0.582; $p < 2 * 10^{-16}$	0.417 - 0.600; $p < 2 * 10^{-16}$

Site name	Traps per acre	Estimated year of population establishing	Change in proportion of small male crayfish	Change in proportion of medium male crayfish	Change in proportion of large male crayfish
Bird in the Hand Pool	46.511	30	0.54-0.999; $p = 3.91 * 10^{-63}$	0.431-0.0016; $p = 5.77 * 10^{-59}$	0.04-4.085e-05; $p = 1.148 * 10^{-06}$
Hatfield Forest Lake	1.761	10	0.05-0.648; $p = 9.24 * 10^{-128}$	0.573-0.455; $p = 6.037 * 10^{-06}$	0.527-0.02435268; $p = 3.39 * 10^{-100}$
Rookery Reservoir	27.322	10	0.033-0.158; $p = 1.28 * 10^{-07}$	0.221-0.735; $p = 1.635 * 10^{-36}$	0.758-0.15444744; $p = 2.33 * 10^{-49}$
Starmount Fishery	11.858	3	0.405-0.488; $p = 0.029$	0.482-0.350; $p = 0.0005$	0.115-0.16572825; $p = 0.0606$
Thornhill Road Pond	17.910-29.851	1	0.313-0.105; $p = 0.033$	0.529-0.414; $p = 0.322$	0.198-0.49504833; $p = 0.0056$
Yeadon Tarn	1.310	6	0.057-0.559; $p = 1.06 * 10^{-96}$	0.21-0.205; $p = 0.859$	0.786-0.28934638; $p = 1.88 * 10^{-71}$

Site name	Traps per acre	Estimated year of population establishing	Change in proportion of small female crayfish	Change in proportion of medium female crayfish	Change in proportion of large female crayfish
Bird in the Hand Pool	46.511	30	0.16-0.999; $p = 1.081 * 10^{-19}$	0.773-7.6e-06; $p = 4.49 * 10^{-17}$	0.12-0.00007; $p = 3.12 * 10^{-3}$
Hatfield Forest Lake	1.761	10	0.051-0.609; $p = 5.81 * 10^{-87}$	0.792-0.434; $p = 1.89 * 10^{-33}$	0.258-0.029; $p = 1.2 * 10^{-26}$
Rookery Reservoir	27.322	10	0.015-0.200; $p = 1.326e - 10$	0.187-0.798; $p = 5.9 * 10^{-43}$	0.818-0.091; $p = 6.93 * 10^{-59}$
Starmount Fishery	11.858	3	0.438-0.534; $p = 0.038$	0.409-0.38; $p = 0.5292$	0.156-0.089; $p = 0.026$
Thornhill Road Pond	17.910-29.851	1	0.076-0.2; $p = 0.276$	0.54-0.477; $p = 0.7151$	0.396-0.329, p=0.683
Yeadon Tarn	1.310	6	0.036-0.602; $p = 4.78 * 10^{-128}$	0.33-0.272; $p = 0.0239$	0.741-0.208; $p = 6.15 * 10^{-84}$

Annex 9. Questionnaire responses

Participants were asked to provide as much information as you possible that summarises thoughts and learning during the project. This was to focus on any differences between the start and finish of the project and include suggestions for what could have been done better or for further work.

Summary sentences have been added in Bold.

Logistics & Citizens science

Approximately how many working hours have you spent on the project per week?	
Bird in the hand	8 -10 hours per week, i.e. cleaning traps, repairs etc.
Hatfield	3-4 hrs. per person with a 3-5-person team for each session
Rookery	6 hours
Thornhill Road	Emptying and re-setting traps: 1.25 hours' x 2 people, plus travelling time 0.5 hrs x 2, twice PW. Nov 2013 – 20/6/14 once PW since, plus 0.5 hr PW admin.
Yeadon Tarn	8 Hours
Summary Text	**Average times spent on the project per week was between 6 to 12 hours. This varied on trap and volunteer numbers.**
Has the project been completely supported by club members or others involved in the water? If not, what were the concerns or difficulties	
Bird in the hand	I can honestly say that the landowner and all members have been completely supportive of the project all the way.
Hatfield	Yes, supported by National Trust. Also supported by permit fisherman who use the water.
Rookery	Yes. No negative feedback from club members
Thornhill Road	There has been no opposition to the project but most of the work has been done by our club secretary and dam official. Nothing new there, then – although 2 committed volunteers are often better than a dozen unwilling conscripts.
Yeadon Tarn	Yes
Summary Text	**Project teams received universal support from club members, landowners and other stakeholders.**
Has the awareness of club members to the issues caused by crayfish been raised by this project?	
Bird in the hand	The awareness of club members to the damage caused by these crayfish has risen 100%. As we have learned this has been passed on to members.
Hatfield	Yes, Visitors to the N.T. site have become more aware of the issues. This has also involved awareness sessions with the local children visiting within school groups conducting pond dipping. The National trust local staff have also taken on board all the related issues.
Rookery	Yes. Most anglers have been asking about the impact caused by crayfish. Less well known was the plague they carry, posing the treat to our native species
Thornhill Road	Yes, there was a presentation to club members' / associates members at the beginning of the project and our dam official reports regularly to our monthly

	club meetings. We have put up notices at the dam for those members / associate members who do not attend meetings (about 50%).
Yeadon Tarn	Yes, more members are now aware of the problem
Summary Text	**Awareness has been raised for not only club members and anglers but other water users such as pond dipping school children to national trust members through a variety of outreach methods.**
Have there been any issues regarding the running the project or collecting the data?	
Bird in the hand	No problems at all. In fact, members have stated that since the start of trial no one has hooked a crayfish in the last 12 months.
Hatfield	Maintaining regularity of trapping sessions due to a variety of external unrelated issues. This can be mitigated by having a larger team of volunteers but volunteer interest levels need to be maintained by creating additional related tasks to be involved with on an ad-hock basis. We have added Water Quality Testing on All water bodies within the site to the work framework devised for the volunteer team. This has raised the overall profile of the CEFAS project work conducted by providing a basic overview of the water environment for the crayfish within the landscape.
Rookery	Keeping motivation of the volunteers was key to success. I kept them informed of numbers caught and the importance of recording nil catches as this also has a scientific value. Overall the project ran very well.
Thornhill Road	No issues encountered.
Yeadon Tarn	The only issues have been when the lake had ice on or wind been too strong to work
Summary Text	**Sites generally did not experience too many problems in running the project or collecting the data. Issues of motivation were resolved by keeping the volunteers informed. Adverse weather impacts such as frozen lakes or strong winds were unavoidable.**

Effects on the Environment

Have you observed any changes in the environment (either positive or negative) as result of the trapping project? *If so, please detail any changes*	
Bird in the hand	Yes. The most significant change we have noticed is the amount of small fish coming through. Also no crayfish being caught on the hook.
Hatfield	The beneficial effect of all the work conducted, is that the National Trust conservation work on the immediate area local to the lake has been concentrated on reducing tree cover beside the lake which has dramatically reduced leaf-fall into the lake. Approximately 150 metres of Alder Trees (4-7mtrs. High) have been removed from the dam. This has taken place over the last 18 months. IT appears that crayfish populations are now beginning to gather where main residual leaf-fall concentrations could be expected.
Rookery	No observable environment change

Thornhill Road	We do not believe that the project has had any significant impact on the environment (perhaps a tiny amount of CO_2). We presume that removing over 300 crayfish will have benefitted the fishery but this is hard for us to quantify.
Yeadon Tarn	Yes, I have noticed that the amount of fry we get now has increased and the wear to the bank has cut down
Summary Text	**Observations on changes to the environment were inconclusive. Two sites observed increases in the numbers of fry coming through and one a reduction in bank erosion. However, two other sites did not observe any environmental change.**

Effects on Angling

Has the angling at the water been effected (either positively or negatively) as a result of the project?	
Bird in the hand	Most certainly, more fish being caught and less crayfish.
Hatfield	Positive benefits: - Less crayfish predation on fishing baits. Negative benefits: - occasional fish caught up on a trap. (not a real problem)
Rookery	Positive impact on the angling observed. The regular anglers have reported less bait theft, false bite indications and claw score marks on the bait. The water margins can now be fished without undue disturbance from crayfish.
Thornhill Road	Our dam is a water where margin – fishing is usually productive and the presence of the traps has hampered this to some extent (carp in particular appearing to learn quite quickly that circling the ropes used to tether the traps helped them to shed our barbless hooks. About one carp in 20 hooked in the margins would be lost this way.
Yeadon Tarn	Yes, the fishing has got better since we have been catching the crays. Previously anglers had to put a new bait on every 20 minutes now they can leave them for a few hours.
Summary Text	**All sites bar one have experienced a reduction in problems that crayfish cause for the baits of anglers. Two sites experienced problems with lines being caught around traps although this was not considered a major issue.**

Observations during the project

Have you observed any overall changes to the population structure of the signal crayfish that are present?	
Bird in the hand	The only obvious change we have noticed is more males are being caught and less females.
Hatfield	Areas of lake without leaf-fall have significantly reduced levels of crayfish catch. Predation damage on a significant proportion of caught crayfish 25% females, 10% males.
Rookery	Less berried females caught this season.

Thornhill Road	No – our primitive initial analysis of total catches of small, medium & large, male & female & berried crayfish for 2014 & 2015 suggests that the results are surprisingly consistent.
Yeadon Tarn	Yes
Summary Text	**Two site observed that more males and less females are now being caught but one site thought catches for 2014 & 2015 were consistent.**
What are your observations of the overall size of the crayfish being caught in comparison to the start of the project?	
Bird in the hand	The overall size of the crayfish is getting smaller.
Hatfield	Virtually no large specimens are now caught. The average weight has reduced by approximately 35%. Largest individuals weight by approx. 50%. More smaller berried females being caught
Rookery	The average size has reduced. Catches now consist of small to medium, rather than all large. No very large ones caught.
Thornhill Road	We found no discernible difference comparing 2014 & 2015 results.
Yeadon Tarn	at the start we were getting a lot of large crays and now we get a lot of small crays which does put a positive on trapping
Summary Text	**All sites bar one have observed that the overall size of the crayfish caught has reduced with catches now consisting of medium and smaller specimens.**
Please summarise your experience with accidental by-catch during the project?	
Bird in the hand	We have not experienced to many problems with by-catch at all just the odd little perch.
Hatfield	No By-catch in 2014 year of project. During 2015 we have had small numbers of perch fry up to 30mm in length in individual traps at various location on the lake. These mainly near overhanging shrubbery which is probably used as a nursery site by fish.
Rookery	Perch fry were frequent visitors to the modified traps, and occasionally in the non-modified traps. Largest perch caught was approx. 10cm in length. The fry were all returned safely. It seems that the bait was attracting them in, and the traps offered some shelter from predators.
Thornhill Road	The most unexpected by catch was a dead mink. The largest fish was a carp of about 4lbs which was returned alive, as were all the other fish caught. These were mostly small roach & perch but on 2 occasions we caught a dozen or more small tench from one trap – this out of a batch of 70 stocked 2 years ago.
Yeadon Tarn	We had perch hiding in pots and roach and gudgeon and found a dead rat but it gave us a look at what we thought had vanished.
Summary Text	**Accidental by-catch was not generally an issue with small numbers of perch, roach, gudgeon and carp being returned to the waters. A dead Mink and rat were also reported.**
In your opinion what were the main factors that affected the number of crayfish caught?	
Bird in the hand	The increase in traps from 20 to 40, the change to raw liver and also the intensity of checking the traps.
Hatfield	Location of traps relative to local tree fauna.

Rookery	Water temperature.
Thornhill Road	Water temperature & crayfish lifecycle (However, we do not record weather or moon phases, nor did we try other baits or putting traps elsewhere than in the margins. (how significant might barometric pressure be ?)
Yeadon Tarn	Weather
Summary Text	**The main factors affecting catch numbers was water temperature, the trap locations relative to habitat and the intensity of trapping.**
Did you notice any changes in catches due to phenomena such as moon phases, water temperature whether conditions?	
Bird in the hand	Yes, the weather and water temperature plays a large part in catches.
Hatfield	Water Temp. seems to affect overall activity especially as it increases.
Rookery	During the September and October full moon the catches seemed to go up. Calmer weather conditions also saw increased catch rates. This may have coincided with the breeding season? so crayfish are mobile searching for mates and peak water temperatures.
Thornhill Road	We did not record moon phases or weather conditions but we did record water temperatures & we do think that catches are highest from the beginning of May to the end of October. We seem to think that Nov & Dec 2013 were unseasonably warm. The lifecycle of the crayfish must be a factor but we think this is also temperature related.
Yeadon Tarn	Weather conditions play a vital part as when it was warm the number were high and when it was cold they were low. The wind direction plays a part in the number of crayfish in the pots as well.
Summary Text	**Increasing water temperatures increased catches across sites. Single observations suggested that wind direction could affect catches and that catches improved in calmer conditions. Single observations also suggested that higher crayfish were caught during full moons.**
What unexpected or unusual observations have you made during the trapping project?	
Bird in the hand	The one observation that stands out is that the crayfish tend to prefer fresh liver to older liver that has been left in the traps. The more you change the better the catch rate.
Hatfield	Absolute devastation of all plant life within the lake body. (photo's available for confirmation). This seen when lake was drained down 0.66mtr for dam inspection. Resident Mirror and Common Carp appear not to be successfully breeding. No grown on small fish being caught.
Rookery	Cannibalism occurring in the traps. Partial remains discovered when catch rates were up. This suggests that a more frequent emptying may be required, but this was not possible.
Thornhill Road	Males outnumbered females by 1.8 :1 in both 2014 & 2015.
Yeadon Tarn	We potted all around the edges and I found that if I put a pot near rocks the numbers caught were higher
Summary Text	**Unexpected observations varied and included bait preference, effects of crayfish on plant life, male:female ratios, habitat preference and frequency of emptying traps.**

Has your opinion on the benefits of trapping changed from the start of the project to the end?	
Bird in the hand	Not at all, in fact we are more determined to carry on trapping.
Hatfield	Yes, fish populations of young perch fry have increased. We have noticed significant predation of berried females this season. This recognised by lost limbs/claws and predated egg sacks. This not apparent in first season. Our thoughts are that this is the result of reduced food levels within the lake (mainly due to dramatically reduced levels of leaf-fall. There is no significant difference in fishing/baiting levels by permit fisherman this season.
Rookery	No, I have always felt that it would have a positive effect.
Thornhill Road	We presume that the presence of crayfish threatens the health of our own fishery but harmful results are hard to detect if the aim is eradication. Our trapping results suggest to us that the residual crayfish population remains discouragingly stable.
Yeadon Tarn	No, as I think trapping is a good control method.
Summary Text	**Four of five sites have the same positive view on trapping as at the start of the project. One site has observed different trapping effects over time such as increased predation on berried females. One site questioned the benefits as it felt that the population remained discouragingly stable.**

Trap design and effectiveness

What were your observations on the trap modifications?	
Bird in the hand	The trap modifications to us did not work effectively.
Hatfield	Specific modifications made, caused problems mainly due to volume of silt within the lake. This blocked the mesh and significantly increased the trap weight making lifting more difficult. Catch numbers reduced in modified traps. This proved by having one position with both old and new traps alongside each other for a number of cycles, no difference in sizes caught. No increase in numbers between traps. No significant difference in crayfish size was observed between original and modified traps.
Rookery	The mods made little difference to catching adult crayfish. It did result in a few juveniles of less than 5cm overall length being trapped, but the numbers caught wouldn’t make the mods worthwhile. Towards the end of trapping, the stocking covers were being torn so would need replacement.
Thornhill Road	Reviewing the figures, our first impression is that the trap modifications made little difference to trap performance.
Yeadon Tarn	The modification was a good idea but the tights would only last so long but you get the baby crayfish that would normally fall through the holes in the pots
Summary Text	**The consensus view was that the modifications had little effect on catch numbers and created more problems than they were worth.**

Could they have been performed differently and achieved better results?	
Bird in the hand	In our opinion, yes.
Hatfield	Experimentation with shorter, smaller electrical ties within the trap mouths may have given better access for the crayfish.
Rookery	Instead of stocking material a wire mesh could have been wrapped round to reduce hole size. This would be more robust, but also allow improved visibility into the trap for the crayfish to see the food source and the presence of other crayfish.
Thornhill Road	More traps might have increased the total catch. We do not know how many crayfish escape from the traps & thus can only speculate about whether more frequent emptying & re-baiting would improve performance. We would have had difficulty with minnow traps. When we switched from emptying and rebaiting once PW instead of twice, we thought this made little difference to the total catch.
Yeadon Tarn	An inner mesh would have been better but that’s all that would have made it better.
Summary Text	**Modifications would have been better if they had used a firmer coarser mesh for functionality and possibly visibility and detection of bait.**
Please detail any observations about which traps have performed the best and provide suggestions for why you think this might be the case?	
Bird in the hand	The Open traps worked best. The use of full cover stockings on traps to us tended to mask the scent of liver also blocked up easily. To us it would be easier to make smaller openings using longer ty warps woven into traps.
Hatfield	Original traps performed better. Size of electrical ties seemed to prevent smaller sizes entering traps.
Rookery	Standard traps are easier to work with in terms of time to make, maintain and empty. When the modified traps sink into the silt, they require a lot more effort to pull up.
Thornhill Road	The most effective traps appear to be those along the right side of the dam. (The side furthest from the river Calder). This is the side with the least shade when the sun is at its hottest.
Yeadon Tarn	Pots 40 to 50 did best as they were near a lot of rocks and they had the least amount of wind hitting them and pot 50 was near a rock structure
Summary Text	**Generally, most sites preferred the original design traps for ease of use. Those traps located near rocky habitat and in sunniest locations were mentioned as having the best catch rates.**

Future work

Will you continue to trap when the project has finished?	
Bird in the hand	Definitely
Hatfield	Yes, if allowed.

	A refuge type trap with a variable size slot access to control size of crayfish accessing the trap is being planned for use during 2016. This may be igloo shaped with an inverted dish shaped circular slot at apex. Predation of crayfish has been observed on crayfish within traps. This could be studied to try and determine reasons for and how this could be promoted within general population as a means of self-control.
Rookery	Yes
Thornhill Road	Yes, we will if we get the necessary authorisation.
Yeadon Tarn	Yes
Summary Text	**All sites are hoping to continue trapping if they get the necessary authorisation.**
If so will this be at a greater trap density or lesser trap density?	
Bird in the hand	The same as now.
Hatfield	We intend to have groups of traps in localised areas of lake where we have higher crayfish concentrations.
Rookery	As yet unsure, as volunteer numbers will dictate what is maintainable. Ideally the same.
Thornhill Road	We intend to retain 20 traps.
Yeadon Tarn	Keeping the same amount of traps
Summary Text	**Three sites will retain the trapping density as it is now. The others will vary according to habitat and volunteer numbers.**
Would you empty the traps more frequently or less?	
Bird in the hand	The same as now.
Hatfield	Probably about the same. May experiment with increased trapping cycle.
Rookery	Same frequency.
Thornhill Road	We will probably continue emptying traps weekly
Yeadon Tarn	No Ansa
Summary Text	**All sites will initially empty traps at the same frequency but one site may experiment with increasing the trapping cycle later.**
Would you be prepared to be part of further or similar projects in the future, possible including the trials of other methods of controlling crayfish?	
Bird in the hand	Most definitely, really enjoyed it.
Hatfield	Yes. We intend to experiment with alternative trap designs to catch 1st year crayfish. We have joined the Project starting 2016 by the Fresh Water Habitats Trust looking at Great Crested Newts. We also have a volunteer who is part of the RiverFly Partnership project who will be assisting with ARMI work on a seasonal basis.
Rookery	Yes, I believe the club will actively support any further projects.
Thornhill Road	We intend to continue trapping & will continue to record our catches. As we do not seem to be eradicating our crayfish, we would be pleased to be involved in any future projects.
Yeadon Tarn	Yes

Summary Text	**All sites would be prepared to be part of further studies.**
Do you have any suggestions for how the study could have been improved?	
Bird in the hand	No not really.
Hatfield	Water Testing alongside River-fly Partnership ARMI evaluation of water body.
Rookery	A trap to catch the small juveniles would be useful, as this part of the population is not being targeted. The trap could be a series of narrow diameter pipes to mimic the tunnels used by adults, but only allowing juveniles to enter.
Thornhill Road	We cannot think of any unless the statistical data could be simplified.
Yeadon Tarn	Cut down the empty times from 1 week to 2 weeks in the winter months
Summary Text	**Suggestions for improvement included adjusting the trapping frequency between summer and winter, testing of water quality and designing different traps to catch the juveniles.**
Do you think that eradication of the crayfish would be possible?	
Bird in the hand	Yes, with patience.
Hatfield	Possibly, if population level can be reduced by trapping then followed by possible changes in the environmental condition of the lake and/or take advantage of the services of a suitable predator. The food levels within the lake from leaf-fall appear to also create changes in behaviour and increased inter-crayfish predation.
Rookery	No, as the less there are, the harder it is to catch the remaining individuals.
Thornhill Road	The prospects do not appear very likely just yet.
Yeadon Tarn	Yes
Summary Text	**Views on the possibility of eradication appear split. Two sites thought it will be possible with persistence. One thought it might be possible with the introduction of suitable predators. Two sites thought it unlikely.**
If so, what do think this would require?	
Bird in the hand	Long term trapping and dedication of all concerned.
Hatfield	We have two lakes within 50 meters of each other with broadly similar habitats. However, we only have crayfish in the larger lake. This proved by failed trapping in smaller. We have and continue to evaluate both water bodies to try and determine why one lake does not have crayfish. As yet we have no answers, hence the water testing and ARMI work.
Rookery	Targeting of juveniles to prevent mature adults developing who can reproduce. Time will then reduce the population to such an extent it has no impact.
Thornhill Road	Although the dam has not been flooded in the last 30 years we have owned it, we are only metres away from the River Calder, which we understand to be seriously infested with signal crayfish.
Yeadon Tarn	Potting and the right fish that will eat crayfish
Summary Text	**Requirements for eradication suggested by site included a better understanding of water quality, stocking of predatory fish, long term trapping with dedication and targeting of juveniles.**

References

Abrahamsson, S. A., 1971. Density, growth and reproduction of the crayfish *Astacus astacus* and *Pacifastacus leniusculus*. Oikos 22, 373-388.

Bean, R. A. & Huner, J. V., 1979. An evaluation of selected crawfish traps and trapping methods. Freshwater Crayfish 4, 141-151.

Bills, T. D. & Marking, L., 1988. Control of nuisance populations of crayfish with traps and toxicants. Prog. Fish-Culturist. 50(2), 103-106.

Campbell, L., & Whisson, G. J., 2000. Catch efficiency of five freshwater crayfish traps in south-west Western Australia. Freshwater Crayfish 13, 58—66.

Cullen, P., Copley, L. & McCarthy, T. K., 2003. Observations on experimental trapping of *Austropotemobius pallipes* (Lereboullet) in a western Irish stream. Management and conservation of crayfish proceedings. Environment Agency R&D Project W1-070.

Holdich, D. M., Peay, S., Foster, J., Hiley, P. D., & Brickland, J. H., 2006. Studies on the white-clawed crayfish (*Austropotamobius pallipes*) associated with muddy habitats. Bulletin Français de la Pêche et de la Pisciculture 380-381, 1055-1078.

Holdich, D. M., Gydemo, R., & Rogers, W. D., 1999. A review of possible methods for controlling alien crayfish populations. Pages 245-270 in F. Gherardi and D.M. Holdich, eds. Crayfish in Europe as alien species. How to make the best of a bad situation? A. A. Balkema, Rotterdam and Brookfield.

Ibbotson, A. T., Tapir, G., Furse, M. T., Winder, J. M., Blackburn, J., Scarlett, P., & Smith, J., 1997. Impact of the signal crayfish *Pacifastacus leniusculus* and its associated crayfishery on the River Thames. Report for the Environment Agency, Thames Division, Reading, UK.

Fjälling, A., 1995. Crayfish traps employed in Swedish fisheries. Freshwater Crayfish 8, 201-214.

Frutiger, A., Borner, S., Büsser, T., Eggen, R., Müller, R., Müller, S., & Wasmer, H. R., 1999. How to control unwanted populations of *Procambarus clarkii* in central Europe? Freshwater Crayfish 12, 714–726.

Gherardi, F., Aquiloni, L., Diéguez-Uribeondo, J., & Tricarico, E., 2011. Managing invasive crayfish: is there a hope? Aquatic Sciences 73, 185-200.

Klosterman, B. J. & Goldman, C. R., 1983. Substrate selection behavior of the crayfish *Pacifastacus leniusculus*, p. 254-267. In C.R. Goldman (ed.), Freshwater Crayfish V. Papers from the Fifth Internat. Symposium on Freshwater Crayfish, Davis, CA. AVI Publishing Co., Westport, CT.

Kirjavainen, K. & Westman, K. 1999. Natural history and development of the introduced signal crayfish, *Pacifastacus leniusculus*, in a small, isolated, Finnish lake, from 1968 to 1993. Aquat. Living. Resour. 12, 1-15.

Lewis, S. D., 1997. Life history, population dynamics, and management of signal crayfish in Lake Billy Chinook, Oregon. Master's thesis, Oregon State University.

Lowery, R. S. & Holdich, D. M., 1988. *Pacifastacus leniusculus* in North America and Europe, with details of the distribution of introduced and native crayfish species in Europe. In *Freshwater crayfish: biology, management and exploitation*, edited by D.M. Holdich and R.S. Lowery, 283-308. London: Croom Helm.

Mason, J. C., 1975. Crayfish production in a small woodland stream. Freshwater Crayfish 2, 449-479.

Miller, G. C., 1960. The taxonomy and certain biological aspects of the crayfish of Oregon and Washington. M.S. Thesis, Oregon State University, Corvallis. 216 pp.

Miller, G. C. & Van Hyning, J. M., 1970. The commercial fishery for freshwater crawfish, *Pacifastacus leniusculus* (Astacidae), in Oregon, 1893-1956. Res. Rep. Fish. Comm. Oreg., 2, 77-89.

Moorhouse, T. P., & Macdonald, D. W., 2010. Immigration rates of signal crayfish (*Pacifastacus leniusculus*) in response to manual control measures. Freshwater Biology 56, 993-1001.

Morgan, K. B., Hilwig, K. D., & Burke, T. A., 2001. A modified minnow trap to reduce fish entrapment during crayfish removal efforts. Fisheries Technical Report 01-03. Statewide Fisheries Investigations, Federal Aid Project F-7-M-43. Arizona Game and Fish Department, Phoenix, Arizona.

Peay, S. & Hiley, P. D., 2001. Eradication of alien crayfish. Phase II. Environment Agency Technical Report W1–037/TR1. Environ Agency, Bristol, p 118.

Reeve, I. D., 2004. The removal of the North American signal crayfish (*Pacifastacus leniusculus*) from the River Clyde. Scottish Natural Heritage Commissioned Report No. 020 ROAME No. F00LI12).

Ribbens, J.C.H. & Graham, J.L. 2009. Loch Ken (Kirkcudbrightshire Dee) American Signal Crayfish Trapping Project. Marine Scotland Commissioned Report.

Rogers, W. D., Holdich, D. M., & Carter, E., 1997. Crayfish Eradication. Report for English Nature, Peterborough.

Roqueplo, C., Laurent, P. J., and Neveu, A., 1995. *Procambarus clarkii* Girard (écrevisse rouge des marais de Louisiana). Synthèse sur les problèmes poses par cette espèce et sur les essais pour contrôler ses populations. L 'Astaciculteur de France 45, 2-17.

Shimizu, S. J. & Goldman, C. R. 1983. *Pacifastacus leniusculus* (Dana) production in the Sacramento River. Freshwater Crayfish 5, 210-228.

Skurdal, J. & Qvenild, T., 1986. Growth, maturity and fecundity of *Astacus astacus* in Lake Steinsfjorden, SE Norway. Freshwater Crayfish 6, 182-186.

Stebbing, P.D.; Longshaw; M.; Taylor; N.; Norman; R.; Lintott, R.; Pearce; F. & Scott, A., 2012. Review of methods for the control of invasive crayfish in Great Britain. Defra report C5471.

West, R. J., 2010. A review of signal crayfish trapping on the River Lark at Barton Mills, Suffolk, from 2001 to 2009. Lark Angling & Preservation Society.

Westman, K., 1991. The crayfish fishery in Finland — its past, present and future. Finn. Fish. Res. 12, 187–216.

Westman, K., Pursiainen, M., & Vilkman R., 1979. A new folding trap model which prevents crayfish from escaping. Freshwater Crayfish 4, 235–242.

Wright, R. & Williams, M., 2000. Long term trapping of signal crayfish at Wixoe on the River Stour, Essex. In: Rogers, W. D. and Brickland, J (eds.) Proceedings of the Crayfish Conference held on 26th/27th April 2000 in Leeds. Environment Agency, Bristol, 81-88

Centre for Environment Fisheries & Aquaculture Science

Cefas

About us

The Centre for Environment, Fisheries and Aquaculture Science is the UK's leading and most diverse centre for applied marine and freshwater science.

We advise UK government and private sector customers on the environmental impact of their policies, programmes and activities through our scientific evidence and impartial expert advice.

Our environmental monitoring and assessment programmes are fundamental to the sustainable development of marine and freshwater industries.

Through the application of our science and technology, we play a major role in growing the marine and freshwater economy, creating jobs, and safeguarding public health and the health of our seas and aquatic resources

Head office
Centre for Environment, Fisheries & Aquaculture Science
Pakefield Road
Lowestoft
Suffolk
NR33 0HT
Tel: +44 (0) 1502 56 2244
Fax: +44 (0) 1502 51 3865

Weymouth office
Barrack Road
The Nothe
Weymouth
DT4 8UB

Tel: +44 (0) 1305 206600
Fax: +44 (0) 1305 206601

Customer focus

We offer a range of multidisciplinary bespoke scientific programmes covering a range of sectors, both public and private. Our broad capability covers shelf sea dynamics, climate effects on the aquatic environment, ecosystems and food security. We are growing our business in overseas markets, with a particular emphasis on Kuwait and the Middle East.

Our customer base and partnerships are broad, spanning Government, public and private sectors, academia, non-governmental organisations (NGOs), at home and internationally.

We work with:

- a wide range of UK Government departments and agencies, including Department for the Environment Food and Rural Affairs (Defra) and Department for Energy and Climate and Change (DECC), Natural Resources Wales, Scotland, Northern Ireland and governments overseas.
- industries across a range of sectors including offshore renewable energy, oil and gas emergency response, marine surveying, fishing and aquaculture.
- other scientists from research councils, universities and EU research programmes.
- NGOs interested in marine and freshwater.
- local communities and voluntary groups, active in protecting the coastal, marine and freshwater environments.

www.cefas.co.uk