THE DISTRIBUTION OF THE AMERICAN SIGNAL CRAYFISH (*PACIFASTACUS LENIUSCULIS*) IN THE DON RIVER CATCHMENT, SOUTH YORKSHIRE, UK

Don Catchment Rivers Trust

GRADUATE CONSULTANT:

CHRISTOPHER ARTHUR

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Executive Summary

- The Don Catchment Rivers Trust commissioned a study of the distribution of the American signal crayfish, a deliberately introduced invasive species, in the vicinity of Sheffield in South Yorkshire.

- The specific aim of the project was to identify the source of the species introduction and to test the hypothesis that the distribution could be attributed to an introduction at a single site, from which the signal crayfish dispersed to their current locations. The evidence gathered did not support this.

- Historical records regarding previous locations where signal crayfish have been found were collated and used to focus an intensive trapping regime to map their current extent.

- The study tested 123 sites within the Don catchment were surveyed for both signal and native white-clawed crayfish during June and July 2012. This included the Rivers Don, Rivelin, Loxley, Sheaf and Rother, Blacka Dike, the Limb Brook, the Moss and the Shire Brook.

- 26 of these sites were found to contain signal crayfish in 5 isolated populations; located in the Moss, Shire Brook, River Rother, Black Dike and the River Rivelin.

- 3 sites in the Limb Brook were found to contain native white-clawed crayfish. The species was not found at any other locations.

- Geoinformatic systems (GIS) were used to produce maps showing previously known locations, the 2012 survey results and the presence of key environmental factors such as weirs and other barriers.

- The data presented here indicate that the current extent of the invasive signal crayfish has changed little in the recent past, with populations showing slower rates of dispersal than might be expected based on studies conducted elsewhere in the UK.

- Weirs were observed to present barriers to the invasion of signal crayfish in some locations, such as Beighton weir and Woodhouse Mill regulator on the River Rother, which appear to be limiting the species from colonising beyond these extents.

- Environmental variables were found to show little correlation with presence of signal crayfish, though the presence of riparian vegetation seems to have the greatest positive influence.

- Overall, these data indicate that the Don catchment supports several isolated populations of signal crayfish that are the result of multiple deliberate introductions. Rates of dispersal were seen to be slower than could be anticipated based on studies in other catchments in the UK, but in most cases substantial reaches of un-infested waterways are available to accommodate their spread. Based on the survey findings, a bias towards woodland river habitats was observed, though whether this is a preference exhibited by crayfish cannot be substantiated due to the high level of anthropogenic action in determining the presence of signal crayfish.

1. INTRODUCTION

1.1. THE DON CATCHMENT RIVERS TRUST

The Don Catchment Rivers Trust (DCRT) is a charitable organisation in South Yorkshire concerned with the conservation and rehabilitation of 3 major watercourses, and numerous smaller tributaries within the Don catchment. These are the River Don, the River Dearne and the River Rother. The Don flows for approximately 160km from its source to the Humber Estuary and occupies a catchment of 1719km^2. Tributaries add a further 160km to the length of the Don, the Rivers Dearne and Rother contributing 47km and 43.3km respectively. The work of the DCRT focuses on the water quality and hydrology of the rivers, and the flora and fauna that they support. Since the formation of the trust in 2005 they have collaborated with a number of organisations such as the Environment Agency (EA), the Yorkshire Wildlife Trust (YWT) and Crayfish Action Sheffield (CAS) to undertake projects to address these issues.

1.2. INVASIVE SPECIES

A perpetual concern of the trust is the detection and management of invasive species within the catchment. Invasive species are of considerable economic [1] and ecological [2] significance globally due to the loss of native biodiversity that they cause and the resulting disruption to valuable ecosystem services. Whilst the movement of species between areas and their subsequent colonisation is undoubtedly a natural occurrence, human activity has just as certainly increased both their range and frequency [3] and at a rate that continues to increase [4]. Introductions may be accidental or intentional, though in the latter instance species often become invasive where the risk is not fully appreciated and adequate precautions are overlooked [5]. In most freshwater ecosystems across the globe, non-indigenous species (NIS) present the primary or secondary anthropogenic impact [6] and therefore the issue of invasives is one of growing international importance and attention [7]. Numerous studies have identified negative impacts from introductions of exotic species, such as loss of natural biodiversity [8] and damage to ecosystem functioning [9]. The River Don catchment is host to a number of NIS such as American mink (*Neovison vison*), Himalayan balsam (*Impatiens glandulifera*), Japanese knotweed (*Fallopia japonica*) and signal crayfish (*Pacifastacus leniusculus*), which have a range of adverse effects on the ecosystem. For example it is well documented that the American mink has eradicated native populations of water voles (*Arvicola terrestris*) [10][11]. The invasion of the American signal crayfish in to the River Don catchment is the subject of this study.

1.3. AMERICAN SIGNAL CRAYFISH

Image 1. American signal crayfish. The characteristic 'signal' markings can be observed on the claws. Image obtained from http://canalrivertrust.org.uk/media/huge/595.jpg (23/08/2012)

Crayfish are aggressive predatory omnivores with a wide tolerance for a range of environmental conditions [12]. Exotic crayfish species are among the most commonly introduced aquatic organisms [13]. In the UK the most widespread and problematic of these is the American signal crayfish [14]. The signal crayfish is a native of western North America [15] and was introduced into Europe in the 1960s for aquacultural purposes [16]. In 1976 it became an invasive species in the UK, being introduced to waterways primarily through the aquaria trade, use as fishing bait and for harvesting as wild food [17]. By 1988 the species had colonised 250 bodies of water [18] and by 2010, non-indigenous crayfish outnumbered native species by two to one across Europe [13]. Estimates of population density range from 0.9 to 20 individuals per m^2 in UK and US waters [19] [20]. Nearly all catchments in southern England now support populations of signal crayfish, and whilst northern England shows a comparatively patchy distribution, their range is continuing to expand [21]. The presence of signal crayfish has been shown to be responsible for a plethora of undesirable consequences in the UK (and Europe as a whole), most conspicuously the associated decline of the only native British crayfish species; the white-clawed crayfish (*Austropotamobius pallipes*) [14]. Populations of the white-clawed crayfish are being replaced steadily by signal crayfish through a combination of competition for food and habitat [22] and there is evidence to suggest that the colonisation of an area by signals will replace native species completely [23]. Signal crayfish are responsible for the spread of crayfish plague, *Aphanomycess astaci*, for which they are a vector [24], whilst European species exhibit high susceptibility with close to 100% mortality rate among infected individuals [17]. Consequently the native white-clawed crayfish is listed as an endangered species on the IUCN Red list under criterion A2ce and their distribution is believed to have declined by 50-80% in England [25]. The fact that since 2009 the status of *A. pallipes* was upgraded from

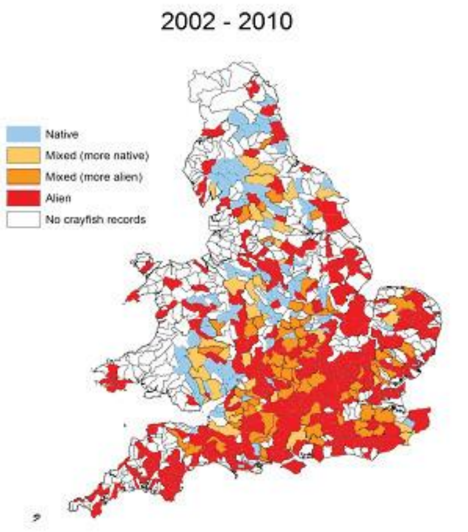

Figure 1 Distribution map of crayfish in UK sub-catchments (Nightingale & Holdich, 2011)

'vulnerable' to 'endangered' by the IUCN [26] shows the continuing severity of its plight. The waterways of central and northern England now exhibit the highest concentrations of white-clawed crayfish in Europe [27] and so conservation of their populations is of global significance. Signal crayfish are also seen to have an adverse effect on fish populations via competition and predation of eggs [28][29] and displacement of benthic species from shelter sites [30][31]. Similarly they are known to predate on amphibian and reptilian eggs and juveniles [32]. The ecological impact of these actions, combined with burrowing activities [17] and interactions with a wider range of aquatic organisms [28] is a severe loss of native biodiversity [33] which in turn has economic ramifications [34]). In recognition of the damage caused by signal crayfish, it is an offence to release them into the wild in the UK under section 9 of the Wildlife and Conservation Act 1981.

1.4. HABITAT

The wide environmental tolerances of signal crayfish allow them to occupy a greater range of habitats than the native white-clawed crayfish [35], in particular sites with lower water quality [36]. Whilst some studies do exist regarding the fine scale habitat requirements of crayfish, they are largely focused on single water bodies and so their robustness when applied over a coarse spatial scale cannot be determined [37][38][39]. There are several environmental factors that are frequently cited by studies of this nature as being of importance in identifying habitat as suitable for crayfish. Of these, the primary requirement is a high concentration of calcium (2.56mg L^{-1}) for calcification of their exoskeleton [35], this is often found in calcareous catchments where dissolution leads to high levels of dissolved ions in the channel. Another important factor influencing the suitability of a site for potential crayfish habitat is the presence of riparian vegetation to provide refuges [40] and shade [33]. Vegetation also provides sources of foods, via roots trapping leaf litter [41] and overhanging branches allowing invertebrates to fall into the water [42]. Crayfish are believed to show a preference for banks composed of clay soils as it provides a suitable substrate in which to create burrows [43], but poaching of soils by livestock has been seen to have an adverse effect on crayfish by both increasing sediment and agricultural loads in the water [37].

1.5. DISPERSAL

A number of studies have attempted to quantify the rates of invasion of signal crayfish in both upland and lowland river systems, though the range of estimates is vast. Dispersal of radio tagged crayfish in the upland River Wharfe in Yorkshire has been measured as 1.5km a year in 2004 [24] and 1.2km a year in 2008 [14]. Peay and Rogers [23] reported a rate of 1-2km a year in the same river, though a significantly lower upstream rate in a smaller tributary in 2009 [28]. In the latter case, the presence of a small waterfall was suggested as a factor in this reduced rate by barring progress. In a number of cases, expansion is seen to be greatest in a downstream direction [16][14], though the difference is not always seen to be significant. A study by Weinlander and Fureder in Austria [44] has recorded downstream colonisation of *P. lenisculus* at rates of up to 24km per year, and upstream at 4km. This is significantly higher than any UK based estimates, and higher temperatures in mainland Europe may be a factor in this instance. Crayfish size is observed to influence the preferred direction of movement, with smaller individuals moving downstream and only larger adults able to disperse upstream [14]. This is believed to be due to the physical strength required to actively move against the current. The effect of high flow events in passively transporting crayfish downstream has been reported by some studies [14] and may explain the variation in estimates provided by the studies cited previously. The substrate and presence of riparian vegetation of a river section is likely to influence this; sections with an abundance of refuges will allow crayfish to escape high flows whilst those unable to seek shelter will be washed downstream.

Gradient appears to have the largest influence on upstream colonisation, and so upland watercourses are invaded upstream substantially slower than less steep, lowland rivers [14][45]. A number of other factors are observed to influence these rates, such as water temperature increasing activity [16] and population density [19] suggesting that there are large seasonal and geographic variations between the invasion rates of separate populations. The relationship between size and movement of individuals is unclear with Moorhouse and McDonald [19] reporting a positive correlation, whilst Bubb et al [16][14] found no such link. Where expansion rates are unusually low, small obstacles such as weirs or waterfalls are offered as explanations [29][14]. The efficacy of barriers such as weirs to crayfish movement is an area that has received little attention but that would have obvious conservation benefits, both in selecting appropriate ark sites for native populations and in installing weirs etc. with suitable designs to prevent crayfish from traversing them. Dangerfield [46] states that many weirs in the vicinity of Sheffield are ineffective in halting crayfish due to gentle gradients, the presence of fish passes and films of algae to facilitate movement. Many weirs in the UK are being altered to include fish passes in order to comply with the Water Framework Directive (WFD) requirement of free passage to migratory fish [47]. Without careful consideration to their design and location, these fish passes have the potential to be navigated by signal crayfish past previously impenetrable barriers. It should also be noted that the ability of crayfish to leave the waterway and bypass barriers by terrestrial means needs to be taken into account. This information regarding dispersal is of significant value in predicting the spread of signal crayfish and in selecting sites to conserve for the benefit of native white-claws.

1.6. MONITORING

There are a number of possible techniques available for monitoring crayfish and these have been looked at in detail by Peay [48][49]. A summary of crayfish surveying methods and the required river conditions is shown in **Table. 1**. It is apparent that no single option is flawless, but that each possibility has advantages and disadvantages that will complement the environmental conditions likely to be encountered at a given site.

Table 1. Requirements, advantages and disadvantages of different survey methodologies for crayfish. The highlighted row shows the methodology utilised in this study

Method	Requirements	Advantages	Disadvantages
Manual Search (Standard method)	Clear Water <60cm depth	Able to search refuges Can catch juvenile individuals Can provide information on abundance, population structure etc.	Disturbs habitat Requires experience in identifying appropriate sites and in working safely near water Ineffective for bankside refuges
Manual Search (Fixed area)	Clear Water <60cm depth Slow flowing water	Can provide information on population densities	As above Labour intensive due to number of samples required
Trapping (Baited)	Moderate/slow flowing water	Can be used in deeper/more turbid waters when manual searches are impractical Relatively little effort	Only suitable for high population densities due to inefficiency Traps may be expensive Traps may be vandalised Care needed to prevent accidental trapping of non-target species Only catches **active** adults
Trapping (Un-baited)	Moderate/slow flowing water	Traps can be left for extended periods Catches juveniles as well as adults No risk to non-target species	Traps must be made Traps may be tampered with Availability of natural refuges will affect efficiency – varies between sites/conditions
Night Surveying	Clear water <1m depth Moderate/slow flowing water	Minimal disturbance as individuals are not caught No risk to non-target species	Safety considerations due to night working Requires calm water Prevents conclusive species ID without catches Affected by seasonal/behavioural/environmental responses

This study used baited trapping due to the range in size of the rivers to be surveyed. Whilst smaller tributaries such as the Moss or Shire Brook would be suitable for manual searches, the main body of the Rivers Don and Rother are far too deep and wide to accommodate such methods. Trapping is known to require relatively high abundances due to its low efficiency [48] and to show bias towards larger individuals [49]. A study by Silver [50] in the Huddersfield canal calculated trapping to have caught 2-4% of the number of potentially trappable individuals, though this will vary between populations depending on the age and size structures of the population, microhabitat use and the number and location of traps used [49]. Factors such as the type of bait used and water temperature [48] will also influence the actual numbers caught. Data obtained

Image 2. The River Don in Sheffield city centre. Image obtained from http://s0.geograph.org.uk/geophotos/02/37/42/2374201_00757589.jpg (23/08/2012)

from trapping is therefore of limited use in attempting to calculate actual population densities, or in comparing numbers between studies using even slightly different methods. Nevertheless, catch per unit effort provides a useful tool for comparing differences between sites surveyed as part of a study where variables are controlled as closely as possible, or in detecting change over time [51][52]. Trapping also has the potential of capturing non-target organisms. This can be reduced with the inclusion of an otter guard to restrict the entrance to the traps.

1.7. MANAGEMENT

Previous attempts to eradicate populations of signal crayfish have been largely ineffective [53]. The only method that appears to work is the use of chemical biocides, though the widespread and indiscriminate damage that they cause to an ecosystem makes them unacceptable in virtually all circumstances [54]. Removal by trapping can decrease numbers of the larger size classes that are able to be caught but leaves juvenile populations almost entirely untouched [19]. This is observed to have little effect on the overall population in the long term [55]. A study by Moorhouse and McDonald [19] suggests that this may be useful in slowing spread at the peripheries, but acquiesce that ultimately no trapping programme will be effective in stopping their spread. In the early 21st century, extensive trapping and manual removal of signal crayfish was conducted on the River Sheaf in Sheffield, but this too proved unsuccessful.

2. PROJECT OBJECTIVES

2.1.1. PRIMARY OBJECTIVE

The primary objective of this study was to examine the spread of signal crayfish through the rivers of the Don catchment to determine the extent and rate at which they have progressed, and to attempt to elucidate the origins of their introduction to the system. This allowed the hypothesis that the current populations are a single population (or meta-population) that emanated from a single point of introduction, rather than numerous discrete populations resulting from isolated introductions to be tested. This has been achieved by conducting a survey of their current distribution to reveal any links between the populations, the existence of which would support the hypothesis. It was believed that information regarding the introduction of the species to the area which would be of conservation value in protecting native white-clawed populations. This information will be of significance as it will reveal how the organisms are continuing to colonise new sites, often isolated from other populations. Once this is known, steps may be taken to prevent any future spread and to protect species, such as white-clawed crayfish, that may be harmed by the presence of signal crayfish.

2.2.SECONDARY OBJECTIVES

Several secondary objectives were undertaken in this study. The rate of dispersal of crayfish within the catchment was calculated by comparing their current distribution with that of a known time period from previous records. Several studies have been conducted in the UK regarding the rates of movement of signal crayfish [16][14][20][23][19], and these estimates will allow comparisons to be drawn against crayfish dispersal in other locations. The efficacy of various obstructions, such as weirs, culverts and roads, would be assessed as barriers to invasive crayfish movement by recording their presence and comparing locations to crayfish distribution. Environmental data such as land use will be collected to enable inferences to be drawn regarding habitat preferences for the species.

There is a possibility that there are still strongholds for the native white-clawed crayfish within the catchment, other than the known sites on the Porter and Limb Brooks. Whilst known sites such as the Porter Brook were avoided to minimise distrubance, it was hoped that any such populations would be uncovered in the course of the study so that appropriate actions can be taken for their preservation. It is also beneficial to record the location of current signal crayfish populations in relation to the aforementioned native populations to determine the threat that their continued expansion may pose.

3. METHODOLOGY

3.1. PREVIOUS LOCATIONS – SYNTHESIS OF MAPS USING ARCGIS

Initially, a GIS map was constructed to document the known populations of signal crayfish from previous surveys. These data was obtained from Crayfish Action Sheffield (CAS) and the DCRT and features results from surveys conducted by the EA, CAS, local councils and Sheffield Wildlife Trust (SWT), as well as casual reports from fishermen and members of the public. The data set spanned a large time period from 1980 to 2010, with the majority of the dates falling in the early part of the 21st century. Easting and Northing co-ordinates were present for each sample location and these were plotted as XY points on ArcMap10[1] over an Ordnance Survey 1:25000 basemap of the area obtained from the Edina Digimap service[2]. Superficial and underlying geology information was also secured from Digimap to provide an environmental perspective to the location of signal crayfish populations. All imagery and data were orthorectified to ensure their geometric uniformity and projected onto the British National Grid to ensure maximum compatibility between layers. Information regarding potential barriers to dispersal such as weirs, culverts, dams etc. was collated from CAS, the EA, Ordnance Survey (OS) and field observations and the locations were highlighted to identify areas of particular interest in assessing the rates and mechanisms of crayfish dispersal.

3.2. SITE SELECTION

Locations known to previously support signal crayfish (see above) provided the starting points for a new survey conducted from June to mid-August 2012. As the historical records were dated, estimates were made regarding the dispersal of signal crayfish, based on previous studies in other catchments. The historic data points were re-sampled to confirm the presence of signal crayfish and new sites were selected both upstream and downstream from these locations to determine the extreme spatial distribution of each population. Sites were identified at 0.5km intervals after consultation with Paul Bradley (a Yorkshire based ecological consultant with considerable expertise in conducted crayfish surveys) as this was considered an achievable spatial resolution given the length of the watercourses and the time frame available for fieldwork. These distances were not achievable in all cases due to the termination of the waterway prior to that point or a lack of safe access to the watercourse, particularly in the case of the River Rother south of its confluence with

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[1] www.esri.com (Accessed 3rd August 2012)

[2] http://edina.ac.uk/digimap (Accessed 3rd August 2012)

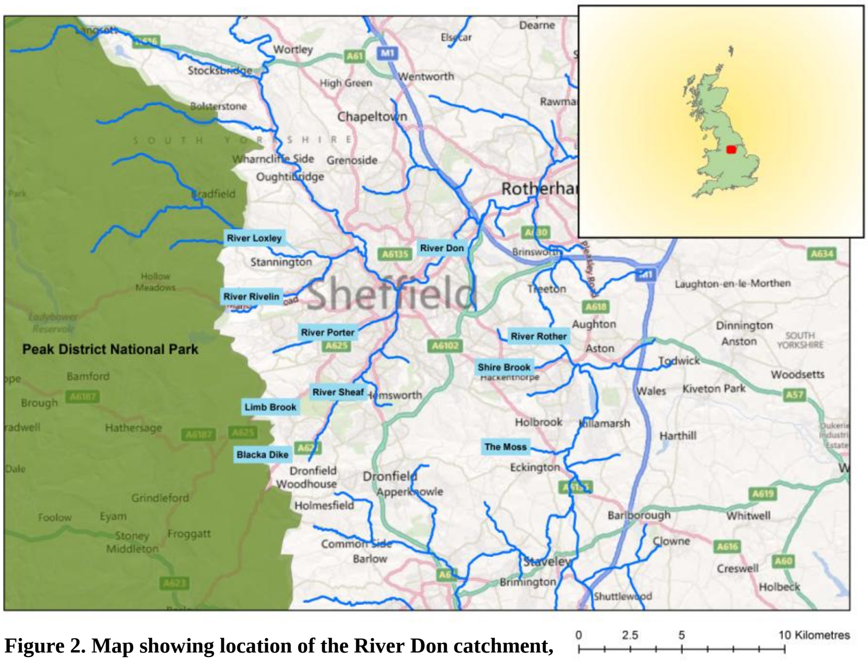

Figure 2. Map showing location of the River Don catchment, and the various waterways within it.

the Don. In such instances the stream or river was surveyed at a corresponding distance in the body of the stem river, or at the nearest suitable location. Due to the presence of signal crayfish at a single site on the River Rivelin, the stretch of river was sampled at a higher resolution of 100m in order to ascertain the true geographic extent of the population. Despite falling in the DCRT's responsibility, the River Dearne was excluded from this study due to the time restraints faced by the author and the rivers comparative isolation from the rest of the study area. It was decided that the River Dearne would not prove essential in testing the hypothesis of the investigation.

Trapping focussed on the body of the River Don and its largest tributaries; the River Sheaf and the River Rother. The intermediary river sections between sites where signal crayfish were present were considered of highest importance. Finding a connective link between populations would support the hypothesis that all signal crayfish in the catchment are the result of a single introduction, whereas substantial gaps between isolated 'clusters' would suggest that there have been numerous points of entry. Certain additional locations were selected as being of particular interest, either because of opinions expressed by the DCRT, or due to their proximity to environmental anomalies such as weirs. Conversing with members of the public during fieldwork uncovered several reports of signal crayfish sightings that had not previously been recorded. These reports are recorded in this document, and were sampled by the author in each instance.

The Porter Brook (a tributary of the River Sheaf) was designated as an ark site for native white-clawed crayfish by CAS, due to the healthy population that it sustains. For this reason no trapping was conducted on this watercourse to minimise the disturbance to known populations of the native crayfish. The Limb Brook, another tributary of the Sheaf slightly higher upstream than the Porter, has also been shown to support native white-clawed crayfish, but was sampled in this study due to records showing that signal crayfish were beginning to encroach on their position.

3.3. SURVEYING

Due to the river conditions found within the River Don catchment, trapping was selected as the most appropriate survey methodology, despite the fact that it is known to have relatively low efficiency [48]. Prior to commencing any fieldwork, authorisation was obtained from the Environment Agency to use instruments other than rod and line to remove fish, yielding the trapper number EW019-Z-889. The traps used were conventional, collapsible lobster pots that are frequently used in this nature of study (**Image 3.**). These pots provide a cheap and easily transportable method of surveying and are easily tailored to comply with legislation authored by the Environment Agency [56]. This specifies that traps must not exceed 60cm in length and 35cm in width and consist of mesh <3cm with an opening of <9.5cm. These regulations are primarily to protect other species such as otters being unintentionally trapped, and were rigidly adhered to throughout all field studies. As a further deterrent, cross wires were added to each trap entrance. Traps were baited using mackerel and replenished at each submersion. This was kept constant at all sites throughout the surveying to prevent any bias arising from variable trapping methodologies. A total of 16 traps were procured which were deployed in pairs at intervals of 0.5km along watercourses and left for 24 hours before being removed. This allowed 8 sites to be surveyed per day covering a distance of approximately 4km. Trapping only took place during periods of normal or reduced flows, where water speed did not exceed 25 metres per second; it is believed that higher rates than this would reduce the foraging activity of crayfish and force them into refuges, thus would be likely to produce erroneous results and potentially false positives. At each site the following data was recorded; species of crayfish present, number of individuals in each trap, depth of survey site and length of crayfish.

Image 3. Example of the crayfish traps used in this study. Image obtained from http://ecx.images-amazon.com/images/I/51rw3CdDaRL._SL500_AA300_.jpg (23/08/2012)

During the course of fieldwork, the author also questioned several fishermen and members of the public about locations where signal crayfish have been sighted within the catchment. Whilst unsubstantiated and unquantifiable, anecdotal evidence such as this is invaluable in identifying sites where crayfish have been found, particularly where they do so at densities low enough to miss detection by trapping.

The biocide Trigene was used to disinfect all equipment after each session to comply with standard biosecurity measures, ensuring that no organisms or diseases (particularly crayfish plague) were transferred between sites. In compliance with the Wildlife and Countryside act 1981, which states that it is an offence to release a non-native species into the wild, all captured signal crayfish were removed from the site having been killed humanely. Consideration was given to the exact location of traps within a site to minimise their visibility for two reasons; firstly to reduce the likelihood of interference by members of the public, and secondly to limit the interest that may be generated by wild food enthusiasts or other groups that may potentially be encouraged to engage in trapping activities without legal consent or appropriate biosecurity measures. To reinforce this latter point, the deployment and harvesting of traps was performed when the number of members of the public was likely to be minimal.

3.4. ANALYSIS/INTERPRETATION

The results of the 2012 survey were overlaid onto the GIS map to show changes in the distribution of signal populations against historical records. The rate of dispersal for each watercourse was calculated by comparing the current extent of the population with that of a known date obtained from existing records. Locations of barriers within waterways were contextualised against the movement of crayfish to assess their efficacy in limiting their spread. The use of OS maps as a base layer allowed elements of environmental interest, such as woodlands, to be extracted from the map. Data of catch per unit effort was calculated for each site by averaging the number of individuals between the two traps. This was then summarised to give a figure for the waterway as a whole.

3.5. TIMELINE

The initial stage of the project was the creation of a GIS database of signal crayfish distribution within the catchment. This information was provided by CAS and the DCRT in the first few weeks and was overlaid on OS map, geology and catchment data. Survey sites were identified from this information and trapping was performed in the summer months of June, July and August. Prior to this, the author obtained all necessary equipment such as traps, and ensured that he was acquainted with all regulations regarding licensing and biosecurity. Care was taken to ensure that all plans adhered to relevant health and safety regulations (eg. working near water, lone worker protocol). These were achieved by consultation/training (as needed) with CAS, DCRT, EA and/or Paul Bradley in the latter half of April and May. In these initial stages of the project, introductory and planning aspects of the report were written to alleviate pressure later on that would be imposed by the late and intensive trapping effort. Due to the optimum surveying period for signal crayfish running into August, the results and discussion components were completed towards the end of the project timeline. With good time management and appropriate preparatory work this did not prove to be a problem. A Gantt chart depicting the proposed timeline for various tasks created at the submission of the interim report is included in Appendix A.

4. FINDINGS

4.1. REPORTS FROM THE PUBLIC

4.1.1. MALIN BRIDGE - THE CONFLUENCE OF THE RIVERS LOXLEY AND RIVELIN (SK324894)

Signal crayfish were reported to have been found during a fishery survey at this location by Paul Gaskell of the Wild Trout Trust via email correspondence. No crayfish were found at this site during this study, though they were found slightly upstream, adjacent to the fishing pond at Walkley Bank.

4.1.2. SALMON PASTURES - THE RIVER DON (SK378893)

A local fisherman reported having caught signal crayfish in the vicinity of the Salmon Pastures nature reserve on the River Don. This stretch of river was sampled at 500m intervals with no trace of crayfish being found. The authenticity of this report can therefore not be confirmed.

4.1.3. CATCLIFFE FLASH - THE RIVER ROTHER (SK424880)

A local fisherman reported catching a single individual at this location on the River Rother, and provided photographic evidence to support their claim. Sampling at 500m intervals found no crayfish on this stretch of river, though upstream in the Woodhouse Washlands nature reserve, the Rother was found to support signal crayfish at a high density. The Woodhouse Mill regulator marks the end of the population found in this study, and is approximately 1.5km upstream of the reported sighting.

4.1.4. BIRLEY SPA POND - FEEDING INTO THE SHIRE BROOK (SK409837)

A member of the ShireBrook heritage group reported a person claiming to have introduced Signal crayfish into the pond at Birley Spa with the intention of cultivating them for profit. If this was accurate, it could explain the origins of the species into both the Shire Brook (into which the pond feeds via Carr Forge pond) and ultimately the River Rother. Surveying found no trace of the species in the pond, and the stream eminating from it was unsuitable for trapping due to being very shallow and at a steep gradient, though extensive numbers of signal crayfish were found in the Shire Brook itself.

Whilst the author was shown this site in person, there is a possibility that the pond being referred to as having signal crayfish deliberately introduced was actually one at Birleyhay on the River Moss. This is a short distance away and has previously been recorded as being heavily populated by signal crayfish. The introduction of the species here for aquaculture could also offer an explanation as to their introduction into the system.

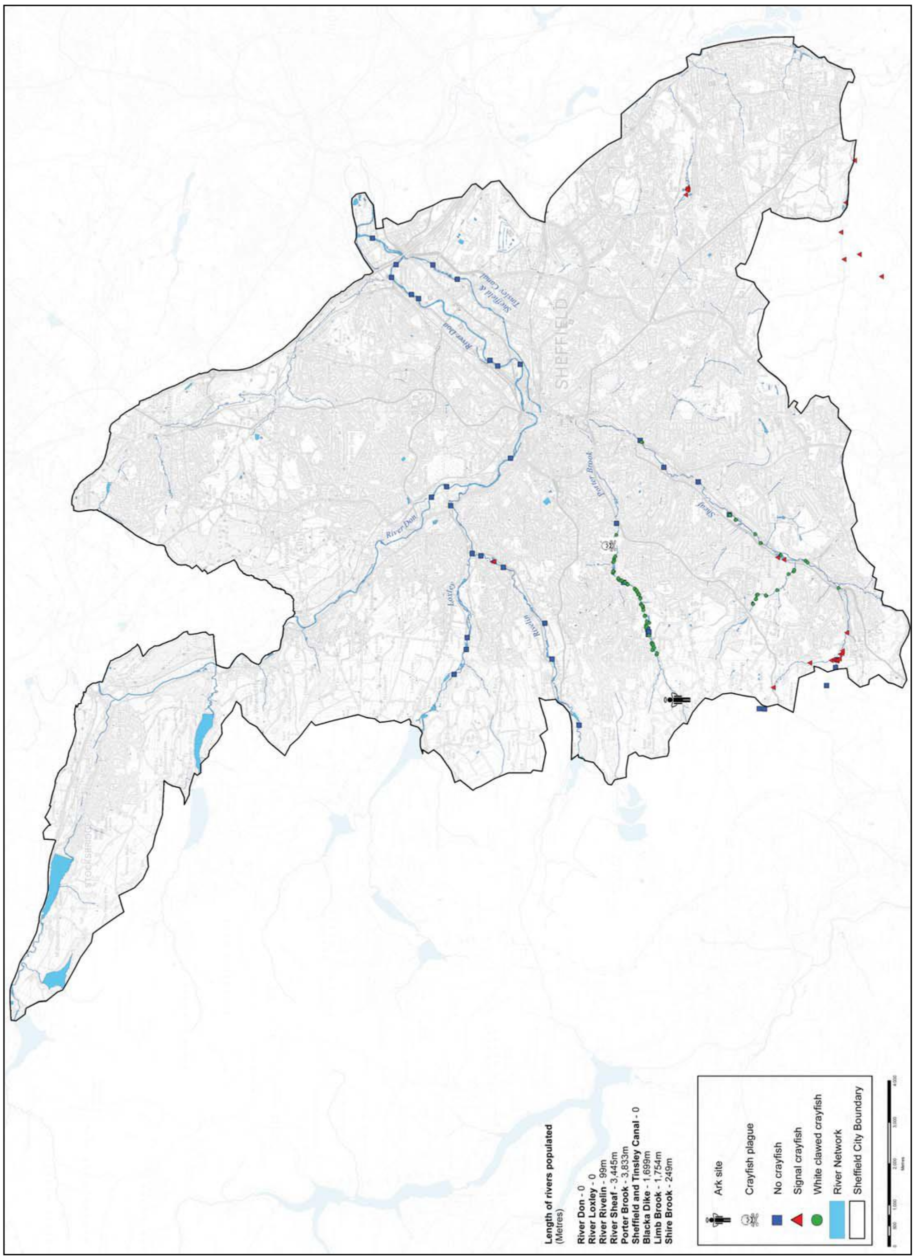

Figure 3. Map of previously known crayfish locations. Collated by Sheffield City Council, 2010

4.2. CURRENT DISTRIBUTION

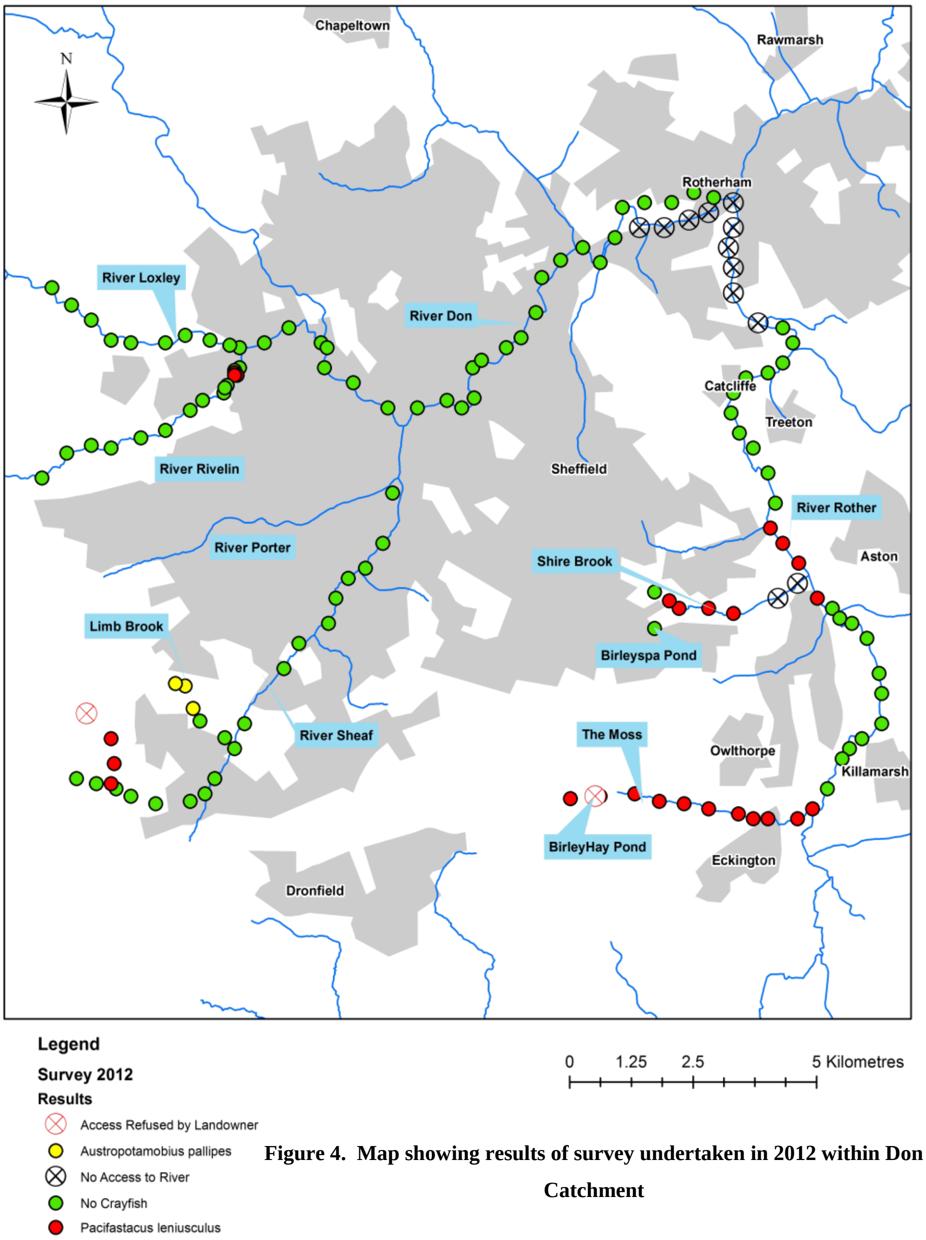

Figure 4. Map showing results of survey undertaken in 2012 within Don Catchment

The results from the survey undertaken in the summer of 2012 show little change from the locations previously known to support crayfish (**Figure 3**). Given the age of many of these populations, it is surprising to observe little or no expansion from their previous extents, and in each instance the observed distances were less than the conservative estimate of 1.5km per year derived from previous studies

[14][20][23]. Of the two populations that showed an expansion, the average downstream dispersal was 0.96km per year, and there was no observed upstream movement. It must be noted that in many cases only positive survey data are available for watercourses, there is very little information regarding sites that have previously been surveyed but that have not been found to support crayfish. The document in **Figure 3** produced by CAS is the only one with such information, but unfortunately does not have data regarding the River Rother. Each watercourse is looked at in deatail in the following section.

4.2.1. RIVER DON AND CANAL

Despite anecdotal evidence of signal crayfish found at the Salmon Pastures nature reserve, no crayfish of either species were detected between the confluence with the River Loxley (SK342894) and Blackburn Meadows nature reserve (SK403921). Between this point and the confluence with the River Rother no access was possible to the river, but no crayfish were found in the canal section.

4.2.2. RIVER ROTHER, SHIRE BROOK AND THE MOSS

Between Woodhouse Mill and the weir at Beighton (SK446842) a significant population of signal crayfish was discovered, occuring at every location surveyed at 500m intervals and at high densities. Only one site immediately below the weir produced negative findings, likely due to the faster current produced by the weir stream. It must also be noted that one of the traps at this site was removed by persons unknown, reducing the trapping effort. Upstream of the weir no crayfish were found on the River Rother. This is indicative of the Beighton weir presenting an insurmountable obstacle to the crayfish and providing an effective barrier against their spread. Due to the density of vegetation and distance of paths from the river banks, no access was possible to the River Rother between its confluence with the River Don (SK425923) and the M1 (SK436893). Between this point at the Woodhouse Mill regulator (SK432857) no crayfish were found, though a fisherman reported a sighting at Catcliffe Flash nature reserve (SK424880).

Image 4. A trap containing signal crayfish from the River Rivelin at Walkley Bank Tilt. Image from author's collection.

A single individual was also recorded immediately downstream of the confluence with the Moss Brook (SK441801). This is likely to be a recent extension of the Moss Brook population, and poses a serious threat as there are no barriers in the vicinity, but a large stretch of well vegetated, relatively slow moving channel that presents a viable habitat capable of sustaining a large new population of signal crayfish.

The Moss continues to support great numbers of signal crayfish, as has been recorded previously since 2005. Records from the 1990's show that native crayfish were also found here, but they have been absent for at least a decade. At every site between the mill pond at Birleyhay and the confluence with the River Rover, signal crayfish were found in vast quantities with a maximum of 35 individuals recorded at a single site. At one site a trap was also found to be damaged and empty of crayfish, though the adjacent trap contained many individuals. The author cannot say whether this trap was caused by a particularly aggressive signal crayfish, or some other animal such as a rat.

The population in the Moss Brook appears to have shown the second largest expansion of 2.4km (0.6km per year) downstream into the body of the River Rother. Extensive surveying in 2008 record the furthest downstream location on the Moss as SK421801, though there is no record of negative results further downstream from this. Given the estimate of 1.5km a year, the signal population could be expected to have dispersed 6km from this point by now, and so they could be expected to have reached the Rother Valley Country Park. This study found the actual extent to be just North of the Moss/Rother confluence SK441801.

Anecdotally, the mill pond is cited as the source of the introduction, and this is supported by the vast quantities of crayfish found downstream, compared to a single specimen found upstream from this location. Regrettably no data is available for the pond from this survey as permission was denied by landowners, however previous surveys have shown them to be present in the mill pond in large numbers.

The Shire Brook continues to be infested with signal crayfish at a high density between Carr Forge pond (SK413842) and the culvert under the A57 (SK425840). Previous reports from as early as 1995 (substantiated in 2005 and 2009) indicate that this population has been present for many years. No crayfish were recorded at the Western extent of the Shire Brook nature reserve (SK408845) during this study, and they have not previously been found at this location. However, this population has shown the largest downstream movement of any within the catchment, stretching 4km in 3 years (1.33km per year) into the River Rother where they have expanded both upstream and downstream to occupy the 1.7km strech of river between the Woodhouse regulator and the bridge under the A57 downstream of the weir at Beighton.

4.2.3. RIVER SHEAF, BLACKA DIKE AND THE LIMB BROOK

Though isolated records exist of the presence of both white-clawed (SK330824 – 2005) and signal (SK324819 – 2007) crayfish in the River Sheaf in the lower stretch of the river, the 2012 survey found no cases of the native species. The signal population was focused upstream between SK299815 and SK300816 in Blacka Dike without exception. This was marked at its lowest extent by a small weir. Access to a potential site was denied by the landowner at Fern Glen Farm (SK293800) and so it is unknown whether the population extends this far upstream. The signal population on the River Sheaf/Blacka Dike around Totley has actually reduced spatially since the Yorkshire Wildlife Trust survey in 2009/10. At a conservative estimate of 1.5km a year expansion rate, this population could be predicted to have spread approximately 3km downstream into the channel of the River Sheaf by 2012, but instead was seen to have retracted by 0.7km. The population appears to be confined to Black Dike and no specimens were recorded in Totley Brook, where they were previously found. It cannot be stated with certainty that the population has truly receeded, as the possibility of obtaining false negatives from trapping exists.

The Limb Brook was found to still support native crayfish at numerous sites between the A625 (SK311826) and Eccleshall Wood (SK316821), at increasing densities upstream. No signal crayfish were found at any point along the stream, and with no historic record of their presence here. This suggests that they pose no immediate threat to the population of white-claws residing there.

4.2.4. RIVER RIVELIN

A single site was found to contain signal crayfish on the Rivelin, at the stretch of river adjacent to Walkley Bank Tilt (SK323888). At 500m resolution, no crayfish were found either upstream or downstream of this location, suggesting that the population is concentrated within a narrow geographic range. To test this hypothesis, the stretch of river was re-surveyed at a finer resolution of 100m. This found the population to be limited to a 300m segment that was directly adjacent to the fishing pond, which also contained signal crayfish. Due to the popularity of the pond amongst local fisherman, the author considers it likely that this is the origin of this infestation. The distance between the pond and the river channel is <10m in places, and so the crayfish would have little trouble in travelling between the two

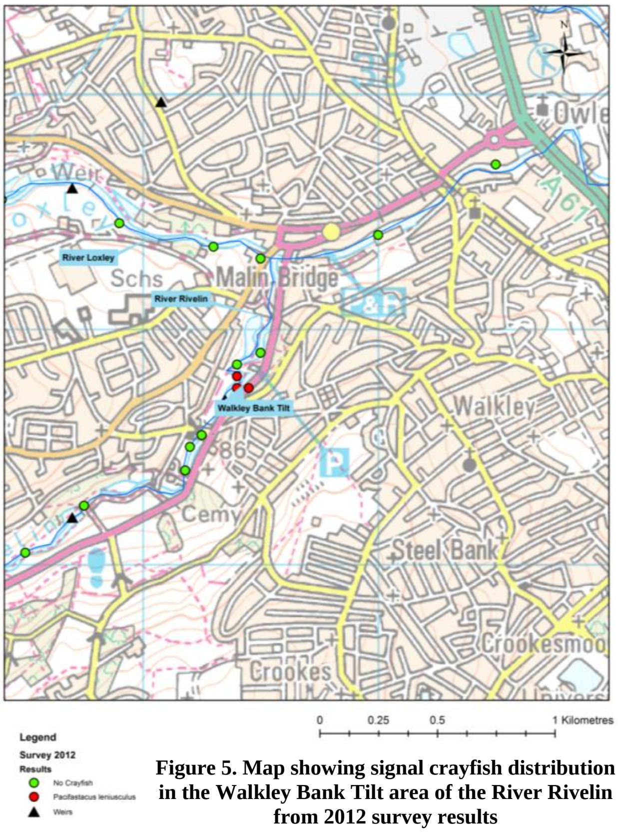

Figure 5. Map showing signal crayfish distribution in the Walkley Bank Tilt area of the River Rivelin from 2012 survey results

bodies. Whether they were introduced directly as bait or a source of aquaculture, or via improperly cleaned equipment carrying eggs or larvae cannot be determined. As there is only a single record of signal crayfish previously in this location from 2009/10 (**Figure 3**), it is highly likely that this is a very recent infestation that potentially could expand a long way beyond its current limits. The historical exploitation of the River Rivelin for industry has created a network of slow moving, deep, secondary channels and ponds along its course which could provide ideal habitat for signal crayfish. It is the authors opinion that this population should be monitored carefully in the future, as the newest, smallest and most isolated of the signal crayfish populations in the catchment it could provide both the best study conditions and the best opportunity to intervene in their movements.

4.2.5. RIVER LOXLEY

The River loxley was found to be completely free of both signal and native crayfish between its confluence with the River Rivelin (SK324893) and the Damflask reservoir (SK287906). Trapping at 500m intervals found no trace of crayfish and there are no historic records of any incidences. Similarily no anecdotal evidence was found to suggest the presence of either species on this watercourse.

4.3. CATCH PER UNIT EFFORT AND SIZE

Whilst the size bias incurred by crayfish trapping negates its reliability in accurately estimated population densities [49], catch per unit effort (CPUE) is still useful in comparing the relative abundances of populations. Catch rates were found to be highest in the Moss Brook reaching 35 individuals at a single site and an average of 16.8 per site. Evidence of this population date back as far as 1995, whilst sites with lower catch rates such as Blacka Dike and the River Rivelin, have only been recorded recently, in the 2009/10 Sheffield Wildlife Trust survey with average catch per site rates of 4 and 6 respectively. The second highest catch rates of 7 individuals average per site were found in the Shire Brook, where data exists to confirm their presence since 2005. From this information, it is possible to infer that catch per unit effort is linked to the age of the population. Unfortunately, no historical data are available for the River Rother (either of previously recorded populations or negative survey results), however the lowest average catch rate of 2.8 individuals per site was found on this river. By plotting the date when crayfish were first recorded against the average CPUE of a waterway, a linear trend was found and the approximate age of a population extrapolated for a given CPUE (**Figure 6**). In this way, the date/density relationship for the River Rother suggests it was infested sometime during 2011, which would tally with the theory that it is the result of expansions of the older populations found in the Shire and Moss Brooks. It would also explain why there are no older records of signal crayfish in the river.

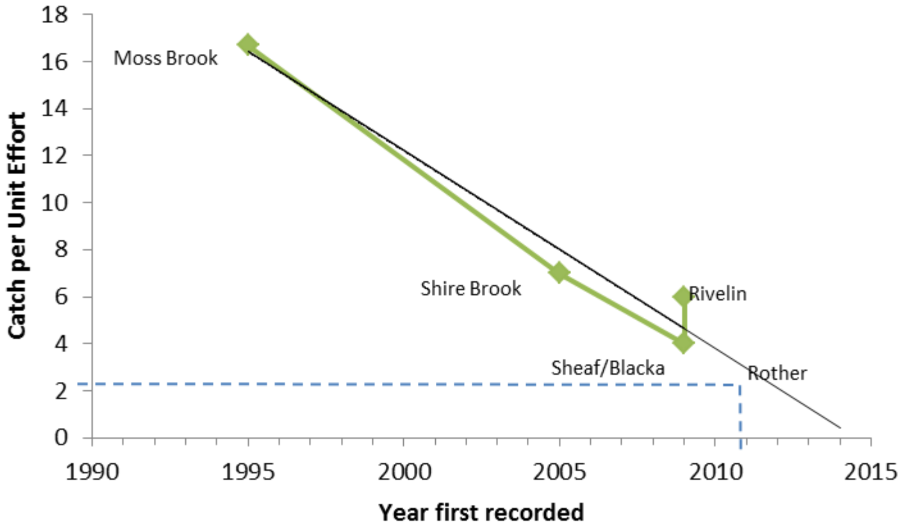

Figure 6. Scattergraph showing CPUE against first record of crayfish for each waterway in the Don catchment survey. A linear trendline (Black line) allows the approximate age of a population to be calculated from CPUE (Dashed line). For the River Rother, a CPUE of 2.8 dates the population as having infested the river in 2011.

Previous studies have demonstrated that the size of crayfish at a site is linked to the depth of water [57] with larger, adult individuals inhabiting deeper pools, whilst smaller or juvenile crayfish show a preference for riffles [58]. This could be due to a number of reasons. Pools have been shown to contain greater numbers of invertebrates [59] which could thus support larger crayfish. Predation by fish is more likely in deeper, slower water and so smaller crayfish more susceptible may migrate from them or be consumed. The slower flow rates in pools also leads to a finer substrate being deposited than in riffles which may have some significance. Signal crayfish captured in this study were observed to have larger average body sizes in the main river channels of the Rother and the Rivelin, than in the smaller Moss and Shire Brooks and the Black Dike. Where possible, traps were placed in deeper pools (often the outside of bends) within the smaller watercourses to ensure the minumun required depth of 60cm was achieved (**Table 1.**), but depth was seen to vary greatly, often reduced to <10cm over riffles. In contrast, the larger Rother and Rivelin Rivers provided a more homogenous environment with consistently greater depths. These data are summarised in **Table 2**. Using SSPS[3], the relationship between average depth of site and average length of crayfish captured for each waterbody was explored. A Pearson correlation coefficient of 0.954 was achieved at a P value of 0.01, satisfying the criteria of high statistical significance of the relationship between the two variables. Each site was entered individually, rather than averages for each watercourse, to increase the sample size and allow a more robust analysis (**Appendix D**).

[3] http://www-01.ibm.com/software/analytics/spss/ (Accessed 15th August 2012)

Table 2. Average depth of sites for each waterway surveyed, with average size of crayfish recorded and maximum individual size.

Waterbody	Average depth of site (M)	Average Size (cm)	Maximum size (cm)
Rother	2.4	14.8	18
Rivelin	1.6	9.7	15
Sheaf/Blacka Dike	0.8	6.3	7
Shire Brook	1	6.1	9.5
Moss Brook	1.2	7.5	11

4.4. ENVIRONMENTAL VARIABLES

4.4.1. VEGETATION

123 sites were sampled during this study, of which 26 were found to contain signal crayfish and 3 containing native white-clawed crayfish. Each site was classified into one of three categories depending on the predominant landuse. These were urban (heavily industrialised with mostly concrete lining the waterway and often subjected to extensive channelisation), woodland and grassland. The Rivers Don and Sheaf largely fell into the urban category, whilst the River Rother was observed to run through grassland for most of the study area. The Rivers Rivelin and Loxley, Blacka Dike and the Limb, Shire and Moss Brooks were all classed as woodland habitats.

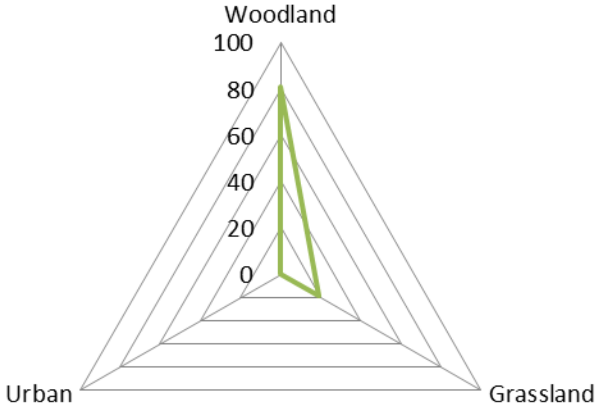

Figure 7. % of sites where signal crayfish were found for different land uses. A clear preference can be observed for woodland river systems

Figure 7 shows the distribution of crayfish (both species) sites amongst these various habitats, and it is immediately apparent that the majority of sites fall into the woodland r iver systems (urban - 0; grassland – 5; woodland – 21).

Previous studies have identified the presence of riparian vegetation as a key factor in determining the suitability of a site for crayfish in providing both shade and refuges [40]. The findings from this study support this theory, particularly as many sites recorded as grassland still contain sparsely distributed trees along the bank. This may also explain why distribution rates observed in this study were lower than predicted, as the expanding populations were leaving favourable woodland river conditions found on the Shire and Moss Brooks and entering the more open grassland conditions of the River Rother. Livestock was observed to be grazing on much of the grassland adjacent to the River Rother, which has been linked to increased sediment and chemical in the river channel producing unsuitable conditions for crayfish [37]. All urban sites were found to be free of crayfish, potentially due to the impenetrable nature and relatively few refuges afforded by concrete lined channels. Where the river did flow through natural channels, vegetation was observed to be much sparser than found in either woodland or grassland systems. Due to the high level of anthropogenic interference, it is very difficult to assess the true value of these habitat characteristics in determining suitable habitat for signal crayfish. Whilst patterns as described above are discernible, they may be due to human preference for discrete and/or aesthetically pleasing environments. For example, heavily wooded sections of river channel will provide more cover and privacy in which to harvest introduced crayfish populations for wild food.

4.4.2. WEIRS

Figure 8 shows the locations of weirs (and locks on the canal) within the catchment and in relation to survey sites where crayfish were found. The River Sheaf and River Don can be seen to be heavily developed in this respect, with large numbers of obstructions over short distances. The River Rother, Moss and Shire Brook are all seen to be relatively unobstructed in this respect. It is difficult to gauge the role that obstructions such as these play in limiting the dispersal of crayfish, as many of the populations are small and occur in areas where there are few if any barriers. However, there are a few sites where weirs do seem to have imposed some degree of control over their movements. Most pronounced of these is the River Rother North of the village of Beighton. Here a healthy population of signal crayfish is bracketed

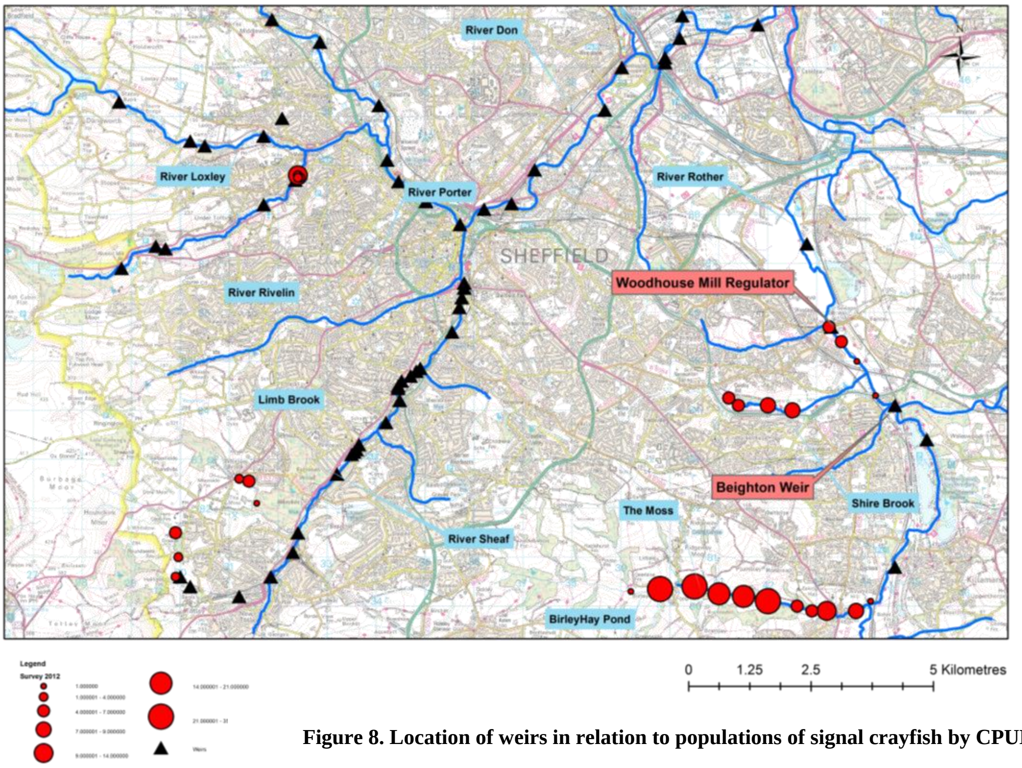

Figure 8. Location of weirs in relation to populations of signal crayfish by CPUE

neatly by the Woodhouse Mill regulator at its Northern extent, and the Beighton weir at its Southern extreme. Weirs can also be seen on the River Rivelin immediately upstream of the signal crayfish infestation, though due to the limited spatial distribution of this population and its believed recent introduction, it is not thought that this weir has influenced the distribution at this time. There is a large volume of unoccupied territory downstream that would provide equally favourable conditions to accomodate the expansion that is likely to ensue. However, this weir may prove useful in protecting the upstream river once the signal population is more established. Downstream of the population in Blacka Dike is a small weir that marks the limit of their current distribution. Historical records show that signal crayfish have previously been present downstream of this obstruction, and so it is doubtful that it is effective in blocking their passage. It is unknown if this population was introduced up or downstream from the weir. They are well established upstream in Blacka Dike, and landowners on a farm refused to allow surveying on their land. This could be interpereted as an indication that they had introduced the species to the stream running through their property, and wished this to be unknown. However, isolated records of signal crayfish further down the River Sheaf that could indicate otherwise. Previous studies regarding movement of crayfish have focussed on river sections free from obstruction, being primarily concerned with the size of individuals and their direction and distances travelled [16][20]. The ambiguity of the efficacy of weirs as barriers to crayfish found in this study highlights the importance of researching this relationship further. As stressed previously, whilst a signal population cannot realistically be eradicated, influencing its dispersal and being able to ensure certain river stretches will be un-infested is of paramount conservation concern.

4.4.3. GEOLOGY AND WATER QUALITY

As noted in the introductory section of this report, crayfish have been associated with high levels of calcium which is required for the development of exoskeletons [35]. This is often found in limestone river catchments which also support high levels of invertebrates and so would provide ample food sources for crayfish. The rivers of the Don catchment, however, rise in the millstone grit of the peak district national park [60] and flow through bands of sandstone, mudstone and gritstone (**Figure 8.**). A region of magnesian limestone is reached further to the West, but falls outside of the study area. The presence of crayfish despite the non-calcareous nature of the bedrock suggests that either this is not a defining habitat requirement of the species, or that the water is enriched with calcium from another source. Given the high level of industrial activity [60] in the area this is a possibility though no data regarding water quality could be obtained for analysis in this study. It can be observed that rivers close to the industrial centres of Sheffield (notably the River Don and lower reaches of the River Sheaf) are free from infestation of signal crayfish. Whether this is due to the reduced water quality resulting from industry and sewage discharges, channelisation of the river removing refuges or any other factor (or indeed combination thereof) cannot be determined from the information currently available.

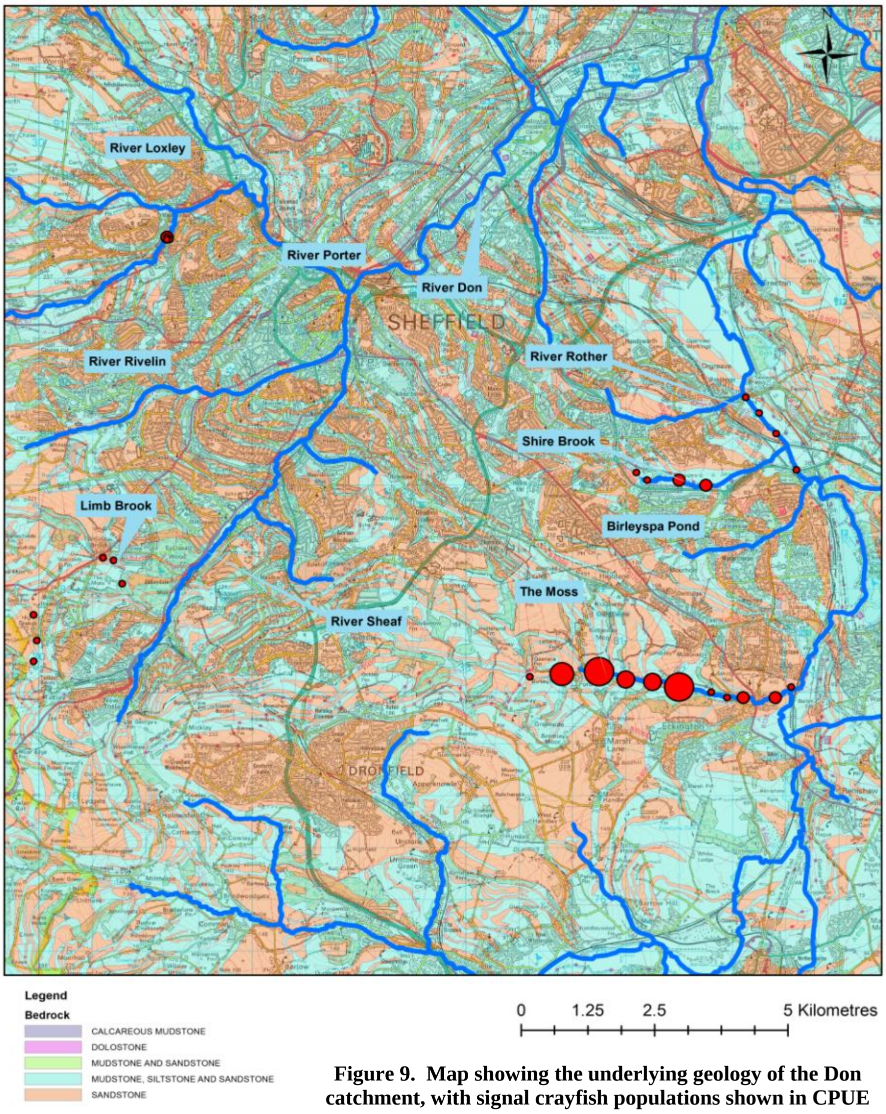

Figure 9. Map showing the underlying geology of the Don catchment, with signal crayfish populations shown in CPUE

5. CRITICAL ANALYSIS

5.1. DISCUSSION/CONCLUSION

The distribution of signal crayfish was seen to have changed little from the previous records in the Don catchment (**Figure 3 & 4**), with five distinct populations extant on the Moss Brook, Shire Brook, Blacka Dike, River Rother and River Rivelin at Walkley Bank Tilt. Due to the extensive stretches of connecting waterways between these locations where no trace of crayfish was found, the findings of this study strongly contradict the hypothesis that all populations eminated from a single point. There is anecdotal evidence that signal crayfish were introduced to BirleyHay pond on the Moss Brook as a crude form of aquaculture in the late 20th Century. Whilst inferences can be drawn regarding the origins of other populations, it is unlikely that they can ever be confirmed due to the high level of anthropogenic activity involved and the anonymity of those responsible. Signal crayfish are dispersing at a rate of 0.96km per year in a downstream direction, with no movement upstream recorded. This is significantly less than could be expected based on previous studies in other catchments, where a conservative estimate of 1.5km per year in either direction could be anticipated. A clear bias was observed for woodland rivers, though grassland flanked river channel also provided suitable habitat for signal crayfish. Watercourses that were heavily channelised and flowed through urban landscapes were seen to free from infestation, though the role of human preference in determining the presence or absence of signal crayfish is unquantifiable.

Catch per unit effort of crayfish provides a useful point of comparison between isolated populations within the catchment. A strong linear trend was identified between the age of the population, based on previous records, and the number of individuals at each site (**Figure 6**). Signal crayfish have been found in the Moss Brook since 1995, and this study found it to consistently have the highest CPUE of any waterway. A method of dating a population was proposed based on CPUE, which appears to be accurate in the context of this study. Whether it will prove effective in other watercourses, or stand up to robust analysis of larger sample sizes, remains to be seen.

Crayfish size and water depth is a well documented relationship [57][58] that is supported by the findings of this survey. Larger rivers such as the Rother consistently yielded larger crayfish than the smaller tributaries such as the Moss and Shire Brooks. Size of crayfish appears to be independent of the age of the population, as the two most recently colonised watercourses, the Rivers Rother and Rivelin, supported the largest individuals. Size of indivual may influence CPUE, though whilst the aforementioned rivers had both low CPUE and high indivual size, no trend was identified across all watercourses in the catchment.

Weirs provide neat ‘bookends‘ to the extent of the signal crayfish population on the River Rother between the Woodhouse Mill regulator and Beighton Weir (**Figure 8**), though elsewhere their efficacy as barriers cannot be evaluated as there are no crayfish in close proximity. Rivers such as the Don have frequent and large weirs but no crayfish at this time, or any records of their previous inhabitance. It could be speculated that the lack of crayfish is a result of the prohibitive number of barriers, though this cannot be supported. The lack of similar studies regarding crayfish dispersal and barrier efficacy is an obvious gap in our knowledge that would have considerable conservation implications.

5.2. PROJECT DESIGN

As mentioned previously, crayfish trapping is inefficient (thus requiring high population densities) and is biased towards larger adult individuals within a population [48] All possible methods have their disadvantages, and given the range of environmental conditions encountered at various sites, the author believes that trapping was the most appropriate surveying technique. Due to the low efficiency of 2-4% estimated by Peay [48], sites where crayfish were absent in this study cannot be considered free of infestation with complete certainty. In some cases anecdotal evidence exists of sightings where this study found negative results, most notably around the Salmon Pastures nature reserve on the River Don and the Catcliffe Flash nature reserve on the River Rother. It is possible that signal crayfish do exist in these locations but at densities too low to be detected by trapping. As neither case was reported to CAS, the EA or any other body, no official records exist. In both of these instances, river conditions are too deep to allow manual searches, which are not as reliant on high population densities and so they can be neither confirmed or disproved. The use of un-baited artificial refuge traps may be beneficial in cases such as this, as their bias towards individual size is less pronounced. Unfortunately the cost of using such traps was prohibitive in this study.

5.3. ABNORMAL WEATHER

The summer months of June and July in 2012 were subject to exceptionally adverse weather conditions, which resulted in several environmental conditions falling outside the paremeters that would be expected for this time of year. Rainfall for June in Sheffield was recorded at 182.3mm; substantially greater than the average of 68.3mm since 1955, and the average temperature was 13.4^{o}C, against the average of 14.3^{o}C[4]. These climatic abnormalities have resulted in far greater volumes of water in the rivers and at correspondingly higher flow rates. Previous studies have found

[4] http://www.sheffieldweather.co.uk (Accessed 3rd August 2012)

conflicting effects resulting from such high flow events, with Bubb et al [16] finding them to be of little concern whilst numerous other papers have observed significant displacement of individuals [61] and mortality [62] from heightened flow. Crayfish have been observed to show reduced levels of activity at lower temperatures, both in the field [16] and in laboratory conditions [63]. It is therefore necessary to consider the effects of the abnormal weather conditions experienced during the study period when interpreting the results of the survey.

5.4. TAMPERING OF TRAPS

As mentioned previously, one trap was removed from the River Rother immediately downstream of the weir at Beighton. Every care was taken during fieldwork to place traps out of sight and at times when bystanders would be kept to a minimum, in order to reduce the likelihood of tampering. Whilst one trap was removed from the site, the other was left untouched but yielded a negative result. Due to the placement of the second trap around a corner from the one that was removed, the author believes that the second trap was overlooked, rather than tampered with and its contents removed. It is impossible to say with certainty that no other traps were tampered with, but each was checked for this possibility prior to removal from the watercourses, and in no instance was there evidence to suggest the contrary.

A trap placed on the Moss Brook (SK426800) was also found to be damaged; a hole was created that would allow crayfish to escape. The bait pouch was also damaged and all of the bait was removed, suggesting that this was the result of a wild animal rather than human interference. Due to the fine nature of the threads that compose the trap, it is possible that the damage was caused by a particularly aggressive signal crayfish, though the possibility of another animal, such as a rat, causing the damage cannot be ruled out.

5.5. FUTURE WORK

The findings of this study are strongly contrary to the hypothesis that the Don catchment contains a single population (or meta-population) of signal crayfish due to the isolated nature of the extant populations, and the absence of crayfish in the connecting river segments. The identification of several likely sources of introduction (Walkley Bank Tilt, Birleyhay pond) and anecdotal evidence further strengthen this argument. The possibility remains however, that all populations originated from a single introduction, but have fractured and become isolated over time. This could be tested more robustly in two ways. Firstly, the use of more sensitive equipment such as artificial refuge traps may detect populations at lower densities in the areas where this study found no crayfish. The presence of signal crayfish in the River Don would indicate the possibility that all populations spread from a single point, as it would need to have been navigated at some point. Secondly, the ancestral lineage could be traced by examining the genetic similarities between populations within the catchment. A study of this nature was performed on populations of *Austropotamobius italicus* in the Iberian Peninsula, using mitochondrial DNA to trace their lineage [63]. The level of expertise and cost of such of work was obviously beyond the scope of this project, but it would prove a fascinating and useful project for future work.

Some information regarding the capabilities of weirs and other barriers in limited crayfish movement was found during the initial literature search for this study, though very little in the way of empirical evidence. Fully understanding the efficacy of weirs in this respect, and the effect that design and location has on them, would allow land managers to implement barriers to greatest effect and exert maximum level of control of the dispersal of crayfish populations. It is therefore suggested that this line of research be prioritised for any future studies. **Figure 10** shows sites

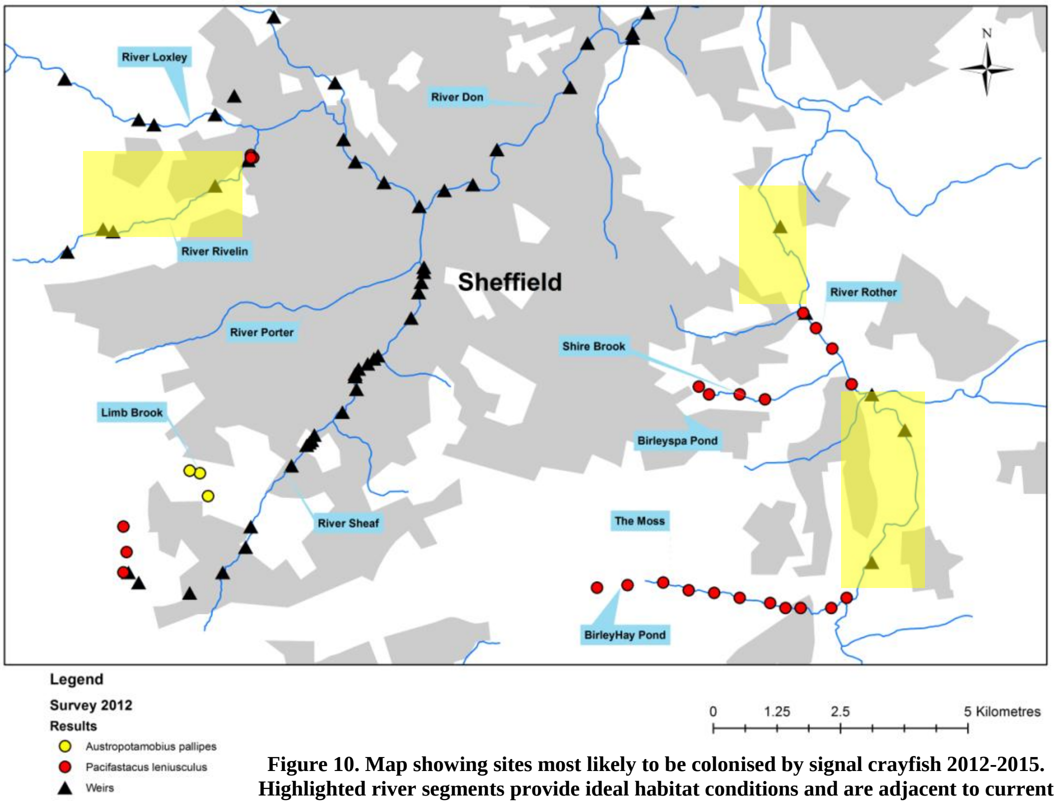

Figure 10. Map showing sites most likely to be colonised by signal crayfish 2012-2015. Highlighted river segments provide ideal habitat conditions and are adjacent to current populations.

believed to be most pertinent in focussing future conservation effort. These sites all provide suitable habitat for signal crayfish and are adjacent to extant populations. At the 0.9km per year dispersal reported in this study, these sites will likely be colonised in the next few years unless intervention takes place. These locations would provide ideal sites to test the efficiency of barriers such as weirs against crayfish movement.

The River Dearne also forms part of the DCRT area, but was excluded from this study because a.) it is comparatively isolated from the rest of the study area, its confluence with the River Don is a much further downstream, b.) the relative scarcity of crayfish records and c.) time restraints of the project. Future work not hindered by the last of these considerations may choose to include this waterway in their study area.

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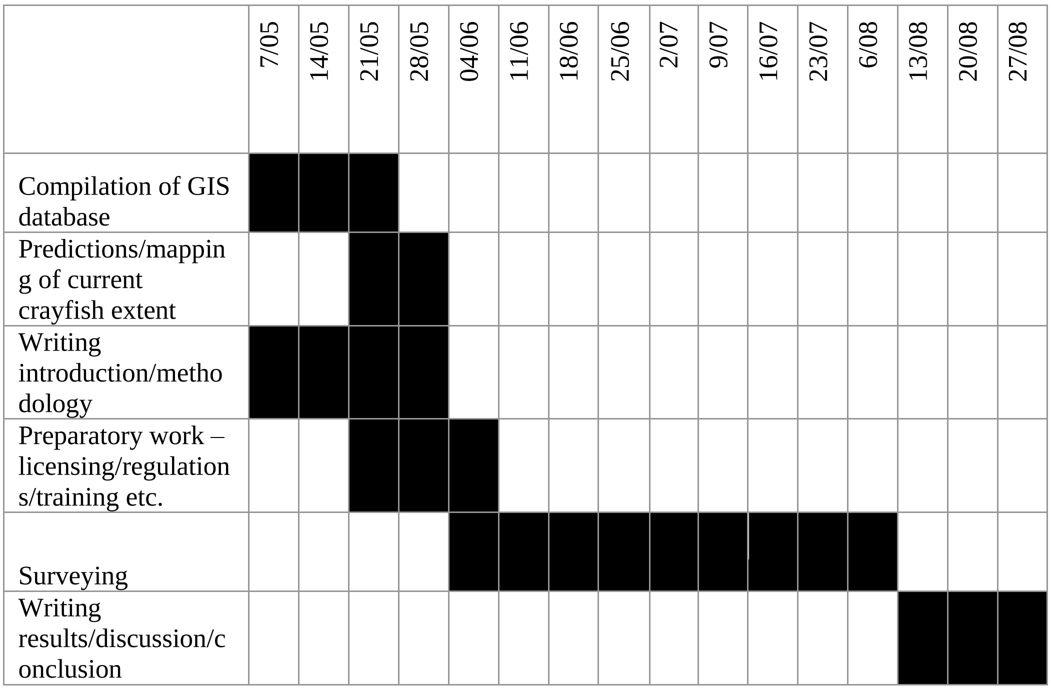
7. SUPPORTING INFORMATION

7.1. APPENDIX A

Gantt chart depicting proposed time line for the project



7.2. APPENDIX B

List of weirs/barriers within the catchment. Compiled from data obtained from EA, CAS, OS and field observations.

River	Name	Grid	Easting	Northing
Don	Huthwaite (lower)	SK2917399724	429173	399724
Don	Wortley Upper	SK2945699126	429456	399126
Don	Wortley Lower	SK2971898991	429718	398991
Don	Tin Mill gabion upper	SK2928298795	429282	398795
Don	Tin Mill gabion lower	SK2923198672	429231	398672
Don	Stocksbridge Woods	SK2947498357	429474	398357
Don	Wharncliffe Side upper	SK2983495180	429834	395180
Don	Wharncliffe Side	SK2993994441	429939	394441
Don	Crag View	SK3072593885	430725	393885
Don	Middlewood	SK3078693369	430786	393369
Don	Middlewood Iron Works	SK3098193114	430981	393114
Don	Beeley Woods	SK3152092516	431520	392516
Don	Claywheels Lane	SK3187191982	431871	391982
Don	Niagara	SK3285491519	432854	391519
Don	Owlerton	SK3405690224	434056	390224
Don	Ward End	SK3420789967	432078	389967
Don	Sandbed	SK3422489110	434224	389110
Don	Packhorse	SK3445688671	434456	388671
Don	Kelham Island	SK3501788265	435017	388265
Don	Wicker	SK3571387795	435713	387795
Don	Walk Mill	SK3620588109	436205	388109
Don	Burton	SK3676588220	436765	388220
Don	Sandersons	SK3723688911	437236	388911
Don	Brightside	SK3867290133	438672	390133
Don	Hadfields	SK3901691003	439016	391003
Don Canal	Lock	SK399911	439900	391100
Don Canal	Lock	SK399912	439900	391200
Don Canal	Lock	SK402916	440200	391600
Don	Jordans	SK4025392058	440253	392058
Don	Ickles	SK4179391870	441793	391870
Don	Tesco	SK4269492839	442694	392839
Don	Aldwarke	SK4500994452	445009	394452
Don	Kilnhurst	SK4679497453	446794	397453
Sheaf		SK358866	435800	386600
Sheaf		SK358865	435800	386500
Sheaf		SK3575863	435750	386300
Sheaf		SK357861	435700	386100
Sheaf		SK3555856	435550	385600
Sheaf		SK3498486	434900	384860
Sheaf		SK3482848	434820	384800
Sheaf		SK347847	434700	384700
Sheaf		SK3452846	434520	384600
Sheaf		SK3445845	434450	384500
Sheaf		SK34458445	434450	384450
Sheaf		SK3448842	434480	384200
Sheaf		SK3428375	434200	383750
Sheaf		SK3365833	433650	383300
Sheaf		SK336832	433600	383200
Sheaf		SK33558315	433550	383150
Sheaf		SK335831	433500	383100
Sheaf		SK332827	433200	382700

Sheaf		SK324815	432400	381500
Sheaf		SK323811	432300	381100
Sheaf		SK323810	432300	38100
Sheaf		SK3185806	431850	380600
Sheaf		SK318804	431800	80400
Sheaf		SK312802	431200	380200
Sheaf		SK302804	430200	380400
Sheaf		SK300806	430000	380600
Rother	Orgreave Weir	SK428874	442800	387400
Rother	Woodhouse Mill Regulator	SK433857	443300	385700
Rother	Beighton Weir	SK446841	444600	384100
Rother	Meadowgate Regulator	SK4525834	445250	383400
Rother	Killamarsh Weir	SK446808	444600	380800
Rivelin		SK3235887	432350	388700
Rivelin		SK317882	431700	388200
Rivelin		SK297873	429700	387300
Rivelin		SK2958735	429500	387350
Rivelin		SK288869	428800	386900
Loxley		SK317896	431700	389600
Loxley		SK305894	430500	389400
Loxley		SK302895	430200	389500
Loxley		SK2875903	428750	390300

7.3. APPENDIX C

Complete results from survey conducted in 2012

River	Date	Grid	Easting	Northing	Results	Count
Sheaf	20/06/2012	SK292807	429200	380700	No Crayfish	
Sheaf	20/06/2012	SK296806	429600	380600	No Crayfish	
Sheaf	20/06/2012	SK430000	430000	380500	No Crayfish	
Sheaf	20/06/2012	SK299806	429900	380600	Pacifastacus leniusculus	3
Sheaf	20/06/2012	SK299815	429900	381500	Pacifastacus leniusculus	6
Sheaf	20/06/2012	SK2996810	429960	381000	Pacifastacus leniusculus	3
Sheaf	20/06/2012	SK3038035	430300	380350	No Crayfish	
Sheaf	20/06/2012	SK308802	430800	380200	No Crayfish	
Sheaf	21/06/2012	SK3158025	431500	380250	No Crayfish	
Sheaf	21/06/2012	SK318804	431800	380400	No Crayfish	
Sheaf	21/06/2012	SK320807	432000	380700	No Crayfish	
Sheaf	21/06/2012	SK324813	432400	381300	No Crayfish	
Sheaf	21/06/2012	SK326818	432600	381800	No Crayfish	
Sheaf	21/06/2012	SK330824	433000	3824000	No Crayfish	
Sheaf	21/06/2012	SK334829	433400	382900	No Crayfish	
Sheaf	26/06/2012	SK337834	433700	383400	No Crayfish	
Sheaf	26/06/2012	SK343838	434300	383800	No Crayfish	
Sheaf	26/06/2012	SK3445843	434450	384300	No Crayfish	
Sheaf	26/06/2012	SK347847	434700	384700	No Crayfish	
Sheaf	26/06/2012	SK3505849	435050	384900	No Crayfish	
Sheaf	26/06/2012	SK354854	435400	385400	No Crayfish	
Sheaf	26/06/2012	SK3567864	435600	386400	No Crayfish	
Sheaf	N/A	SK294820	429400	382000	Access Refused by Landowner	
Limb Brook	27/06/2012	SK3228152	432200	381520	No Crayfish	
Limb Brook	27/06/2012	SK3178185	431700	381850	No Crayfish	
Limb Brook	27/06/2012	SK3156821	431560	382100	Austropotamobius pallipes	1
Limb Brook	27/06/2012	SK3148255	431400	382550	Austropotamobius pallipes	6
Limb Brook	27/06/2012	SK312826	431200	382600	Austropotamobius pallipes	3
Rivelin	03/07/2012	SK325893	432500	389300	No Crayfish	
Rivelin	26/07/2012	SK3258895	432500	388900	No Crayfish	
Rivelin	26/07/2012	SK3248885	432400	388850	No Crayfish	

Rivelin	26/07/2012	SK324888	432400	388800	Pacifastacus leniusculus	12
Rivelin	03/07/2012	SK324888	432400	388800	Pacifastacus leniusculus	4
Rivelin/Walkley Bank Tilt	26/07/2012	SK32458875	432450	388750	Pacifastacus leniusculus	4
Rivelin	26/07/2012	SK3248875	432400	388750	Pacifastacus leniusculus	4
Rivelin	26/07/2012	SK32258855	432250	388550	No Crayfish	
Rivelin	26/07/2012	SK3218884	432180	388400	No Crayfish	
Rivelin	03/07/2012	SK322885	432200	388500	No Crayfish	
Rivelin	03/07/2012	SK31758825	431750	388250	No Crayfish	
Rivelin	03/07/2012	SK3158805	431500	388050	No Crayfish	
Rivelin	03/07/2012	SK3108765	431000	387650	No Crayfish	
Rivelin	03/07/2012	SK305875	430500	387500	No Crayfish	
Rivelin	03/07/2012	SK399873	429900	387300	No Crayfish	
Rivelin	04/07/2012	SK2958735	429500	387350	No Crayfish	
Rivelin	04/07/2012	SK290872	429000	387200	No Crayfish	
Rivelin	04/07/2012	SK285867	428500	386700	No Crayfish	
Loxely	04/07/2012	SK287905	428700	390500	No Crayfish	
Loxely	04/07/2012	SK2919015	429100	390150	No Crayfish	
Loxely	04/07/2012	SK2958985	429500	389850	No Crayfish	
Loxely	04/07/2012	SK2998945	429900	389450	No Crayfish	
Loxely	04/07/2012	SK303894	430300	389400	No Crayfish	
Loxely	05/07/2012	SK310894	431000	389400	No Crayfish	
Loxely	05/07/2012	SK3148955	431400	389550	No Crayfish	
Loxely	05/07/2012	SK3198945	431900	389450	No Crayfish	
Loxely	05/07/2012	SK3238935	432300	389350	No Crayfish	
Loxely	05/07/2012	SK330894	433000	389400	No Crayfish	
Loxely	05/07/2012	SK335897	433500	389700	No Crayfish	
Loxely	05/07/2012	SK3415894	434150	389400	No Crayfish	
Don	05/07/2012	SK3427893	434270	389300	No Crayfish	
Don	06/07/2012	SK3422889	434220	388900	No Crayfish	
Don	06/07/2012	SK348886	434800	388600	No Crayfish	
Don	06/07/2012	SK355881	435500	388100	No Crayfish	
Don	09/07/2012	SK361881	436100	388100	No Crayfish	
Don	09/07/2012	SK3678825	436700	388250	No Crayfish	
Don	09/07/2012	SK370881	437000	388100	No Crayfish	
Don	09/07/2012	SK3725883	437250	388300	No Crayfish	
Don	09/07/2012	SK3722889	437220	388900	No Crayfish	
Don	09/07/2012	SK3748905	437400	389050	No Crayfish	
Don	09/07/2012	SK379893	437900	389300	No Crayfish	
Don	09/07/2012	SK382895	438200	389500	No Crayfish	
Don	11/07/2012	SK385900	438500	390000	No Crayfish	
Don	11/07/2012	SK3862907	438620	390700	No Crayfish	
Don	11/07/2012	SK3919105	439000	391050	No Crayfish	
Don	11/07/2012	SK3945913	439450	391300	No Crayfish	
Don	11/07/2012	SK398910	439800	391000	No Crayfish	
Don	11/07/2012	SK401915	440100	391500	No Crayfish	
Don	11/07/2012	SK4025921	440250	392100	No Crayfish	
Don	N/A	SK406917	440600	391700	No Access to River	
Don	N/A	SK411917	441100	391700	No Access to River	
Don	N/A	SK41609185	441600	391850	No Access to River	
Don	N/A	SK420920	442000	392000	No Access to River	
Don Canal	12/07/2012	SK407922	440700	392200	No Crayfish	
Don Canal	12/07/2012	SK4125922	441250	392200	No Crayfish	
Don Canal	12/07/2012	SK417924	441700	392400	No Crayfish	
Don Canal	12/07/2012	SK421923	442100	392300	No Crayfish	
Rother	N/A	SK425922	442500	392200	No Access to River	
Rother	N/A	SK425917	442500	391700	No Access to River	
Rother	N/A	SK424913	442400	391300	No Access to River	
Rother	N/A	SK425909	442500	390900	No Access to River	
Rother	N/A	SK425904	442500	390400	No Access to River	
Rother	N/A	SK430898	443000	389800	No Access to River	
Rother	12/07/2012	SK435897	443500	389700	No Crayfish	

Rother	12/07/2012	SK437894	443700	389400	No Crayfish	
Rother	13/07/2012	SK435890	443500	389000	No Crayfish	
Rother	13/07/2012	SK432888	443200	388800	No Crayfish	
Rother	13/07/2012	SK4275887	442750	388700	No Crayfish	
Rother	13/07/2012	SK425884	442500	388400	No Crayfish	
Rother	13/07/2012	SK4245880	442450	388000	No Crayfish	
Rother	13/07/2012	SK4262876	442620	387600	No Crayfish	
Rother	13/07/2012	SK429873	442900	387300	No Crayfish	
Rother	13/07/2012	SK432868	443200	386800	No Crayfish	
Rother	14/07/2012	SK4335862	443350	386200	No Crayfish	
Rother	14/07/2012	SK4325857	443250	385700	Pacifastacus leniusculus	6
Rother	14/07/2012	SK435854	443500	385400	Pacifastacus leniusculus	5
Rother	14/07/2012	SK4382850	443820	385000	Pacifastacus leniusculus	1
Rother	14/07/2012	SK442843	444200	384300	Pacifastacus leniusculus	1
Rother	14/07/2012	SK445841	444500	384100	No Crayfish	
Rother	14/07/2012	SK4465839	444650	383900	No Crayfish	
Rother	14/07/2012	SK449838	444900	383800	No Crayfish	
Rother	17/07/2012	SK452835	445200	383500	No Crayfish	
Rother	17/07/2012	SK4545828	445450	382800	No Crayfish	
Rother	17/07/2012	SK455824	445500	382400	No Crayfish	
Rother	17/07/2012	SK455818	445500	381800	No Crayfish	
Rother	17/07/2012	SK451815	445100	381500	No Crayfish	
Rother	17/07/2012	SK4485813	444850	381300	No Crayfish	
Rother	24/07/2012	SK447811	444700	381100	No Crayfish	
Rother	24/07/2012	SK444805	444400	380500	No Crayfish	
Rother	24/07/2012	SK441801	444100	380100	Pacifastacus leniusculus	1
Shire Brook	N/A	SK438846	443800	384600	No Access to River	
Shire Brook	N/A	SK434843	443400	384300	No Access to River	
Shire Brook	16/07/2012	SK425840	442500	384000	Pacifastacus leniusculus	9
Shire Brook	16/07/2012	SK420841	442000	384100	Pacifastacus leniusculus	8
Shire Brook	16/07/2012	SK414841	441400	384100	Pacifastacus leniusculus	6
Shire Brook	16/07/2012	SK4128425	441200	384250	Pacifastacus leniusculus	5
Shire Brook	16/07/2012	SK4098443	440900	384430	No Crayfish	
Birley Spa Pond	16/07/2012	SK409837	440900	383700	No Crayfish	
The Moss	24/07/2012	SK438799	443800	379900	Pacifastacus leniusculus	9
The Moss	24/07/2012	SK432799	443200	379900	Pacifastacus leniusculus	14
The Moss	24/07/2012	SK429799	442900	379900	Pacifastacus leniusculus	5
The Moss	24/07/2012	SK426800	442600	380000	Pacifastacus leniusculus	7
The Moss	25/07/2012	SK420801	442000	380100	Pacifastacus leniusculus	35
The Moss	25/07/2012	SK415802	441500	380200	Pacifastacus leniusculus	21
The Moss	25/07/2012	SK4108025	441000	380250	Pacifastacus leniusculus	19
The Moss	25/07/2012	SK405804	440500	380400	Pacifastacus leniusculus	29
The Moss	25/07/2012	SK3988035	439800	380350	Pacifastacus leniusculus	27
The Moss	25/07/2012	SK392803	439200	380300	Pacifastacus leniusculus	1
Birley Hay Pond	N/A	SK3978035	439700	380350	Access Refused by Landowner	

7.4. APPENDIX D

Pearson correlation coefficient for depth of study site against average size of crayfish, achieved using SSPS.

Correlations

		VAR00001	VAR00002
VAR00001	Pearson Correlation	1	.954**
	Sig. (2-tailed)		.000
	N	26	26
VAR00002	Pearson Correlation	.954**	1
	Sig. (2-tailed)	.000	
	N	26	26

**. Correlation is significant at the 0.01 level (2-tailed).

7.5. APPENDIX E

Metadata

File Name: SK26; SK28; SK46; SK48	**File Path**: H:\Geog413\Mapdata	
Description: OS colour raster base maps		
Source: Ordnance Survey via Edina Digimap		
Data Type: image	**Source Format**: tiff	**Scale**: 1:25,000
Date Obtained:01/05/2010	**Reference Date**:	
Notes: Multiple tiles to cover study area		

File Name: Rivers.dbf	**File Path**: \\geog-files\gisdata\National\EA_Drainage\06_YorksOuse V.1.0	
Description: Catchment data		
Source: Environment Agency		
Data Type: image	**Source Format**: dbf	**Scale**:
Date Obtained:01/05/2010	**Reference Date**:	

File Name: EW100_sheffield_v6 _geology_bedrock_polygons	**File Path**: H:\Arthurc\Data2\ EW100_sheffield_v6_geology_bedrock_polygons	
Description: Geological Survey Data		
Source: Edina Digimap		
Data Type: Raster	**Source Format**: .dbf	**Scale**: 1:25,000
Date Obtained: 01/05/2010	**Reference Date**: 23/04/2012	

File Name: Council records	**File Path**: H:\Arthurc\collatedcouncilrecords	
Description: Collated crayfish data by DCRT		
Source: DCRT		
Data Type: Spreadsheet	**Source Format**: .xcl	**Scale**:
Date Obtained: 01/05/2010	**Reference Date**: 2012	

7.6. APPENDIX F

Learning Journal created as part of academic requirements

Learning Journal

'Distribution of the invasive American signal crayfish in the Don catchment, South Yorkshire'

Chris Arthur – 30480818

Timeline

February

27th – Initial meeting with the Don Catchment Rivers Trust (DCRT) and Carly Stevens at the University of Sheffield. A speculative project was agreed upon to evaluate chemical control methods for the invasive floating pennywort within the catchment. I agreed to meet with Chris Firth (DCRT) and Andrew Virtue from the Environment Agency (EA) at the EA offices in Leeds to seek their advice and opinions regarding the project.

29th – Met with Chris Firth and Andrew Virtue. Andrew rejected the idea outlined above for a number of reasons, primarily the growing season for floating pennywort being unsuitable for the timeframe required for the project, but also difficulties in licensing for the use of chemical controls. After much discussion the American signal crayfish was identified as being a more suitable study species, which was agreed upon by all parties. Having related this information to my supervisor, Carly Stevens, she felt insufficiently experienced in this area to act as supervisor and so began the process of finding another member of staff to take on the role.

March

1st – 6th – A number of emails were exchanged with Andrew Virtue, Stephanie Peay (an expert on crayfish studies in Yorkshire) and Martin Nowacki (head of Crayfish Action Sheffield (CAS), with whom the DRCT work) about possible study topics and extents.

7th – Spoke with Paul Bradley (an ecological consultant with extensive knowledge on crayfish) about potential projects, the history of CAS and methodologies.

8th – Met with Ed Shaw of the DRCT and Martin Nowacki at the University of Sheffield. A project was finalised and a hypothesis suggested – that the current extent of signal crayfish in the Don catchment is the result of numerous introductions rather than a single continuous population that emanated from a single point.

12th – Submission of interim report.

14th – Met with Paul Bradley at his offices in Settle. We discussed the methodologies of crayfish trapping and he was kind enough to show me the sort of traps to be used and suggest conventional practices in performing the surveys. He also provided extensive information regarding the nature and history of crayfish introductions.

22nd – Dr. Richard Bardgett was assigned as new supervisor. Whilst he also does not have direct experience of this sort of field work, he agreed to take me on and provide supervision regarding the scientific requirements, acquisition of materials etc.

April

Throughout April and early May, information regarding previous locations of crayfish was collated. A basemap was developed on ArcMap 10 featuring 1:25,000 OS data, river data from the EA and geological data from the British Geological Survey via Edina Digimap. The historical records were overlaid on this to graphically illustrate previous crayfish distribution. Using this, and anecdotal evidence from a variety of sources, a list of study sites was created throughout the catchment at 0.5km intervals (where possible).

Work also began on writing introduction/method sections of final report to alleviate pressure later on. Due to the survey period running into mid-August, good time management and completion of such sections will be paramount in ensuring the report is of the highest possible quality.

May

Work continued to further refine the GIS map made previously and improve sections of the report. Emails were exchanged with Paul Bradley, Martin Nowacki and Ed Shaw to check details, obtain information etc.

10th – Applied to the EA for license to use traps to catch crayfish in the Don catchment.

11th – Met with Dr. Bardgett to fill him in on the project and ensure it meets assessment criteria.

20th- Received license from the EA. Purchased traps and other equipment needed to perform fieldwork.

28th – Borrowed GPS unit from university to assist in locating/recording study sites. Also acquired trigene disinfectant to help observe biosecurity measures in the field.

31st – Met with Dr. Bardgett to finalise project plan and methodology. Later, met with DCRT at their quarterly meeting in Sheffield to update on progress and seek guidance.

June

4th & 5th – Preliminary surveying to acquaint myself with the use of traps and ensure methodologies are realistic, safe and achievable.

6th – Masters poster day at Lancaster University.

19th-21st – Began surveying the River Sheaf. Practical work ran smoothly but cut short due to heavy rainfall creating unfavourable river conditions; levels too high and flow too strong for trapping.

25th-27th – Completed survey of River Sheaf and its tributary, the Limb Brook. Practical work ran smoothly but cut short due to heavy rainfall creating unfavourable river conditions; levels too high and flow too strong for trapping.

July

2nd – 5th – Completed Survey of the Rivers Rivelin and Loxely, and began work on the Don. Practical work ran smoothly. Conversed with local fishermen who reported finding signals on the Don just East of the Wicker at Salmon Pastures.

9th – 17th – Completed survey of the River Don and canal, the Shire Brook, and began surveying the River Rother. One day lost to bad weather. Met a member of the public who met someone that claimed to have introduced signals into Birley Spa pond. This could have been origin source for the system but trapping found no crayfish. Possible she got confused and meant Birleyhay pond on the Moss, where records show signals have been found previously.

23rd – 27th – Completed survey of the River Rother and Moss Brook.

30th – 3rd **August**

Entered all survey data into excel spreadsheet and then into ArcMap as XY data. Also integrated weir data (collated from CAS, EA, OS and field observations) in the same way.

Created Maps using above data to display current distribution.

Analysed number of individuals caught to give catch per unit effort data, and related this to date when populations were first recorded to create scattergraph displaying positive correlation between age and number of individuals caught.

Interpreted data on average size of individuals and depth of survey sites and found positive link. This is supported by literature from previous studies.

Reflections on the Project

I have found this a rewarding and beneficial project that has allowed me to gain experience in working in a professional capacity to create a piece of work for an external partner, and to develop a range of skills. Most pertinent among these is a greater knowledge of GIS systems and the practical experience of conducting a field based survey of an invasive species.

However, there have been several pitfalls along the way which have hampered progress, though I believe these to have been unavoidable. The largest problem that I faced was the decision of my original academic supervisor not to oversee the project, as they felt unable to do so effectively. This left me without guidance for several weeks at a crucial stage of the project, where I was finalising a topic with the Don Catchment Rivers Trust and creating my interim report/project outline. After numerous meetings with the trust, Crayfish Action Sheffield director Martin Nowacki, and Andrew Virtue at the Environment Agency, it was agreed that I would study the distribution of signal crayfish, and try to elucidate how they came to infest the Don catchment. This is a topic that immediately stimulated me; having worked alongside rivers previously and with a particular interest in aquatic organisms I had attempted to find a supervisor for such a project previously, but without success. I was eventually assigned to a new supervisor, but due to the nature of the project they were unable to advise on the practical aspects of the study. I was therefore required to learn all new techniques and methodologies without supervision, relying primarily on literature to do so. I was also fortunate enough to converse with Paul Bradley, an ecological consultant with expertise in crayfish, who offered advice and helped shape the projects aims and methods. Whilst this was not an ideal situation to be placed in, I am grateful for the level of flexibility this gave me and the opportunity to use my initiative to identify gaps in my knowledge and rectify them.

Once I began my fieldwork, I was unfortunate that it coincided with a period of particularly unfavourable weather, where I was often only able to survey for one or two days at a time before the rivers reached prohibitive levels and speeds. The EA monitoring station on the River Don which can be accessed online was invaluable in allowing me to remotely gauge the conditions before leaving Lancaster. Perseverance paid off, and despite being repeatedly drenched whilst conducting fieldwork, and having to cease for a day mid-week to allow rivers to return to more normal conditions, I was able to complete the fieldwork within the time frame that I had allocated myself.

Key Skills Acquired

When I embarked on this MSc, it was with the intention of preparing myself to work in an ecological capacity, and thus I selected modules to suit this purpose. I chose this dissertation topic for the same reason, because of the experience I would gain from it and the skills I would acquire. I have strengthened by knowledge of GIS by using it extensively to create maps and draw inferences based on data I have collected from a range of sources, including my own study findings. I have immensely enjoyed learning new things by reading literature and through trial and error.

I have also developed a detailed knowledge of the ecology and distribution of crayfish in the UK and to a lesser extent invasive riverine species as a whole. I believe this to be of particular merit, especially considering the predicted increase in such invasions resulting from increasing globalisation and climate change.

I have also been fortunate to work with several external partners and gain experience creating an industrial report to compliment my academic report writing skills.