SCOTTISH NATURAL HERITAGE

COMMISSIONED REPORT

Commissioned Report No. 020

The removal of the North American signal crayfish (*Pacifastacus leniusculus*) from the River Clyde

(ROAME No. F00LI12)

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COMMISSIONED REPORT Summary

The removal of the North American signal crayfish (*Pacifastacus leniusculus*) from the River Clyde

Commissioned Report No. 020 (ROAME No. F00LI12)
Contractor: Dr I D Reeve

Background

North American signal crayfish are an invasive, aggressive, and opportunistic species that have a considerable impact upon most aspects of the riverine ecology. Around 1990 signal crayfish were introduced into the waters of the Upper Clyde, a thriving and expanding population was soon established. By 2001 about 5km of main river had been colonised. The waters in this area are neutral to alkaline and support a highly diverse fauna, an abundance of submerged macrophytes, and a game fishery based upon brown trout. There are no salmon.

The report aimed to ascertain the feasibility of either removing or containing the signal crayfish population, or of substantially reducing the size of the population. These aims were investigated using a variety of techniques and ideas, namely trapping, electro-fishing, biological control, pH modification, turbulence, and pheromones.

Main findings

- Eradication was at first not considered possible, although a method did become apparent which could potentially achieve this. This would involve suppressing the pH at a time when it is at its natural lowest, by about one point to between 6.0 and 6.5. The critical period for signal crayfish being between July and September, inclusive, which is their moulting season. The juveniles are particularly sensitive to acid stressing and so this would also eliminate annual recruitment. The method required to do this involves installing a series of acid rock riffles of a precise total quantity just sufficient to suppress pH outwith the buffering capacity of summer flow levels.
- Containment is considered possible, both upstream and downstream. With respect to the former a customised weir with acid rock riffles immediately up- and downstream would be sufficient to limit the population. The downstream expansion could be limited by installing a pH/turbulence barrier of acid rock filled gabions and riffles, the design of which needs to create an extreme degree of extensive and persistence turbulence, and that suppresses only the summer flow pH of at least 5km of river in the manner described above. This would need to be located well downstream of the existing population.
- Eradication and containment would only work for an indefinite period and certainly cannot be guaranteed in the long term. Consequently, biological control using otters, grayling, eels, or perch, is advised.
- An integrated approach using a variety of strategies would be optimal. This would include installing weirs with acid rock riffles to limit the upstream expansion, encouraging signal crayfish predators to reduce numbers within the main population, and an intensive trapping and electro-fishing regime to limit the downstream spread.

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1 INTRODUCTION

1.1 Signal crayfish

The North American signal crayfish (*Pacifastacus leniusculus*) is aggressive by nature, highly opportunistic when feeding, and highly fecund. Therefore, given favourable conditions, signal crayfish can cause quite severe ecological imbalances by impacting upon all but the lower levels of the tropic pyramid (Nystrom *et al.* 1996). Signals can passively filter feed as well as graze heavily on certain macrophytes. They are also predators of invertebrates, especially molluscs which are taken to supplement their calcium intake, and fish which, when wounded by a pincer nip, often die from the resulting infection. Crayfish in general have very few predators native to Britain, namely certain species of fish (including grayling, eels, perch, and brown trout), otters, and some bird species. Grayling, perch and eels are all capable of consuming large numbers of signal crayfish; grayling and perch preying on smaller individuals, whereas eels will tackle the largest of signals and are very adept at flushing individuals from burrows etc (Blake & Hart, 1993). Eels are present in the Clyde below the Falls at New Lanark.

Signal crayfish are also cold-water tolerant and, like all other crayfish, are acid intolerant (ie pH levels lower than 6.5). When under pH stress the calcium ion pump of the crayfish haemolymph fails and osmotic control is fatally lost (Appelberg, 1985). When under acid stress the gills can be seen to swell out from under the crayfish carapace. Prolonged exposure to even mild acid stress will kill a crayfish by preventing its annual moult, for which calcium uptake is essential. The threshold for adult signals lies between ***pH 6.0*** and ***6.5***, providing no direct sources of calcium are present, ie for ingestion (Reeve, 1990), even *Astacus astacus*, a relatively acid tolerant species, suffers rapid and heavy mortalities at ***pH 5.9***, with newly hatched juveniles being even more sensitive (Fjeld, Hessen, Roos & Taugbol, 1988). For dissolved calcium, the lowest recorded threshold for signals at a favourable pH is 0.4mg/l, again providing no other sources of calcium are available; when not at a favourable pH the threshold is about 5mg/l (Stebbing *pers. comm.*). All N. American crayfish can also carry a fungal parasite, crayfish plague (*Aphanomyces astaci*), that is lethal to all non-N. American crayfish species.

It is known that signals are capable of expanding their range by actively seeking new waters at quite considerable rates, simply by walking and by always swimming downstream when alarmed or escaping from conflict. In small water courses this can be by as much as 4km per year, in a downstream direction which, all other things equal, is about twice the rate as that upstream (Reeve 1990). This is either prompted by population density pressure, resource availability, or sub-optimal environmental conditions (water chemistry, lack of cover etc), such that only when a particular threshold is reached will signal crayfish attempt to expand upon their range. There are frequent anecdotal reports of signals leaving confined waters in search of new, and if needs be signals can even graze bank-side vegetation to a degree that leaves a visible grazing line which can be up to 2m from the waters edge.

If signals gain access to open waters that have not previously supported any crayfish species, the prime effect they have is upon the distribution of biomass. A thriving population of signals will take a significant proportion of the total faunal biomass available, at the expense of a number of other species. This effect is most prominent in the early stages of colonisation, until predation and other regulating factors become effective. Certain macrophytes, such as freshwater moss (*Fontinalis* spp) and some crowfoots (*Ranunculus* spp), can be heavily grazed, especially if in abundance. Diversity of both flora and fauna is not generally affected, at least in open waters. However faunal and floral biomass and diversity are severely affected if signal crayfish are introduced into either closed waters, or where the population is in some other way restricted. In such situations, a thriving signal population can completely strip the substrate of any submerged macrophytes and also decimate many emergents, only floating macrophytes are invulnerable; of the faunal families, only the beetles, boatmen, dragon- and damsel-flies seem able to co-exist in any numbers.

1.2 The Upper Clyde

The Upper Clyde covers the catchment of the River Clyde upstream of New Lanark, and includes the sizeable tributaries of the Douglas water, the Medwin, and Duneaton. It is adjacent to the catchments of the Tweed and Nith, both sharing a considerable boundary, and the Annan, Lyne, and Ayr, to which there is less of a contact (see Figure 1).

1.2.1 Geology

As to the drift geology, much of the Upper Clyde, from Abington upstream to the Daer Reservoir and the Potrail Burn, flows through heavy deposits of boulder clay; a glacial deposit which can be acidic or alkali. In the wide floodplain upstream of Elvanfoot this deposit forms much of the riverside banking (see Figure 2), however from Telford Bridge to Abington the river flows predominantly *over* it, although in places boulder clay does form a bank. The solid geology underlying this area is of an acid series (pH of around 4–5) of greywackes, sandstone, siltstone, and mudstone.

Just downstream of Abington three changes in the geological character of the Upper Clyde coincide; The drift geology changes such that boulder clay becomes less evident and sand & gravel becomes more prominent, especially around Coulter Motte and Thankerton. Secondly, near Lamington, the solid geology changes from greywackes etc to a complex mixture of old red sandstone (around neutral), andesitic and basaltic lavas and tuffs (can be very acidic, as low as pH 3, usually around pH 4), and carboniferous limestone (very alkali pH 8–9.5) of which there are considerable outcrops around Lanark. Thirdly, the Clyde is joined by the Duneaton, itself a catchment almost as big as that of the Upper Clyde, and one that also flows through heavy deposits of boulder clay. Around Carstairs alluvial flats become extensive, after which sand & gravel terraces return at the Lanark loop. Downstream of Lanark the river once again comes into contact with frequent deposits of boulder clay. As the river continues towards Hamilton alluvial deposits become predominant, and remain so downstream to the Clyde Estuary.

1.2.2 Physical character

The character of the Upper Clyde upstream of Elvanfoot is most uncharacteristic of an upland river, in having an extensive floodplain, 5km long and between 0.2 and 1.3km across, with the river meandering sharply in strong riffle and pool systems. The river engineering works required for the motorway and railway has straightened about 1.5km of the main river which is of uniform depth, width, and flow. There are frequent spates throughout, at any time of the year, that can in places take away up to a meter of banking overnight; with significant shifts in the position of the gravel beds , this is an extremely dynamic part of the river. There are a small number of ox-bow lakes which can become inundated when the river is in heavy spate. Upstream of the meetings (the confluence of the Daer and Potrail, where the river becomes the Clyde) the floodplain narrows and riffles start to predominate. The main river is fed by a considerable number of tributaries, the Potrail, Elvan, Midlock, and Clyde's burn being the most extensive in this locale. Below the Telford Bridge the river assumes a more typical character with closer confines, a riffle and pool system which becomes extensive, with relatively stable banks, and longer curves. The river maintains these features past the Falls of Clyde and onto Motherwell, by which time it has become a typical lowland river (see Figure 1).

1.2.3 Ecology

The Upper Clyde is a clean, relatively pollution-free, Class 1A river (National River Classification System, 2000), although there has been a slight eutrophication in recent years due to nitrate run-off and silage leachate from some fields and farms (Miller, *pers. comm.*). Algal blooms have been seen both in the Clyde and some of its tributaries, and sewage fungus found frequently in a tributary, the Midlock. There are extensive beds of macrophytes (see Figure 2), in particular water crowfoot, occasional water milfoil, *Elodea*, and at least 2 species of *Potamageton*. Freshwater moss (*Fontinalis* sp.) is abundant.

With regard to invertebrate communities (see Appendix 2), the Upper Clyde has scored highly on the Biological Monitoring Working Party (BMWP) system for the last 6 years, the range being between 96 and 176, from a site just downstream of the confluence with the Elvan. The Average Score Per Taxa (ASPT), which is derived from the BMWP and gives a more precise indication of the quality of the invertebrate community, ranges between 6.00–6.86 with an average of 6.47 (SEPA). In all, 6 *families* of stonefly are represented, 5 of mayfly, and 8 of caddis fly; apart from the crayfish, the only other crustaceans present are Gammarids and Asselids. Of the molluscs, 4 taxa have been recorded, namely the *Ancylidae*, *Lymnaeidae*, *Sphaeriidae*, and *Hydrobiidae*. There are no confirmed native crayfish populations in this or any neighbouring catchment. With regard to vertebrate species, there is a healthy population of brown trout (stocked) whereas other fish species are much less common (grayling and brook lampreys are occasional), with the possible exception of sticklebacks. Salmon are not present owing to the Falls of Clyde.

1.3 Signal crayfish and the Upper Clyde

Signal crayfish were introduced in 1990 when an unknown number of berried females were put into an artificially constructed duck pond connected to the main river and adjacent to Crooked Stane Burn (see Figure 2). Being silt laden and small, with reeds forming the edge, the habitat is far from suitable and consequently the crayfish would certainly have attempted to find a more favourable habitat. There were many ways of gaining access to the main river and signals would almost certainly have been in the main river by the summer of 1991. Only after at least 4 years would the population finally have a diverse age structure. Indeed it was only in 1996/7 that signals were seen in any great numbers. Yet, by the time this project started in early 2001 the population covered about 5km of main river, and up to present can be found from Bellfield up to just downstream of the Meetings (see Figure 3).

With respect to signal crayfish, and considering most variables, the main river provides signals with a very favourable habitat, eg there is an abundance of shelter (boulder clay banking for adults, beds of water crowfoot for juveniles – see Figure 2). The only uncertainty would be the pH levels of the water, given this is an upland river surrounded by hills with many a spruce plantation and fed by burns coming off and through peat, it could be expected to be quite acidic.

2 AIMS AND OBJECTIVES

The overall aim is to formulate a strategy by which an invading signal crayfish population can be controlled. Although "eradication [was] deemed unfeasible" in the project brief, it became apparent that the river may be close to the pH threshold at which signal crayfish cannot survive. Eradication of the signal population from the Upper Clyde and its tributaries is therefore considered. To not consider any form of control would have serious consequences, not only for the Clyde catchment, but also for neighbouring catchments as the more widespread this species becomes the higher risk of invasion or introduction.

The implications of not attempting any form of control were considered, whereby the signal crayfish are allowed to spread unhindered. While it is difficult to determine the precise outcomes, an attempt has been made to predict the implications of a widespread expansion of this species, based upon the knowledge of their behaviour and observations made elsewhere.

2.1 Eradication

Eradication means the complete removal of *all* signal crayfish, at *all* stages of growth, and would require constant vigilance.

This report aims to investigate the feasibility of fatally acid stressing the entire signal population. The pH of the main river, and some of its tributaries, would need to be suppressed to below their pH threshold. Critically this would need to be done only in summer during their moulting season. Annual recruitment would also be eliminated as juveniles are particularly sensitive to acid stress. Acid stressing is considered to be the only method by which complete eradication can be achieved.

2.2 Containment

Containment means to limit the spread of the signal population in both the upstream and downstream directions such that crayfish are unable to gain access to uncolonised areas.

For a number of reasons this is very different when considering the upstream or downstream aspects of population expansion.

- Being in the upper part of a catchment, the potential for colonisation downstream is greater than that in an upstream direction. Consequently, the containment of the population at its lower limit is considered to be of more import than upstream containment.
- The effect of spates upon signal colonisation is uni-directional.
- Methods for the containment of the downstream limit may well be inappropriate for the same upstream, and *vice versa*.

2.2.1 Downstream

This report examines the feasibility of constructing a barrier that creates excessive and sustained turbulence, critically during summer flow levels, as a way of mortally injuring the signals by repeated wounding and pressure shocking.

The project also investigated the feasibility of modifying a length of river, located well downstream of the existing population, such that its pH is lowered to below the signal pH threshold, the resulting acid stress being sufficient to kill any signal crayfish.

Additionally, trapping and/or electro-fishing strategies that could restrict, stop, or even push back the downstream limit of the signal population, were investigated.

2.2.2 Upstream

Methods of pH modification, barrier construction, and/or the use of pheromones to prevent the upstream expansion of the signal population or even to push the limit back downstream were also investigated.

2.3 Reduction of population size

Methods of trapping and electro-fishing with the aim of effectively reducing signal crayfish numbers to a controllable level were investigated, in particular focussing on the downstream portion of the population and the alleviation of density pressure. Additionally, the possibility of using predators of signal crayfish as a form of biological control was considered.

3 METHODS

3.1 pH Measurement

Between April and September 2002, a hand held pH-meter was used to take pH measurements from the Middle Clyde to its headwaters, including its tributaries, and focusing upon the stretch occupied by the crayfish downstream to Carstairs Junction. Location of sample points is shown in Figures 4 and 11. A pH profile of the Upper Clyde was considered important to assess two factors; firstly, the potential for signal expansion, particularly in the downstream direction, and secondly, its proximity to the pH threshold of signal crayfish.

3.2 Trapping

The traps used were of the Swedish 'Trappie' type, consisting of a weighted, plastic mesh tube with funnels at both ends and either an attachment device or small box for bait, including crayfish, trout, trout pellets, rabbit, and on one occasion in September, 2001, black pudding. The traps were held in place by tethering to a peg in the bank. Between 70 and 90 traps were used up until September, 2002, when 50 more were added. Also 3 baited buckets were tested once: they were white, about 80cm deep with a 30cm diameter, tight fitting lid, with a 6cm hole cut in it, and were baited with trout and recently killed crayfish. They have a plastic mesh secured over and around the bucket and are simply weighted with stones. Where the substrate allows they can also be dug in such that the top is flush with the substrate

At least five trappies (and up to 10 where possible) were maintained around the downstream limit of the population, with at least 3 more at the next deep pool downstream. When practical these traps were inspected daily. If crayfish were caught downstream of the existing known limit, then most of the traps would be relocated to the new limit, and the remainder downstream to the next deep pool, and so on.

Above the downstream population limit, traps were set on both sides of the river and 'rolled' upstream in blocks of about 10–20 (see Figure 5 – light and dark blue dots), moving them on only when catch returns became negligible. In areas supporting a high density of signals (see Figure 6), one or two traps were maintained to monitor any recovery. Two tributaries, the Clyde's burn and Crooked Stane (see Figure 2), were also covered by up to 3 traps per bank, as were the ox-bow lakes. All traps, where river conditions allowed, were inspected between one and three days of setting, any trapped crayfish being killed bank-side, and the traps re-baited.

With regards to the upstream end of the population, trapping can directly influence the rate of population expansion, simply because crayfish could be attracted by bait in traps in previously uncolonised areas, with no guarantee of trapping these individuals. Consequently, traps were only set in areas that were known to support crayfish, as evidenced by sightings of individuals and/or their burrows, a search for which was effectively continual.

3.3 Electro-fishing

Electro-fishing trials were conducted in early May, 2002, with hand held (two person), battery powered, electro-fishing gear rig, on loan from the Clyde Angling Club, with two or three hand netters following on.

All runs were conducted in an upstream direction, as working downstream was soon discovered to be impractical owing to crayfish becoming obscured by disturbed sediment. Five electro-fishing trials were conducted over varying stretches of river, four on the Clyde (see Figure 5 – red dots), which had been recently trapped, and one on the Little Clyde, which was largely untrapped. All runs were conducted at 50 Hertz whereas two voltages were used on the first run (200V and 275V) with 275V used on the remainder.

3.4 Repellent pheromone

In August, 2002, a field trial, the first, was conducted by Dr Paul Stebbing of Newcastle University using a pheromone extracted from water in which signal crayfish were subjected to stress. The pheromone was fixed in agar and subsequent laboratory investigations were to show that the compound had a significant effect on repelling signal crayfish. If proven useful, this technique would only be useful at controlling the upstream limit of population. Six discs were available, 3 blanks and 3 containing pheromone. These were put into traps baited with trout and recently killed crayfish, ensuring that the 3 blank/pheromone pairs were each located in similar sites (ie depth, flow rate etc), with the blanks located upstream so as to avoid any influence of the pheromone. Traps were inspected the following day.

3.5 Biological control

In order to ascertain the feasibility of using crayfish predators, namely trout, otters, grayling, eels and perch, as a means of controlling the signal population, it was important to determine both their status in the Upper Clyde and the potential for which these species could suppress the crayfish numbers. Reports of sightings were collated (as well as those of otter spraints and their contents) and breeding potential assessed. It was also deemed necessary to conduct a literature search and consult certain specialists in order to obtain information regarding status, home ranges, breeding and dietary requirements, and predator/prey relationship.

4 RESULTS

4.1 pH Measurement

In total 6 pH profiles were taken from the Daer water (NS 955130) downstream to Carstairs Junction (NS 956444) and conducted in April, May, June, July, August, and early and late September (see Appendix 1I and Figures 7 and 8). One pH profile was taken from the Daer downstream to Motherwell (NS 732564), including the main tributaries, and conducted in April and May (see Figure 8). Conditions with respect to the water levels and weather at these times were as follows –

- April – summer flow, fine day, occasional heavy showers in previous week.
- May – summer flow, fine day, no significant rain for three days.
- June – summer flow, fine day, dry for previous week.
- July – spate at Abington, thundery showers, dry for previous week.
- August – approaching summer flow, fine day, periods of heavy rain in previous week.
- September 3rd – summer flow, fine day, mostly dry for previous week.
- September 24th – summer flow, fine day, dry for previous week.

pH readings were taken at two locations along the stretch of the river inhabited by signal crayfish, at Telford Bridge (NS 957183), and the railway bridge (NS 956167). The lowest recorded was ***pH 6.94*** at Telford Bridge, which is just above the tolerance limit of 6.5. The average pH for Telford Bridge was ***7.60*** and that for the railway bridge was ***7.37***. It appears that pH declines slightly upstream such that Potrail (NS 952131) and Daer (NS 955130) have average of ***7.43*** and ***7.21*** respectively.

Tables 1 and 2 below give the pH measurements taken along the Clyde and its tributaries, showing the range of readings and differences between summer and spring/autumn flows.

Table 1 pH readings – highs and lows of ranges and individual readings (OS grid references given below)

	Lowest pH	Highest pH	Lowest pH range	Highest pH range
Clyde	***6.94*** Carstairs	***9.23*** Coulter	***0.86*** Railway bridge	***1.9*** Lamington
Tributary	***6.68*** Midlock	***9.03*** Duneaton	n.a.	n.a.
Daer	***6.98***	***7.63***	(range ***0.66***)	
Potrail	***7.13***	***7.86***	(range ***0.73***)	

Coulter Motte (NT 903615), Midlock Water (NS 9561135), Duneaton burn (NS 934159), Lamington (NS 971102), Railway bridge (NS 957167), Potrail (NS 952131), Abington (NS 934133), Daer water (NS 955130), Carstairs Junction (NS 956444).

The following points can be taken from Table 1:

- The lowest recorded pH is just above the pH threshold of 6.5 for signal crayfish, the highest being well above the threshold.
- The pH ranges increase downstream from the signal site to Lamington.
- The pH recordings from the Potrail are consistently higher than those of the Daer.

Table 2 pH averages and ranges for summer and spring/autumn flow rates on River Clyde (where summer flow is taken to be that during June, July, and August and spring/autumn flow to be taken as that for the remainder of the year)

	Summer flow average	Range	Spring/Autumn flow average	Range
Potrail	*7.29*	*0.21* *7.13–7.44*	*7.52*	*0.57* *7.29–7.86*
Abington	*7.42*	*0.31* *7.29–7.60*	*8.03*	*0.61* *7.74–8.35*
Lamington	*7.38*	*0.17* *7.28–7.45*	*8.97*	*0.36* *8.83–9.19*
Carstairs	*7.33*	*0.61* *6.94–7.55*	*7.74*	*0.64* *7.35–7.99*

The following points can be taken from Table 2:

- The summer flow pH averages are consistently lower than those for the spring/autumn, both of which increase downstream from the Potrail to Lamington and then fall to Carstairs.
- The summer flow pH ranges are consistently narrower than those for the spring/autumn.
- The greatest difference between summer and spring/autumn pH averages occurs at Lamington.
- The narrowest ranges for both summer and spring/autumn recordings occurs at Lamington, whereas the widest both occur at Carstairs Junction.

4.2 Trapping

In February, 2001, the downstream limit of the population as ascertained by trapping was estimated to be just upstream of the railway bridge at NS 956166 (see Figure 9), 300m of the Clyde's burn (confluence with the Clyde at NS 963159), and 500m of the Crooked Stane (confluence with the Clyde at NS 960148).

In August 2001, a large adult male was trapped at Telford Bridge (NS 957183), thus extending the known population by about 1.8km from the railway bridge at NS 956166. Six traps were relocated to Telford, which up to March, 2002, returned a total of 18 crayfish. Trappings between the railway and Telford Bridges returned only 1 crayfish for over 3 years, until August, 2002, since when 10 have been removed.

In early October, 2002, following series of spates, a large male signal was trapped 2.5km downstream of Telford Bridge at Bellfield. Crayfish have yet to be trapped between Telford Bridge and Bellfield. Here the river is of a character that favours juveniles and sub-adults (both untrappable) and is almost certainly populated by such.

The effect upon signal distribution of a single spate is well exemplified by the appearance of signals at Telford Bridge in 2001. The first appears in early August in deep pool just downstream of the bridge, this crayfish could have arrived with a spate or of its own wanderings. However, after a week of no trapped signals there was a spate, following which two more adults were trapped in early November. By March the next year, and after numerous spates, a total of 18 signals were trapped in the same pool, and all this over the period when signals are least active. During spate conditions, any deep pool slows the current sufficiently to allow any signals caught up the current to drop out of the flow.

The spread upstream has been difficult to track owing to the potential for trapping itself to affect the rate of expansion if carried out upstream of the known limit. In February, 2001, the upstream limit of the population was estimated to be situated somewhere between NS 955145 and NS 955144. In August, 2002, the known upstream limit of the population was extended by about 850m to NS 955138 by the trapping of 20 crayfish (most of them large males and all from one deep pool). Since this time over 100 crayfish have been removed from this upper limit.

Trap returns have therefore shown that from their initial point of entry at Crooked Stane Burn, the signal population has spread about 2.8km upstream and 7.6km down, a total of 10.4km of main river in 12 years since they were introduced. Assuming a constant rate of increase in range, this represents an overall rate of expansion of about 0.9km per year, the downstream rate being faster at 0.65km per year, the upstream rate being 0.25km per year. Signals have also colonised at least 2km of its tributaries, including the Little Clyde and Crooked Stane. The expansion in population range is shown in Figure 9. Crayfish were also caught in an ox-bow lake unconnected to the main river.

Between August 2001 and November 2002, 15,254 crayfish were trapped in total (see Appendix 3). Since May 2000 the total number of crayfish trapped is approximately 29,000. Figure 10 shows the numbers of male and female signals caught by trapping each month from August 2001 to November 2002 and variations in male:female ratio.

There is a peak of catch returns in September that is repeated for 2001 and 2002, returns starting to rise in June and returning to its low around December. The corresponding trough for returns extending from January to May, with February having the lowest returns.

The September 2001 peak represents 2,744 crayfish returned using about 90 traps, equivalent to about 30 crayfish per trap over the month. The corresponding peak for 2002 is for 2,127 crayfish returned using 120 traps, equivalent to about 18 crayfish per trap. This represents a decline in catch per trap of about 40%.

The peak is slightly earlier for signals taken from the Clyde's burn, Crooked Stane, and from the main river in this locale. Of the 1,370 signals taken in these areas between 03/01 and 02/02, 30% were taken in August, 12% in July and 13% in September. The corresponding trough being in February and March yielding only 2% of the total catch returns.

Signal crayfish could be trapped at any time of year, although winter trap results were higher during milder weather. Freezing conditions are likely to make the crayfish less active as was demonstrated in

December 2000 when one trap caught 29 individuals during a mild spell of weather and just after a spate, and one week later, during freezing conditions, no signals were trapped. Similarly, the 50% drop in catch returns during June 2002 is thought to be due to particularly cold weather conditions.

The areas where high numbers of signals have been trapped are associated with stretches that have a depth of over 1m with deep boulder clay banks (see Figure 2) and good cover, either of large stones and rocks, usually on or by a bend in the river where the boulder clay is being eroded, the burrowing of the signals quite probably contributing to their erosion. It was also observed that catch returns are high for up to two days following a spate and crayfish were frequently seen, in broad daylight, to become active the day before a spate.

The least effective bait used in traps was rabbit and trout pellets, the latter disintegrating too soon. There was no discernable difference between trout and crayfish, however black pudding appeared to be most attractive, although this bait was used during peak trapping time. The 3 baited buckets returned a catch of 10 signals. In 5 of the usual traps located bank side in the same stretch of river, a total of 18 crayfish were caught.

The average male:female ratio of the crayfish caught between August 2001 and November 2002 was 1:0.67 (see Appendix 3 for monthly data). The proportion of females caught seemed to increase in July following release of newly hatched juveniles. Information on the percentage of females caught that were carrying eggs (berried) is scarce, but in November 2001, and January and February 2002 the figures were 87, 91 and 80% respectively.

A decrease in the size of crayfish being caught has been observed, with approximately 50% of the catch in 2000/2001 being over 15cm long, and in 2001/2002 about 70% caught were under 7.5cm and no crayfish were caught over 12.5cm in length.

Data relating to the appearance of recently moulted young adults in traps is a follows:

- Between the railway bridge and Telford Bridge, a distance of 1.6km, hardly any crayfish had been trapped for two summers until September, 2002, when considerable numbers of small adults of around 7cm were trapped.
- A similar phenomena occurred in July, 2002, in the main river upstream of the Clyde's burn, when returns from 40 traps increased quite dramatically with *all* 100 or so crayfish being around 7cm.
- Since the beginning of August, 2002, about 5,500 signals have been removed, 4,000 of which, mostly about 7–8cm long, were found near the top end of the population, upstream of Crooked Stane, by an unnamed burn at NS 960148 from about 40 traps located in both the main river between this point and NS 959146 and the burn.
- Generally speaking, smaller adults and damaged individuals become more evident as autumn progresses.

4.3 Electro-fishing (see Figure 5)

In 4 hours of electro-fishing a total of 225 crayfish were removed from the Clyde's burn and the Little Clyde. 72% of these animals were caught directly as a result of the electro-fishing process and 28% simply by hand-netting the burns. 13% of females were berried, including a 2+ female. 56% of the crayfish were caught in the Clyde's burn. Table 3 shows the breakdown of age and sex of the crayfish caught in these locations.

Table 3 Age and sex structure of signals taken by electro-fishing

	% of Total		Male:Female ratio	
Age	**Little Clyde**	**Clyde**	**Little Clyde**	**Clyde**
0+	33	41	1:1.1	1:1
1+	29	34	1:0.7	1:1.2
2+	22	18	1:0.8	1:1.1
3++	16	7	1:0.2	1:1.5

The Clyde's burn was much easier to fish because the field was more confined than in the wider river, the consequence being that signals were being affected across the full width of the burn. Of particular note is the higher proportion of females in the Clyde from 1+ crayfish and older, this being especially significant in the over 3 year olds. Afterwards, 4 traps left in the Little Clyde for the whole of June only caught 3 crayfish.

As far as the voltages are concerned, the behaviour of the crayfish when in range (about 1m) was simply to start moving around, in no particular direction, sometimes swimming away, albeit quite ineffectively and impaired. The only noticeable differences between voltages being that the crayfish were slower moving at the higher the voltage, which also had a slightly wider range.

With respect to the various micro-habitats, the most successful returns were from stretches of water of a moderate depth between 0.5 and 1m, steep banking, a moderate level of cover, and smooth flow (which makes affected crayfish visible). Some crayfish, usually juveniles, were missed by the netters. As expected returns were invariably lower than in areas where cover is not as good. Although, if the cover is too good (large stones and clumps of clay, and/or extensive burrow systems) then the crayfish appeared to remain dug in; at least one signal was seen in a burrow that would not come out irrespective of the proximity to the cathode.

4.4 Repellent pheromone

Results of the six traps (3 repellent, 3 blanks) are given in Table 4 below.

Table 4 Repellent pheromone trial results

Trial	Number of Signals Trapped
Traps Containing Repellent	12
Traps Containing Blanks	5
Total	**17**

4.5 Biological control

Otters and their spraints have been seen throughout the area. Spraints seen at NS 959162 (August 2002) and NS 963157 (November 2002) had a considerable proportion of signal remains present.

A large dog otter has been seen at various times and at various locations from Telford Bridge upstream to the Meetings. It is most likely the spraints seen around the top end of the population are those of this male, whose range almost certainly overlaps that of the female (see below). Traps were observed broken open, presumably by otters, at NS 955138 (July 2002).

Over the summer months a mother and cubs have been seen regularly between and around Crawford and Abington with a lone female being sighted at Elvanfoot. It would appear that there is a resident female otter whose range extends upstream from Abington and probably reaches into the bottom end of the signal population. There does not appear to be a resident female upstream of the Elvan as no sightings were seen during the numerous site visits, as have been for the dog otter.

Given the continual activity of signals throughout the year in the Upper Clyde combined, a year round predation of signals by otters would be expected, particularly in the tributaries, namely the Clyde's burn, Crooked Stane (and potentially the Elvan and Glenochar) and upper reaches of the Potrail.

For the Clyde catchment as a whole, an indication of the status of this species is shown by the results of two national otter surveys, the first published in 1978 and the second conducted between 1991 and 1994. Of the 168 survey sites, 22% were positive in 1978 compared to 79% by 1992, most of these being concentrated on the middle reaches (around Lanark and Biggar) and tributaries to that part of the river. If the Clyde is compared to the Tweed (on the whole cleaner and richer) which, in 1978, had 31% of survey sites positive and, in 1992, had 63% positive, it is clear how well the Clyde otter population is doing. However, it is not clear why the Upper Clyde does not have such a concentration of positive sites as it does in its middle reaches.

Only a few years ago it was presumed that grayling had virtually disappeared from these waters, with only a few sightings a year, and have been declining from other parts of the Upper Clyde as well. In the 1980s, a large breeding redd was destroyed with the construction of the M74 new motorway. In late summer, 2002, a few sightings of small shoals of juvenile and sub-adult fish were reported and there has been a noticeable increase in adult numbers and are now reckoned to be using a small breeding redd at NS 960149. However, numbers are far less than prior to the M74 upgrading.

Breeding populations of perch can be found in all the header reservoirs, namely the Daer, Camps, and Culter, and can be found in small numbers throughout the rest of the Upper Clyde catchment, particularly in some of the burns, although increasing downstream to where, at Carstairs Junction at least, there is a good population.

The introduction of adult eels from Strathclyde Park has been carried out previously, although there has been no evidence of them subsequently. Elvers have not been introduced.

5 DISCUSSION

5.1 pH Measurement

Normally, upland rivers tend towards being acidic, and although most of the tributaries of the Upper Clyde are of a lower pH than the main river, they still cannot be called acidic, despite having come off moorland and, in some cases (eg Clyde's burn), having gone through extensive spruce plantations. Furthermore, if solid geology has any effect, then the Upper Clyde and its tributaries should be acidic. With respect to drift geology however, there are extensive deposits of boulder clay throughout much of the catchment upstream of Abington, with lesser deposits in the lower reaches of most of its tributaries. The floodplain occupied by the signal crayfish has, in places, boulder clay banking up to 6m in depth. Downstream of Abington however, deposits of boulder clay become patchy, and are very scarce between Thankerton and Lanark, although become frequent again downstream of Lanark to upstream of Hamilton.

If signal crayfish are dependent upon ingesting boulder clay for their mineral requirements, then the population could well be limited by the direct availability of deposits and would probably not extend much beyond Abington. If the need is only for calcareous material in solution etc then the population could well extend to Coulter Motte. If there is no such need at all, and signals are getting all their bicarbonate etc requirements from the general environment then, then signals could populate the Clyde as far downstream as Motherwell, which including potentially favourable tributaries, means that over 130km of waterway could be colonised. Downstream of Motherwell the water quality becomes a consideration and is quite probably unsuitable, owing to its siltyness, depressed oxygen levels (high organic, nitrate, and phosphate levels periodically), and neutrality in terms of pH.

Boulder clay can contain varying levels of carbonate and bicarbonate, of fair proportion of which is usually bonded to calcium. In solution carbonates and bicarbonates are alkali. Although the chemical composition of the boulder clay of the Upper Clyde is not known, much of Lothian and the Borders in the east, to Cumbria in the west, is underlain by Carboniferous limestone, which, prior to glacial erosion, would have overlain the older Devonian sandstones and Ordovician and Silurian rocks, over which the Upper Clyde now flows.

There is a considerable amount of evidence suggesting that at least some of the boulder clay deposits are calcareous to a degree, particularly;

1 There is a thriving signal population which must be getting calcium carbonates from some source. Signals have been observed consuming boulder clay and are also highly active, day and night, for days following a spate. The absolute need for this resource is demonstrated by the risk of predation taken when out in the open in broad daylight, presumably maximising their uptake during periods when the river is loaded with these essential minerals. The availability of boulder clay and its diffusion downstream could be critical to the survival of signals in these waters.

2 The pH levels at their lowest are neutral and at their highest are distinctly alkaline. The underlying greywackes etc are acidic and of the surrounding rock types the Old and New Red sandstones, Millstone Grit, and Coal measures are neutral, whereas the granites, basalts, and other volcanic rocks are all acidic. The only alkaline rock type of any substantial outcropping within a 100km radius of the Upper Clyde is that of Carboniferous limestone, although there is a lowland bed of calcareous Lias and Keuper Marl around Carlisle. The alkalinity of the Upper Clyde can have only originated from the

erosion by glaciation of limestone, subsequently deposited in boulder clay and then released by fluvial erosion, temporarily raising pH levels.

3 There were thriving, yet discontinuous populations of native crayfish in the Upper Wye catchment, Wales, which is also associated with the very same greywackes etc that underlie the Upper Clyde upstream of Lamington, and more significantly these populations were closely allied to patchy deposits of calcareous boulder clay.

When waters are at their lowest levels in summer (June, July, and August) the pH of the river from its headwaters downstream to Carstairs, at least, is considered to be just above the threshold of acid tolerance for signal crayfish. Of particular note are the July pHs for Telford Bridge and the railway bridge, being ***7.01*** and ***6.97*** respectively, both of which are unusually low for waters occupied by any crayfish species. However, during and after spate conditions, the pH invariably begins to rise into alkalinity, such that after an autumn and winter of fluctuating water levels, the pH in May at the same two sites was ***8.04*** and ***7.83*** respectively. After which the pH falls towards summer flow levels (suffice to say that summer flow levels can occur periodically at any time of year, and in very wet summers may not occur at all).

Although high water levels seem to raise pH, this is not immediate in its effect, as can be seen from a July pH of ***7.29*** taken during a spate, the colour of the water being a light brown. Furthermore, following high water the pH appears to rise downstream to a consistent peak at around Lamington and Coulter Motte, after which the pH invariably declines towards Carstairs. Also, the effect of raised pH following high water is certainly prolonged such that pH remains elevated for at least a week, as Septembers readings show. This effect will be accumulative, although it is not known to what degree. Nevertheless, following heavy rainfall alkalinity is being taken up, firstly it seems in suspension, and then in solution.

Upstream spread of the signal crayfish population is likely to become more limited than downstream spread given that the pH and general character of the river are becoming less favourable. This is especially so for the Daer Water which is very peaty, although for the Potrail conditions may allow signals to survive in pockets. However, there are a number of other burns which could potentially be colonised, the Elvan and Glenochar burns being the principal examples, although whether or not they have been colonised is not as yet known. The signal population in the Crooked Stane has probably reached its limit, that being a waterfall just upstream of the farm, whereas that in the Clyde's burn is probably still spreading upstream and how far it can get is not known. The Elvan and Clyde's burn are quite considerably sized catchments and such waters are frequently more productive than the main river, and consequently can hold considerable numbers of crayfish in a small pockets (as the electro-fishing of the Clyde's burn demonstrated).

5.2 Trapping

The effect of altitude and latitude upon the activity of signal crayfish is demonstrated by their trappability throughout the year. Signals appear to remain relatively inactive through spring and early summer, and become easier to trap in July. Individuals appear to remain relatively active through autumn and well into winter, with catches bottoming out only in December. Compared to more southerly signal populations this activity season is quite unusual. Not surprisingly signals start becoming active earlier in lower latitudes, in southern England around March and April; what is surprising is that crayfish remain active in the Clyde long after their southern counterparts which become inactive after the September breeding season. It is suggested that, being cold water tolerant, and inhabiting a site that allows only a short growing season, the signals have to make the most of any slight rise in water temperature.

In the Upper Clyde female crayfish start to berry up in September and seem to continue doing so right up to January, although it is unlikely that these later layings will survive. The eggs are carried until hatching the following June and are continued to be carried through the first two moults, after which the juveniles are capable of independent existence and subsequently start to drop off such that by the end of July all are free living.

Although the efficiency of trapping is difficult to estimate, there are a number of observations that suggest that trapping may be having some effects on the signal crayfish in the Upper Clyde;

1 An estimated 50% of the 2000/01 catch were over 15cm, whereas no crayfish of this size were taken the following year with most of this catch being half this size.

2 There was a very low proportion of crayfish larger than 8cm in catches from areas previously trapped. This is where previously untrappable crayfish become trappable after a single moult, an event that occurs quite spontaneously once water temperatures are consistently high enough, which for the Upper Clyde appears to be from July through to September.

3 There was a decline in number of crayfish caught per trap of 40% recorded between the September peaks of 2001 and 2002.

However, although trapping efficiency could well be relatively high, it may not be an appropriate way, on its own, of controlling the signal population, either by way of eradication or containment for the following reasons;

1 The type of trap used is capable only of trapping signals in excess of 7cm, thereby leaving at least 3 year classes totally untrapped, namely the 0+, 1+, and 2+ crayfish. This has the effect that each year, throughout the entire population, there is a massive recruitment of 3+ signals that cannot be avoided. The high numbers of crayfish trapped upstream of the Clyde's burn in July, 2002, is indicative of this phenomena, as is the sharp rise, in September, 2002, in numbers of small adults between the railway bridge (NS 958168) and NS 954176. In fact, it is possible that the more efficient the trapping the greater the recruitment, owing to a reduction in competition between trappable and untrappable age classes.

2 Even if all age classes could be trapped, the extent of the population would require a trapping regime far more intensive than that employed here. Any such trapping effort would need to be undertaken for as long as it takes until no more crayfish are returned (given point 1 above, at least five years).

3 Thirdly, each year the population will be expanding and, although it may be just possible to control individuals of a trappable size, it will not be so to do the same for juveniles.

4 The action of a single spate could undermine any containment trapping by sending adults and juveniles alike well beyond the most downstream of traps by anything up to 2.5km.

Because only the banks of the main channel were trapped, only an estimated 20% of the substrate surface area was covered, the midstream being completely omitted. This is offset to a degree by an edge effect whereby the banking will certainly support a higher density of signals owing to the abundance of cover. This being especially so where boulder clay can be burrowed into. The bucket type trap could be of particular use for removing crayfish that occupy the midstream, and could be either used with the standard type trap, and simply weighted down, and/or on their own as permanent fixtures and dug in. Concentrations of these traps, spanning the full width of the river, could then be permanently located on the upstream edges of areas capable of supporting high densities.

The bucket type trap could be of use in drawing crayfish back from recently colonised waters at the downstream edge. The buckets only need to be 25cm deep to prevent trapped signals from escaping, making the traps easier to dig in. However, to prevent them filling up with gravel etc during high waters it may be prudent to leave about 10cm protruding above the substrate level. This way they could be partly dug in and weighted, or even staked, and arranged as a solid line, or three, right across the river. This type of trap may also work better if of a darker colour.

Totally unchecked and at the given rate of downstream expansion of just under 1km per year, signals could be at Abington, 9km downstream, in 9 years. Intensive and strategic trapping could conceivably slow this rate of expansion down, as it probably will have so far. However, this rate is estimated from waters that are far more suitable to signals, and that would slow the rate down further owing to the time it takes for density pressure to build up, and add to this the variability of spates, and its well possible for signals to be at Abington within 2–4 years.

5.3 Electro-fishing

This technique proved to be effective at catching all age classes, with the youngest age classes being consistently returned in higher numbers. The proportion of 0+ and 1+ animals would have been higher still if netting had been more efficient. It was noted that, although signals did respond to the electrical field, there was no consistent pattern of behaviour, making it difficult for the netters to anticipate the movements of individual crayfish. Electro-fishing only works well given quite defined conditions, for example, not too deep nor too shallow, and having good cover, yet not too good.

It was generally acknowledged that at least some signals would not have been affected, owing to being insulated by a long burrow or large stones and clumps of clay. In terms of catch per unit effort, the electro-fishing of the Clyde's burn was more effective than that in the main river, this being a consequence of a bank to bank effect in the smaller water, although in addition tributaries are considered to be more productive owing to an increased edge effect.

Compared to trapping, there was a significantly higher proportion of females taken by electro-fishing, for May, 2002, the male:female ratio within the trapped population was 1:0.24, compared to 1:1.2 for the electro-fished population. It is possible that electro-fishing selects females over males, however, given that females are less active throughout most of the year, it is more likely that trapping may be selecting males over females, and that electro-fishing returns represent a more realistic sex ratio.

The electro-fishing of a berried female under 7cm long, and presumed to be a 2+ individual, means that some crayfish are reaching sexual maturity before they become trappable; such crayfish are either early developers or, and this is considered to be more likely, they are slow growing and reach maturity at a smaller size.

5.4 Repellent pheromone

That the traps containing the repellent returned more signals than did the blanks is curious. Dr Stebbing suggested that either the pheromone was not sufficiently fixed in the agar, and consequently was only effective for a short period, or was not of sufficient strength to override the attraction of the bait.

5.5 Biological control

Otters have home ranges of 30–60km of waterway for adult males and 15–30km for adult females. The range of adult males can overlap with several breeding females, but not with other breeding males. Generally, adult females tend to live on smaller tributaries, where there is a higher biomass and edge habitat and prey are easier to catch, whereas adult males tend to exploit the main river. Although largely solitary animals, feeding sites can be shared by all resident otters as a way of maximising exploitation, different otters feeding at different times (holts also tend to concentrate in such areas). There is a higher proportion of indigestible matter to meat in a crayfish than in a fish, so the amount of spraint from a crayfish meal will be greater than that from a fish meal, which may lead to an over estimation of the value of crayfish in the diet.

In Sweden, crayfish (*Austropotamobius pallipes*) made up to 30% of their total food intake for June, July and August, lowest consumption being from December to April when activity is suppressed (Erlinge, 1968). However, in the more temperate climate of Ireland (*A. pallipes* also), no such decline in winter feeding was recorded with berried females being consumed as frequently as were males; in addition crayfish taken by fish predators were of a smaller size than those taken by otters (McFadden & Fairley, 1984). In Spain, another introduced species of crayfish (*Procambarus clarkii* or red swamp crayfish) that colonised large areas of Catalonia is reckoned to be responsible for the recolonisation of the area by otters.

In Donana National Park, which *P. clarkii* colonised in 1977 a shift from fish to crayfish was observed in the otter diet (see Table 5), although this was due in part to a decline of fish stocks.

Table 5 % composition of otter spraints

% of spraint containing		
Year	**Crayfish**	**Fish**
1974	0	94
1977	59	70
1978	83	58

Although it is unlikely that the arrival of a single new food source would directly and significantly increase otter numbers (with regard to the total number of crayfish predated), it might be possible to increase otter activity in areas well colonised by signals by the careful location of artificial holts if there is a shortage of natural sites, which may be the case in the Upper Clyde.

It may be possible to either increase otter numbers or activity in the area occupied by the signal population. As far as numbers are concerned, this depends upon whether or not there is a female that has as her territory the catchment upstream of Elvanfoot, the female seen at Crawford seemingly having the waters downstream of here – the spraints marking the possible boundary. If this is so then the capacity for otters in this part of the Upper Clyde has probably been reached. Either way, both numbers and/or activity can be increased by the construction of an artificial holt or two up one of the burn valleys, preferably where there is some woodland, and out of the floodplain (Crooked Stane, Clyde's burn or Glenochar having potential).

Many Scottish rivers with otter populations, including the Upper Clyde, have predominanantly salmonid fish populations, and consequently a significant proportion of the otter diet in the Upper Clyde consists of brown trout. To diversify with species of other fish would be expected to lower this proportion. Otters do eat trout, mainly smaller ones except when adults are vulnerable during spawning, yet generally prefer slower species that are so positively selected for that they are present in the diet at a higher level than their proportion in the biomass.

As for predatory fish species, the following points can be made:

- Grayling numbers may be increasing in the Upper Clyde, this increase could be assisted by extending existing redds or creating new ones.
- Perch were found to be a serious predator of *Austropotamobius pallipes* (McFadden & Fairley, 1984), consequently their numbers could be increased by introductions.
- Eels also preyed heavily upon small *A. pallipes* (McFadden & Fairley, 1984). Eels would need to be introduced as hatchlings and over of period of years. However, the falls at New Lanark may act as a barrier to migrating eels.

Keeping signal numbers down by predation will have a minimal impact upon the ecology and in some ways could be seen to be of benefit, those species of plant and animal that were predated upon by signal crayfish will almost certainly do better. This would include plants such as *Fontinalis* spp, *Myriophylum* sp, and some of the finer crowfoots, and animals which would include species such as *Gammaridae* sp and *Asellidae* sp (both crustaceans), *Lymnaeidae* sp (a favourite item of prey), some of the larger invertebrates like the *Ephemerellidae* (mayfly) and *Perlodidae* (stonefly). Other taxa which may well benefit from reduced signal numbers are the soft bodied like the *Rhyacophiidae* (a caddis larva that does not have a case), *Erpobdellidae* (leech), *Tipulidae* and *Simulidae* (both fly larvae), and beetle larvae.

5.6 Customised weirs

Although spates can carry crayfish for unknown distances, there is compelling evidence that crayfish suffer high mortality rates during spates. In a study of ranging behaviour in *Austropotamobius pallipes* using radio tags, a 40% mortality rate was noted during flood events (Robinson, Thom & Lucas, 2000). Although some crayfish were found with lost limbs and cracked carapaces, this would not be sufficient to cause death directly, and besides some crayfish were found dead and intact. It is suggested that sustained exposure to turbulent water will, through repeatedly shocking the crayfish with pressure waves, kill crayfish. The more turbulent the water, the higher the chance of mortality.

If deemed viable, customised weirs would need to be constructed near the confluences of all colonised and vulnerable burns, after all the signals have been eradicated by electro-fishing and trapping. Acid riffles located upstream and downstream of structures would ensure its effectiveness. The weir such as that at NS 933101 could be effective at restricting, or even stopping, the upstream expansion of signals. To prevent signals going overland and around such a structure there would need to be side extensions that extend into and over the banking.

6 OPTIONS AND RECOMMENDATIONS

The consequences of not undertaking any form of attempted control of the signal population, either by eradication, containment, and/or reduction control, would be significant. Numbers of crayfish within the existing population limits would rapidly increase to a peak, causing ecological disruption, such as the overgrazing of certain macrophytes, reduction in numbers of common invertebrate prey species, as well as impacting upon the local brown trout population. Predation of crayfish by fish and other predators is likely to subsequently stabilise the crayfish population level.

The expansion of the population will also gather pace as density thresholds are breached, the scope for colonisation being far greater downstream than upstream. Signals will certainly populate the main river as far as Abington, although overall densities will not be as great as in the floodplain population as the habitat becomes less ideal. Small pockets of high density will become established in deep pools etc where boulder clay deposits are available. Colonisation of the catchment downstream of Abington is more difficult to assess, owing primarily to the changes in solid and drift geology. Crayfish may be able use the occasional deposits of boulder clay and get as far as Lamington, after which the geology becomes neutral and acidic. If signals can utilise the alkaline flushes that accompany every spate, then the population could extend to through to Thankerton. Downstream the pH of spate water declines, although still alkaline, and boulder clay deposits disappear. The stretch between Thankerton to just downstream of Carstairs Junction, over 10km of river, is most unfavourable to signal colonisation in the whole of the Upper and Middle Clyde. This stretch could be sufficiently unsuitable for crayfish to act as a barrier to the downstream spread of the population. If this is not the case, then more favourable conditions return at the Lanark loop, and colonisation could continue downstream to Motherwell.

In an upstream direction from the existing population, the scope for colonisation is much more limited. The Daer is considered unsuitable owing to its peat content, while the Potrail, although suitable in all other parameters, rapidly diminishes in size such that signals could only exist in small pools of increasing infrequency.

Despite the options for containment or eradication given below, there remains a significant risk that human intervention, by moving crayfish to new stretches of water, could undermine any such attempts at control. Ineffective legislation, together with impractical means of enforcement, means that there are very few disincentives for such activities, as has proven in England with the establishment of signal crayfish no-go areas, which continue to be lost, one by one, by signal introductions and/or outbreaks of crayfish plague. In this context, it is considered absolutely critical that what ever is undertaken should be agreed upon by all interested parties, ideally by consensus, and any strategy implemented be *open* and accountable, and be done so with a concerted effort integrating all concerned.

Also, with regard to the human factor, there is only one person known to be harvesting the signals for the table, and, while this is not known to be commercial, it cannot be stressed too strongly that any such activity would be disastrous.

6.1 Eradication

Eradication may be possible by acid stressing the entire signal crayfish population. This could be done by acidifying the main river from upstream of the current population downstream to Crawford, such that the pH over summer months only (June to August inclusive) is lowered to between ***6.0*** and ***6.5***, a drop of about one point from the average range between ***pH 6.97*** and ***7.4***, its lowest yearly levels. The pH levels for the rest of the year need not be affected so much, the buffering capacity of boulder clay only being effective when the flow rate is low; as evidenced by elevated pH levels following high waters. It is estimated that exposure to this level of acidification would be sufficient to kill an adult crayfish in less than one month, with juveniles suffering mortality within one week.

It may be that pH does not change much initially after an attempted acidification, yet when the threshold for buffering capacity is reached the pH may drop quite rapidly. Therefore, such an acidification would need to be done gradually with careful monitoring of pH during periods of low flow. The least impact upon the rest of the system would be if the acidification were achieved using as many locations as possible. Caged signals could be used as a preliminary test of the effects of such acidification over a trial stretch of river, and it also needs to be ascertained that signals are not actively being pushed or washed downstream, and that there is no recovery if such acidification is temporary. This could be done one stretch at a time working upstream from below the downstream edge, or all at once, although side streams would also need to be cleared.

A way of acidification that is considered to be practically easiest, probably cheapest, reversible, and of finest control is as follows. Basically, it involves creating riffles out of an acidic rock type, at as many locations as possible between Crawford upstream and into the Potrail and Daer water – a total distance of about 12km of river that has maybe 10 or so accessible sites. Tributaries holding signals would also need such acidic riffles, although other burns could also be used to acidify the main river. A trial could easily be conducted using easily accessible sites sufficiently upstream of the signals in the Potrail and/or Daer water. By gradually loading the riverbed with acid rocks the summer flow pH can be lowered to between ***6.0*** and ***6.5***. This might be enough to prevent all signals moulting successfully, newly hatched juveniles being particularly sensitive, the consequence being that crayfish invariably die in mid-moult. The pH for the rest of the year need not be that affected, as once the rainy seasons start and bicarbonates etc flood in, the acid buffering capacity increases, pH can now rise into alkalinity, and because there are no potent alkali buffers, should still be peaking around ***pH 9.0*** at Lamington.

If eradication is considered, then by depressing the pH only at the time of year when it is naturally at its lowest, then the impact upon the freshwater ecology may only be minimal. Plants such as crowfoots and *Fontinalis* spp may decline locally, depending upon direct availability of boulder clay, potamagetons may increase. Crustaceans, particularly Gammarids, and molluscs, Ancylids and Lymnaeids, may decline throughout. Caddis, beetles and flies would be mostly unaffected, mayfly species could well change locally, as could stoneflies, species of which may actually increase. The fish population need not be adversely affected, and trout in particular can cope with a wide range of pH, there may even be benefits, eg increased variety of feeding areas, not to mention one less competitor to have to deal with. Although species will be lost locally, in patches over a 15km stretch, including certain tributaries, other species will colonise from other acid burns and headwaters. Therefore, the impact upon the biodiversity and productivity of the system need not be detrimental, indeed if undertaken with due care and attention to habitat creation and/or enhancement, then, considering the Upper Clyde as a whole, biodiversity could be increased with the addition of acidophilic species colonising the newly created riffles.

The use of acidic riffles could be considered a low technological way of eradication: there would be high tech. ways of achieving the same effect without modifying the substrate. For example, a mobile, computer controlled feeder could be installed that constantly monitors the river pH and adjusts the dosage accordingly. Such a technical approach would be more appropriate to acid stress newly hatched juveniles by acidifying from upstream of the population to Bellfield in late June and early July in a manner similar to the above, with same considerations, etc, with the intention of lowering or even eliminating recruitment. This would however need to be repeated, over the entire length of the populated area, for at least five consecutive years.

6.2 Containment

Intensification of trapping, in conjunction with electro-fishing, at and downstream of Bellfield could be undertaken in an attempt to slow down, or temporarily contain, the downstream expansion of the population. Trapping effort could be particularly focussed around the downstream portion of the population so as to alleviate any density pressure and also to reduce the risk of crayfish being flushed downstream in spates etc. Consequently, it would be important to maintain some traps in areas where high densities of signals have been reported. Electro-fishing signals *en masse* for a number of consecutive evenings and/or nights could be attempted by attracting signals with large quantities of fish offal, or the like, such that any crayfish are attracted to a small area, where they can be electro-fished and netted. The rate of expansion would be reduced by starting to trap and electro-fish from below the known downstream limit of the population and continuing until no crayfish are returned. Containment by such would work for a time, although it is highly unlikely that the population would be contained indefinitely.

Another option for containment of the population could be to construct a pH barrier (or barriers) by modifying a short length of river such that it becomes hostile to crayfish by acidifying the main river for up to 5km downstream by lowering the summer flow pH only to between ***6.0*** and ***6.5***. This would need to be done over a stretch that is out of contact with any deposits of Boulder Clay, and some distance downstream of the existing population. The most suitable sites are considered to be downstream of Abington where the drift geology changes from being predominantly of boulder clay to sand and gravel deposits. The basic structure of such a barrier could be constructed out of gabions filled with an unknown quantity of acid rock. Such a rock may well be available locally, the Andesitic and Basaltic Lavas & Tuffs (one of the most acidic of rock types) outcrop in the Clyde valley around Symington, Coulter Motte, and Thankerton. The modifications need only be additional to existing riverine features, ie making a riffle faster, or a cascade longer, and would need to be done causing only minimal, short term, relatively local disturbance to the ecosystem.

A barrier could be constructed in such a way that creates as much turbulence as possible, whereby signals would be killed by passing through even during periods of summer flow as well as during spates etc. Such a design would need to create a maximum degree of turbulence by funnelling and/or riffling the channel. For example, this could be a river wide riffle of even depth, as long as is possible (eg 500m), as shallow as summer flow will allow, with no slack water over its entire length, and that gradually narrows to a fast flowing chute or cascade from which the water is smashed into a gabion wall. The total height of the barrier being considerably lower than the bank height such that, during spate conditions, water can flow over and around the gabions without bursting the banks, which may need to be reinforced. Consequently, suitable sites would ideally be naturally narrow with high banks and a considerable fall. There are a number of road and rail bridges from Abington downstream that are considered suitable sites, as well as other locations where the river has naturally formed such a channel. To create a summer flow pH profile that does not peak sharply and then gradually decline, it is considered optimal to install a large and turbulent pH barrier upstream of a number of acid rock riffles that would maintain a suppressed summer flow pH for the required distance.

All this could be done step by step so as to monitor the effect on the pH profile and its impact upon the ecology, which would be similar to that described in Section 6.1. If the location for such a undertaking is just upstream of a confluence with an acidic burn, then the flora and fauna from that burn would be adapted to, and would colonise, the modified stretch of the main river, thus enhancing biodiversity of the system as a whole.

Additionally, to prevent upstrem expansion of the population, a number of customised weirs could be constructed both upstream of the main population in the Potrail and Daer, as well as in burns near to the confluences with the main river.

6.3 Reduction

Continuation of, or an increase in, trapping effort and electro-fishing any burns containing crayfish, may help to limit the growth of the signal crayfish population in the Upper Clyde and its tributaries. Similarly, introduction of large numbers of hatchling eels (elvers), into the Potrail and Daer water, and investigating the breeding requirements of grayling, with particular consideration to the installation of artificial breeding redds, could increase predation of crayfish.

Predation pressure could also be increased by encouraging increased otter activity around the main population site by the construction of artificial holts and encouraging development of suitable bank-side habitats.

The ecological impact of such an undertaking, using all or one of the above, is difficult to assess apart from that those species predated upon by signals would do better, and overall biodiversity and productivity would almost certainly increase, at least marginally.

6.4 Further research

There are a number of issues that require further investigation, these are as follows and are listed in order of priority:

1. To instigate a thorough survey of invertebrates and macrophytes, identified to specific level, of the Upper Clyde catchment from within and outwith the signal population. This would enable an assessment of the impact that the signals are having and will have, as well as providing baseline data that would be essential if *any* form of control is undertaken.
2. To check for the presence of signal crayfish in neighbouring catchments, namely the Annan, Nith and Tweed, for which there is an anecdotal report of crayfish in its upper reaches.
3. To continue taking pH readings from the study area and other selected sites, specifically those tributaries downstream of the existing population where signal colonisation is a threat.
4. To investigate which types of rock type could be used for acidification trials.
5. To investigate the groundwater chemistry of the various types of boulder clay deposits that may be found throughout the Upper and Middle Clyde (British Geological Survey, Edinburgh, apparently has this data), in particular that of the Clyde downstream to Lanark, and the catchments of the Medwin, Duneaton, Midlock, and Elvan.
6. To continue working with Dr. Paul Stebbing on pheromones and recommendation that they investigate the possibility that male signals also produce a sex pheromone that may attract females in breeding condition. This would be useful in determining how pheromones could be employed as part of a containment strategy.

7 CONCLUSIONS

- **Non-intervention.** If signal crayfish were allowed to spread uncontrollably, they would significantly reduce the biomass and productivity of the rest of the system, especially in the initial stages of colonisation before any natural balancing factors come into effect. Some disruption of the food web would be permanent, even with healthy populations of signal predators present. The loss of some species may occur.
- **Reduction – Trapping.** Trapping over the past two years has removed considerable numbers of signal crayfish and has had some effect on the population in that the average size of trapped signals is noticeably reduced. To maintain this would require a considerable and prolonged trapping regime. However, traps need to be modified in such a way as to be able to catch much smaller individuals.
- **Reduction/containment – Electro-fishing.** Electro-fishing on its own is not considered practical in removing or containing the population of signal crayfish. However, if this technique were used in conjunction with intensive trapping at the downstream edge, it could probably slow down expansion in this direction, and it may even be possible to contain the population (see Recommendations), although this would require a continuous effort. Electro-fishing was proven to be most effective in removing crayfish from side streams.
- **Reduction – Biological control.** Biological control of the signal population is only useful in reducing the ecological impact that signals have upon the system, simply by keeping numbers suppressed. Once populations of candidate species have been established, the suppression of the signal population would continue indefinitely. If otters and grayling, eels and perch are encouraged, signal crayfish numbers could decline significantly.
- **Containment – Pheromone fencing.** If the repellent pheromone can be proven to be effective in field trials then it may be possible to use it in containing the upstream limits of the population, or even to push this limit back downstream. If the attractant pheromone can also be proven to be effective in field trials, then this may be useful in improving trapping efficiency, although is not considered practical for either removing or containing the population, unless it can be of sufficient strength or quantity that removes all males from the population.
- **Containment – Weirs.** Customised weirs of the specific design described above in strategic locations.
- **Containment – pH control.** It is considered possible to both remove and/or contain the signal population, for an indefinite period only, by critically lowering the pH to below their threshold. If this were done in combination with other options then the chances of eradication and/or containment will be enhanced.

Therefore, an integrated approach incorporating many of the options given above, and including certain field trials, would be the optimal approach. The following recommendations are therefore made:

Most urgent and important, a change in trapping strategy should be implemented immediately, supplemented by some targeted electro-fishing, as follows:

- Almost all of the trapping effort between the months of October to July, inclusive, to be concentrated from Crawford upstream to Telford Bridge, in an attempt to slow down the rate of expansion, thereby giving more time to consider and maybe implement other strategies.

- A small number of traps could be permanently located at the road bridge upstream of Abington as a check on any further expansion from around Bellfield.
- Crayfish could also be removed from around Bellfield using baited sacks to concentrate signals in a small area, which could then be electro-fished and netted. This would be most effective if conducted throughout a night, electro-fishing under infra-red, and in the summer at low flow.
- In August and September all the traps upstream of Bellfield to be moved upstream throughout the population, in rolling groups of 10–20, concentrating only upon the areas identified as capable of supporting high densities of signals. The intention being to remove as many signal crayfish as is possible, and therefore the clusters of traps need only be moved on when returns fall below something like 30% of the number initially trapped.

Acid stressing trial. The information from the trial described below could be used to assess the viability of using acid stressing to both eradicate and/or contain the population.

- To investigate acid stressing signals, either for eradication and/or containment, by installing a trial riffle upstream of the population, either in the main river downstream of the meetings, or in the Potrail and Daer upstream of the meetings.
- To monitor the effect upon the pH at the first pool downstream containing signals, with a small number of traps permanently located as a check upon both individual crayfish and the upstream limit of the population.
- A full impact assessment would also need to be conducted with any invertebrate samples being identified to the level of species. The ecological impact would be minimised by starting to install the riffle(s) just after the first spates of autumn, when alkalinity levels begin to rise and any rise in acidity is somewhat buffered. Also, by monitoring the pH during wintertime summer flow rates, an estimation of the summertime pH suppression could be made, gradually adding to the riffle until the summer flow pH falls below pH 6.5. The intention would be to suppress pH only when it is at its natural lowest, ie during the brief summer with the critical period for signals being late summer.

If the acid stressing trial proves to be effective in either killing signals or displacing them downstream, and eradication is considered feasible, another acid riffle should be installed at an appropriate point downstream so as to continue controlling the pH in the way described above. However, by moving downstream in such a manner, throughout the population, a point will be reached where there is a high risk of displacing signals into waters previously uncolonised. For this reason it would be advisable to install an acid riffle downstream of the population, sufficient to contain it, and to also move upstream with further acid riffles. Acid riffles would also need to be installed in every appropriate tributary.

If, however, such an attempt at eradication is deemed or proven in any way too costly, then containment by various combinations of the following barriers could be attempted.

- To prevent the downstream spread
  - An acid/turbulence barrier could be constructed in a manner described in Section 6.2 and located at least 5km downstream of the known population, and including a series of acid riffles such that only the summer flow pH is suppressed to between ***6.0*** and ***6.5*** for at least 5km downstream of the barrier.

  - An intensive group of traps, standard and bucket, can be located in the deep pools downstream of the barrier, as a check of its efficacy in killing crayfish, by way of both pH stress and physical damage/shock. Intensive trapping could also be conducted upstream of such a barrier, in areas well populated by signals, so as to create a buffer zone of low density.

- To prevent upstream spread

  - For areas further upstream of here the signal numbers could be kept to a minimum by encouraging signal predators, namely grayling and otters, and maybe eels, perch, and black bass, or by continual intensive trapping.

  - Customised weirs, in conjunction with acid rock riffles up- and downstream, would be sufficient to limit the spread upstream both in the main river and into vulnerable tributaries.

If containment is not considered feasible, then using signal predators as a way of reducing crayfish numbers and minimising the impact of the population is advised. This strategy would be compatible with a trapping/electro-fishing regime focussing upon restricting the downstream numbers and expansion, and with biological control keeping numbers down at the upstream part of the population. Such reduction could be undertaken even if eradication and/or containment is planned, as way of suppressing the population.

- **Otters** These are the only indigenous, mammalian predators capable of making a significant contribution to the control of signal crayfish. However, because otters are also predators of all the candidate fish species, it is difficult to assess the full effects of the predator/prey dynamics (Figure 15). Otters numbers are increasing in the Clyde (R. Green, *pers. comm.*), they are a protected species and they are included within local and national Biodiversity Action Plans. There are a number of specific measures that could be taken to encourage activity and breeding potential, such as fencing-off banking and the provision of artificial holts.

- **Fish species**

  - Grayling are already present throughout the Upper Clyde, although in severely depleted numbers, particularly in the study area. There are signs that they are making a slow comeback and this should be assisted by the creation and/or extension of breeding redds.

  - Eels are found in the Clyde downstream of Lanark Falls, a pre-glacial period barrier. The introduction of Elvers should be seriously considered. The Falls are an unknown factor with regard to their migration.

  - Perch are present in unknown numbers and there may be scope for increasing their numbers.

Figure 1 Clyde and neighbouring catchments

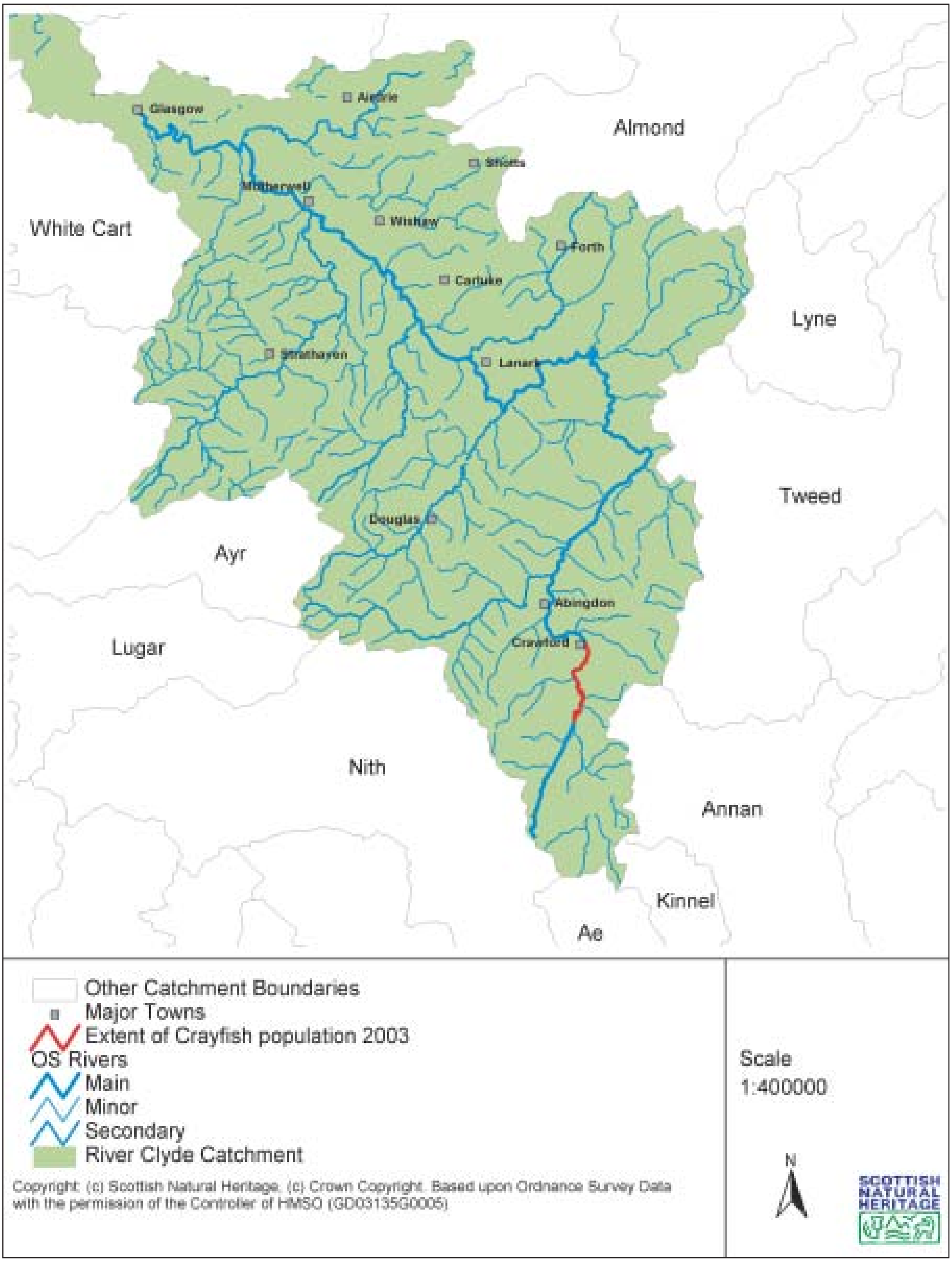


Figure 2 River characteristics

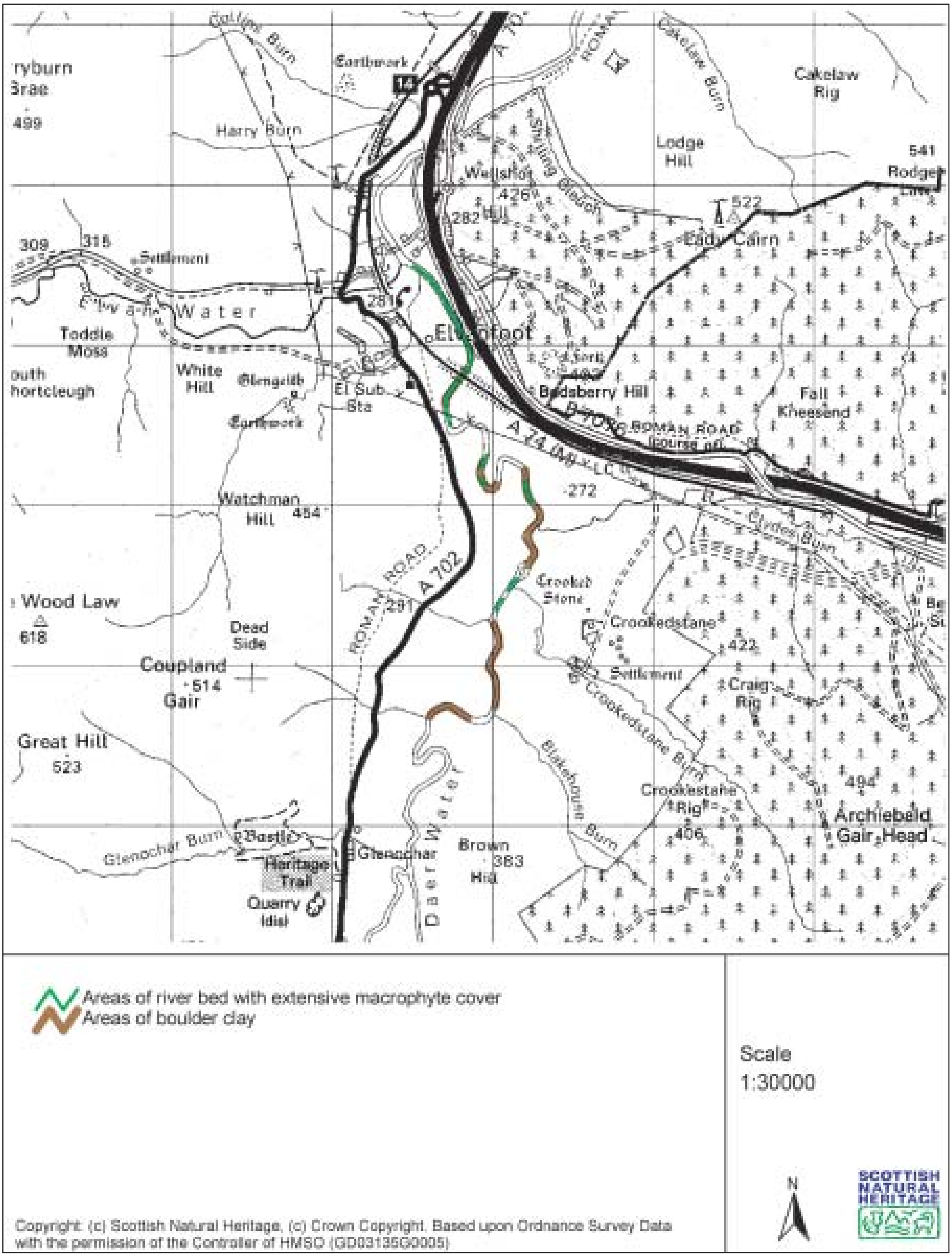
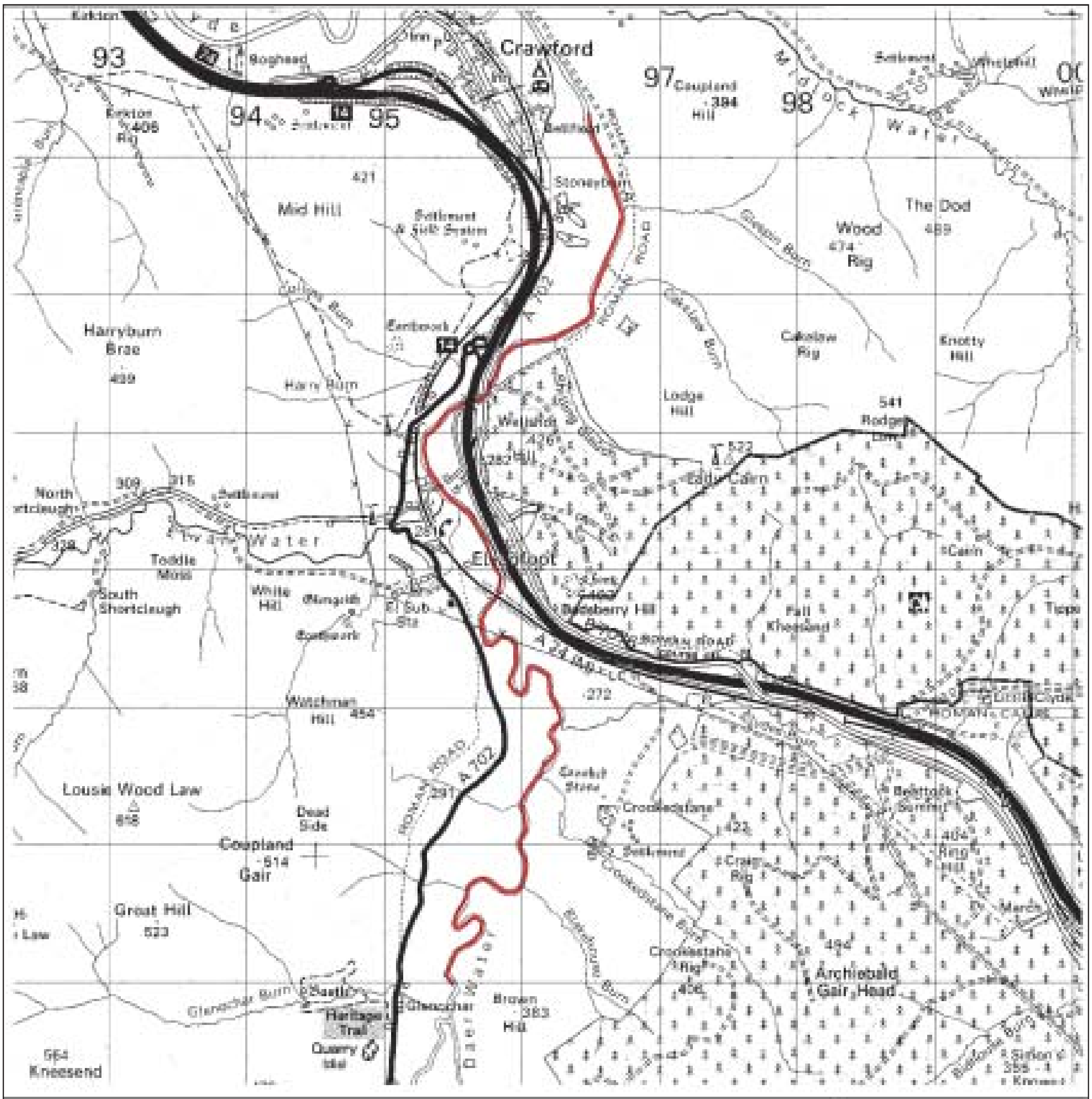


Figure 3 Extent of crayfish population 2002



Extent of Crayfish Population

Scale
1:40000

N

SCOTTISH NATURAL HERITAGE

Figure 4 pH sample points

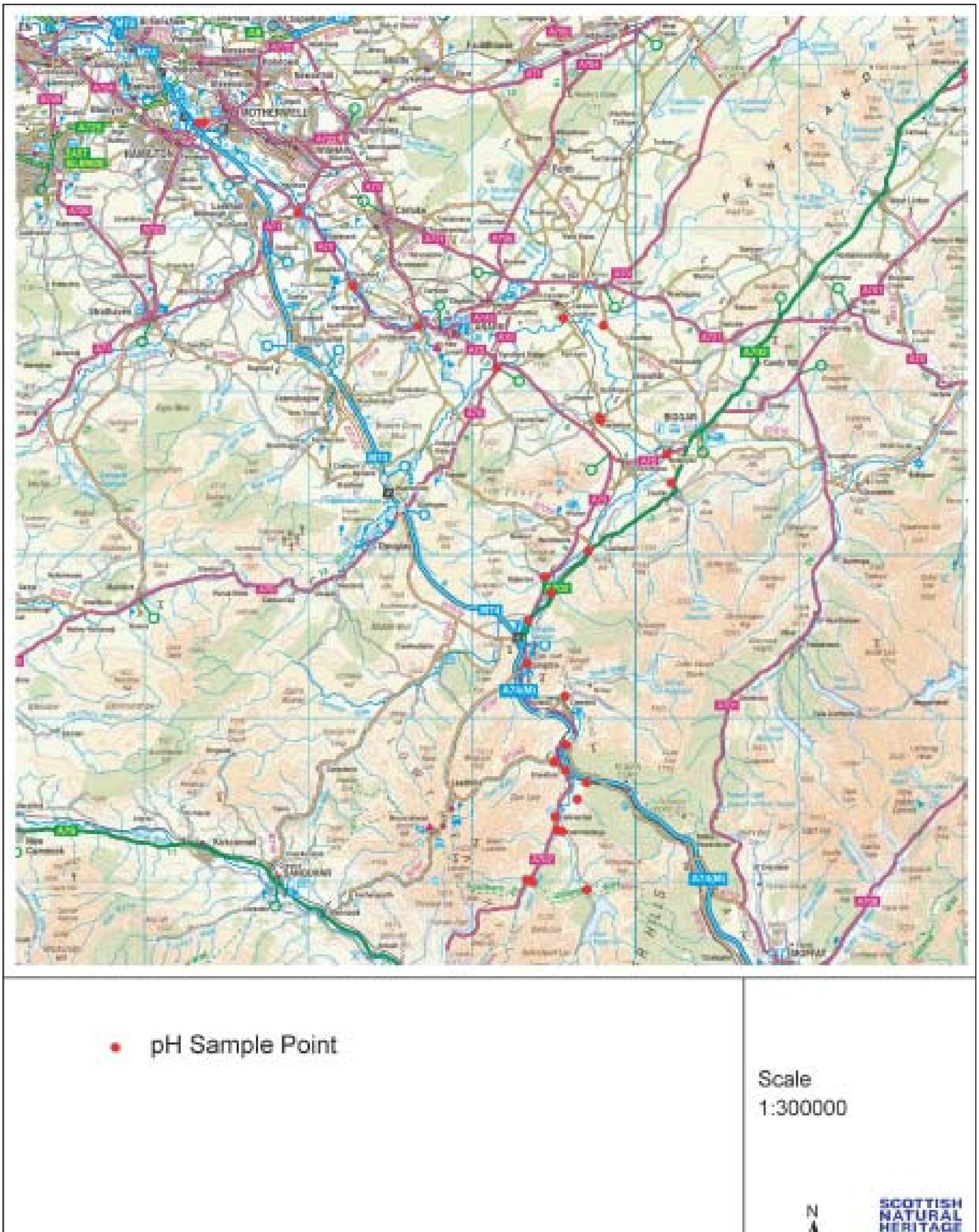


Figure 5 Trap and electro-fishing locations

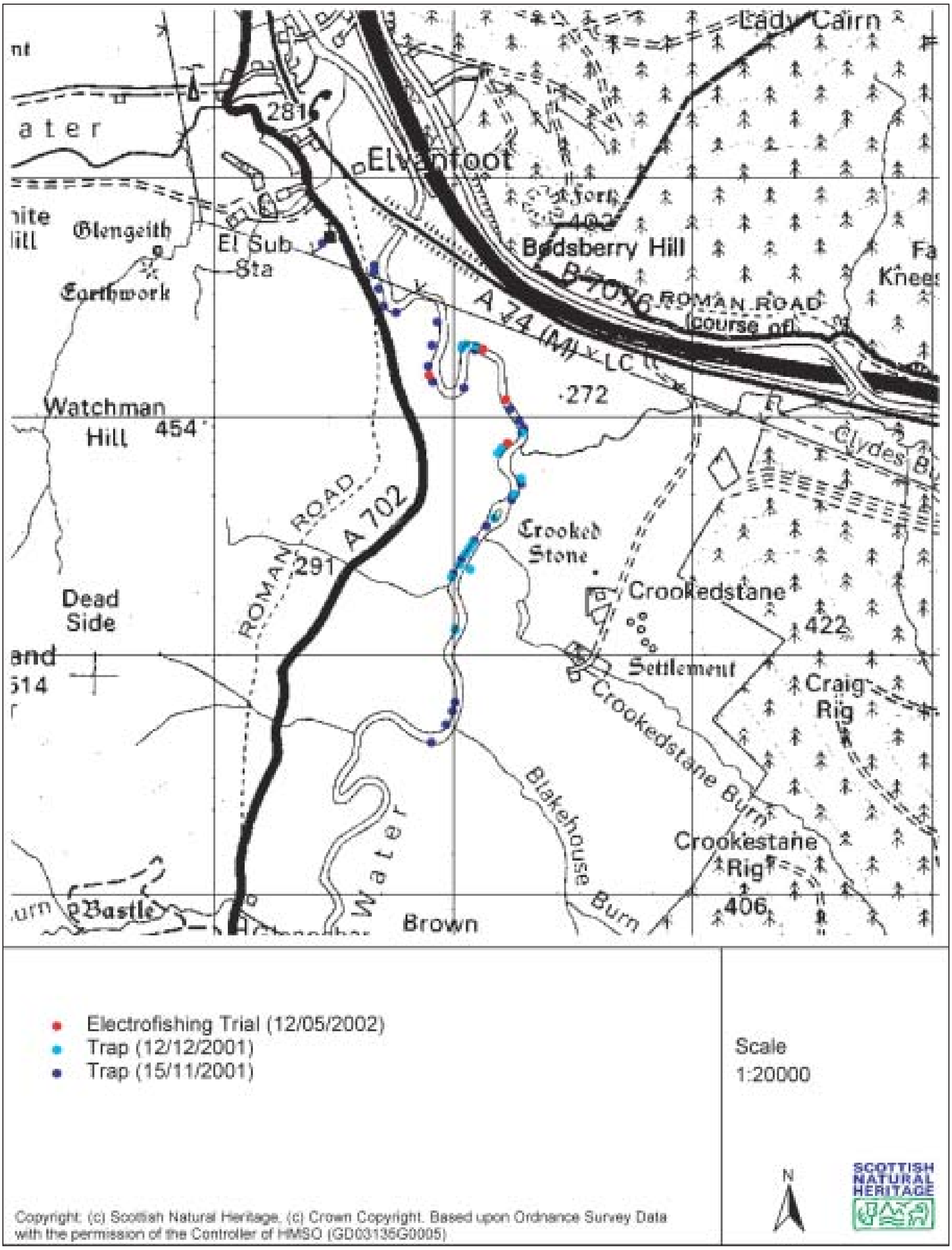


Figure 6 Areas of high crayfish density

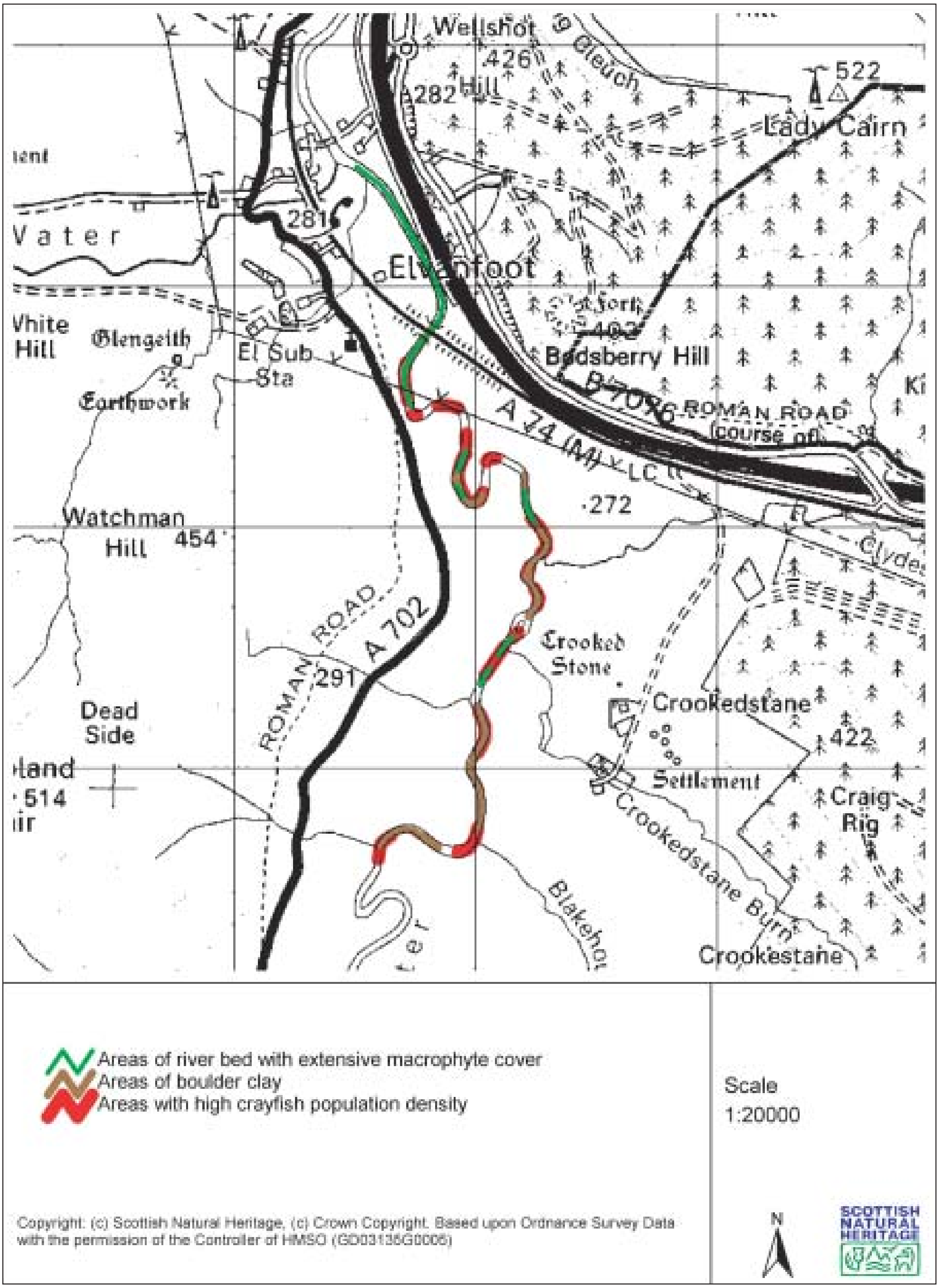


Figure 7 pH readings from Carstairs junction (7) to the Daer (17) for 7 runs from April to November, 2002

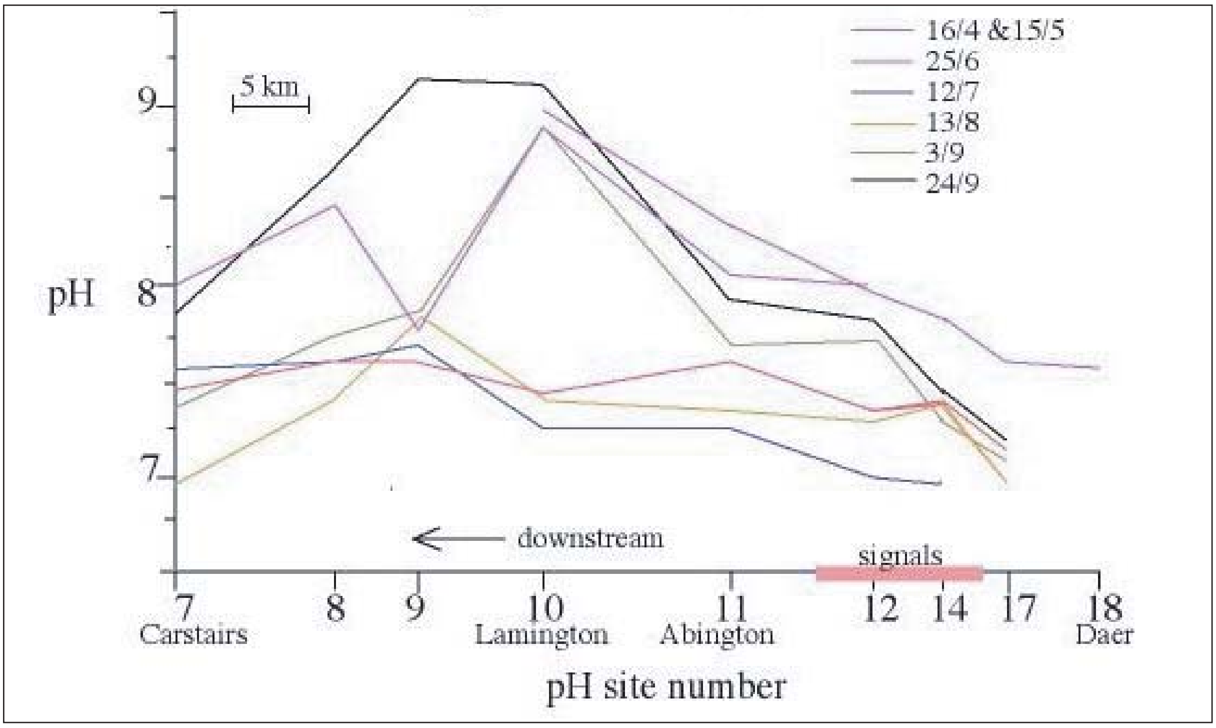


Figure 8 pH readings from Motherwell (1 & 2) to the Daer reservoir (18), taken in April and May, including tributaries, and ranges where multiple readings were taken

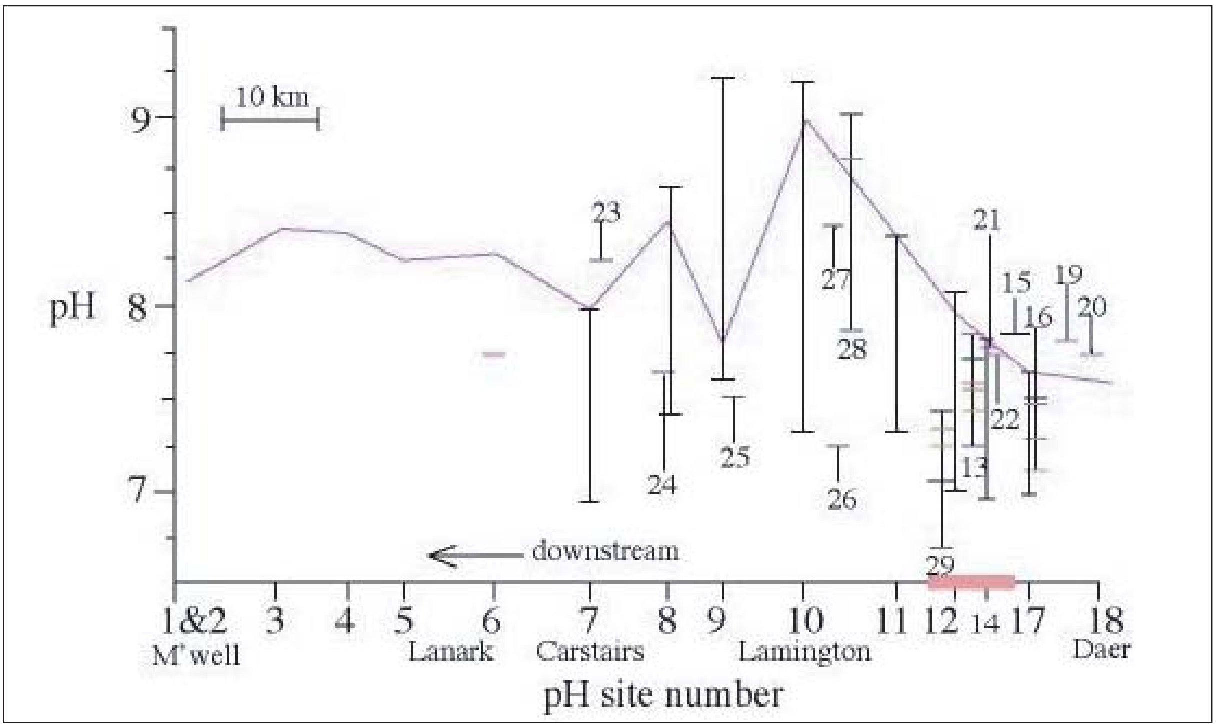


Figure 9 Crayfish population expansion

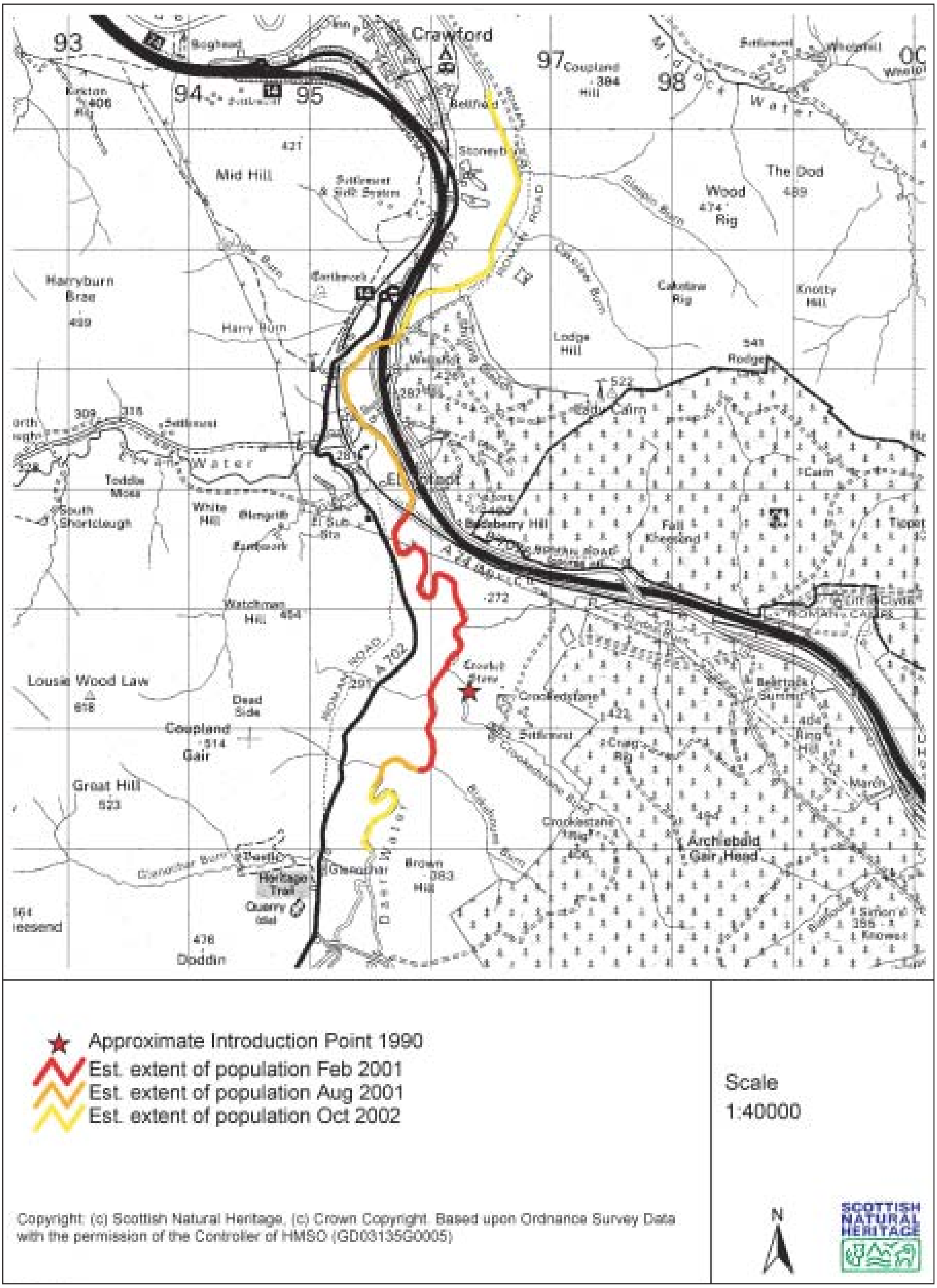


Figure 10 Monthly numbers of male and female signal crayfish taken using c. 90–140 traps with, on the right hand scale, the male:female ratios

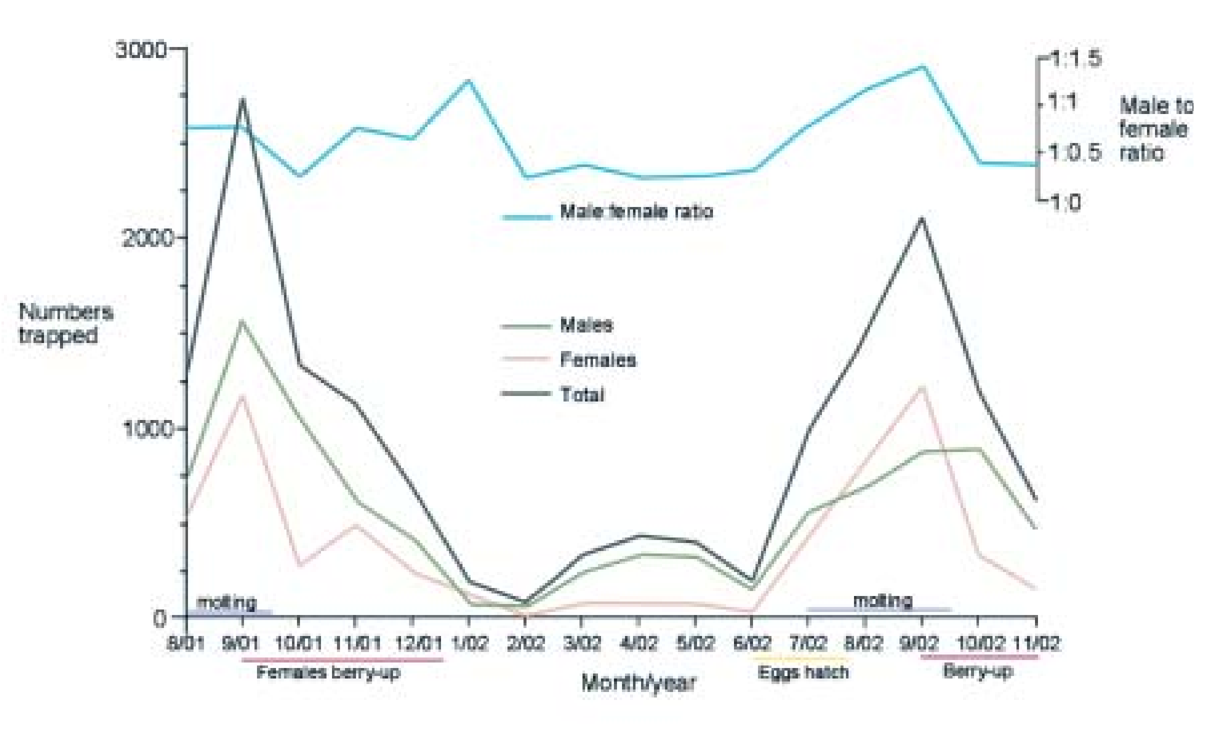


Figure 11 pH sample points with GPS labelled

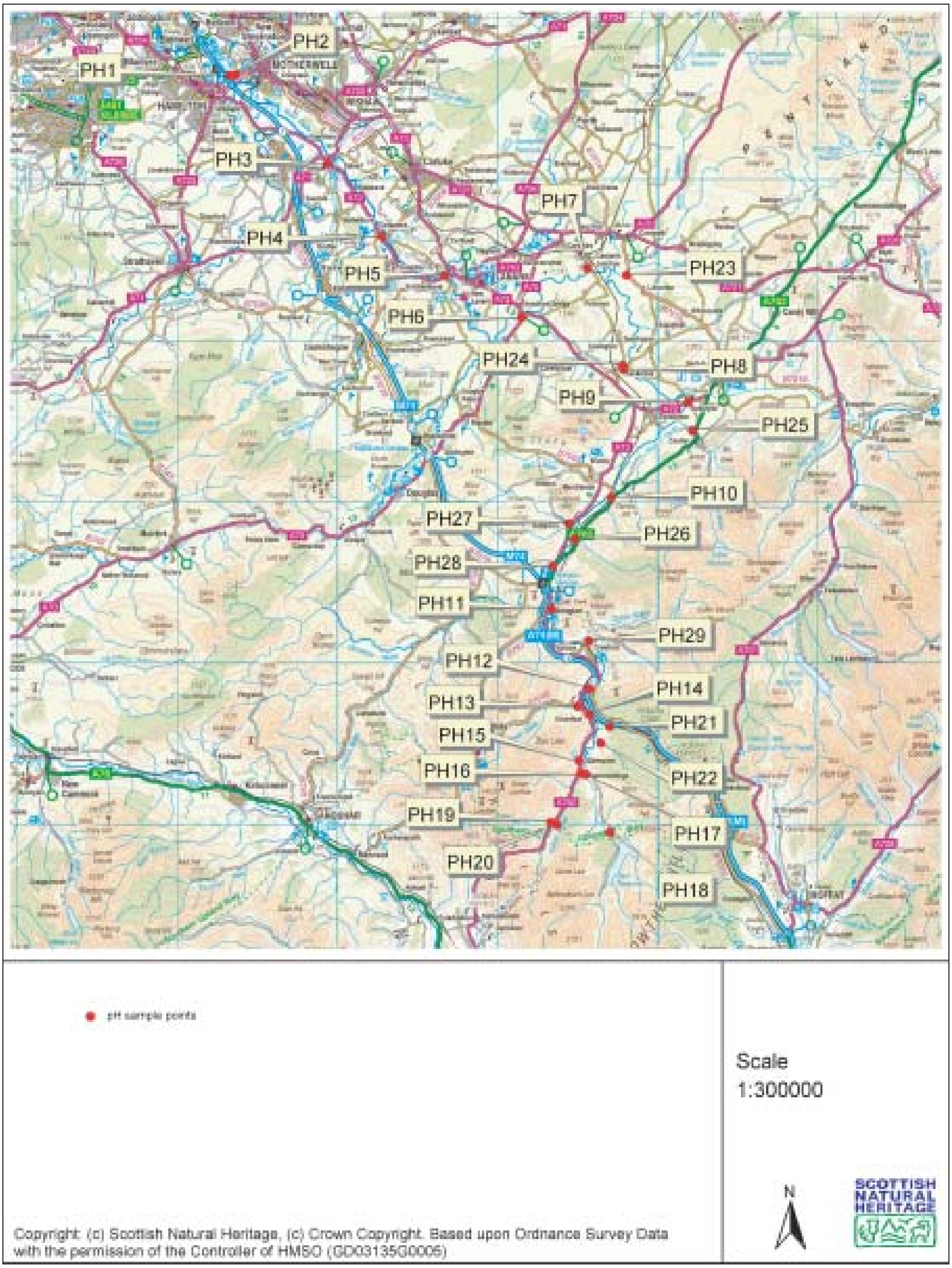


Figure 12 Trap and electro-fishing locations with GPS labelled

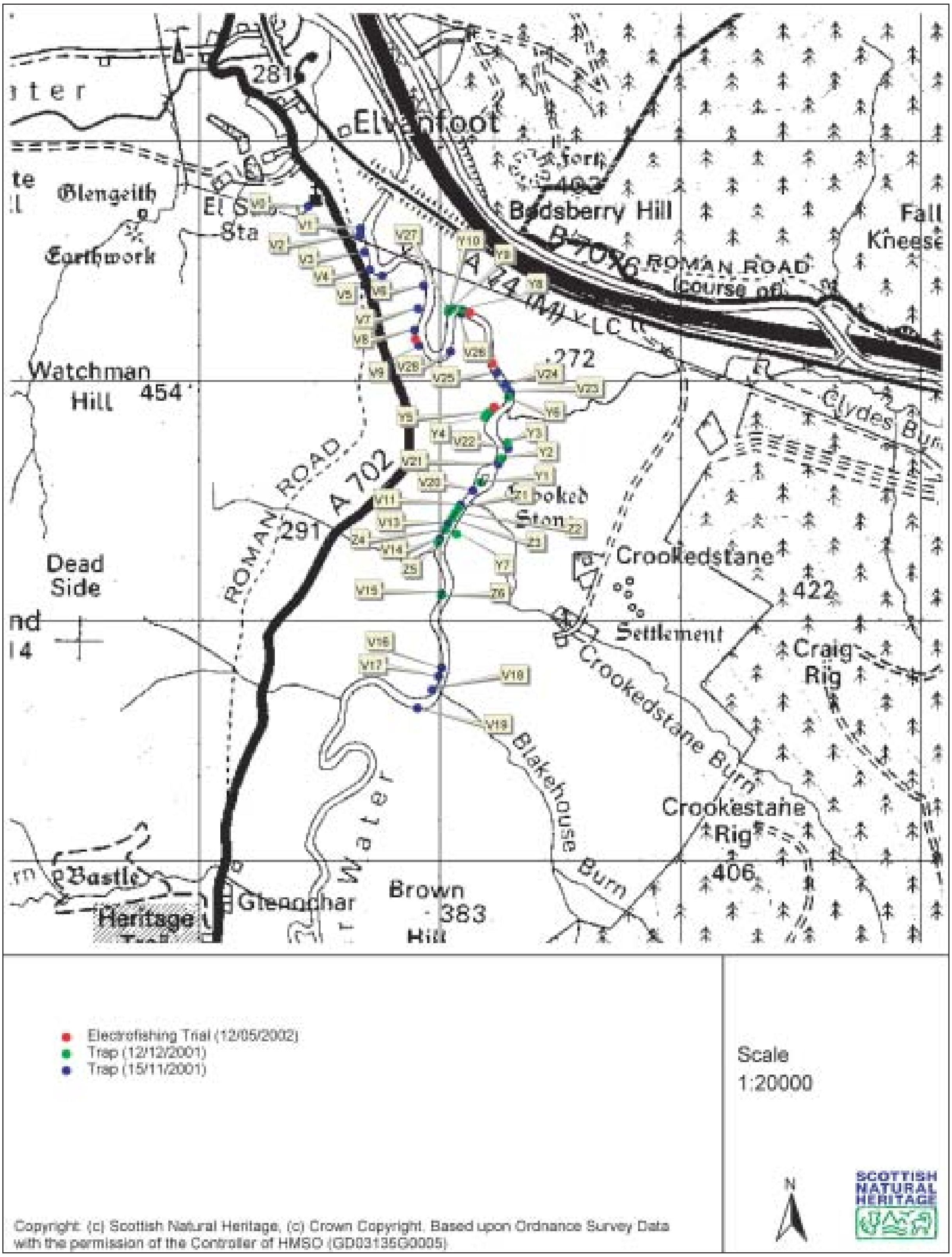


Figure 13 Areas of high crayfish density with GPS labelled

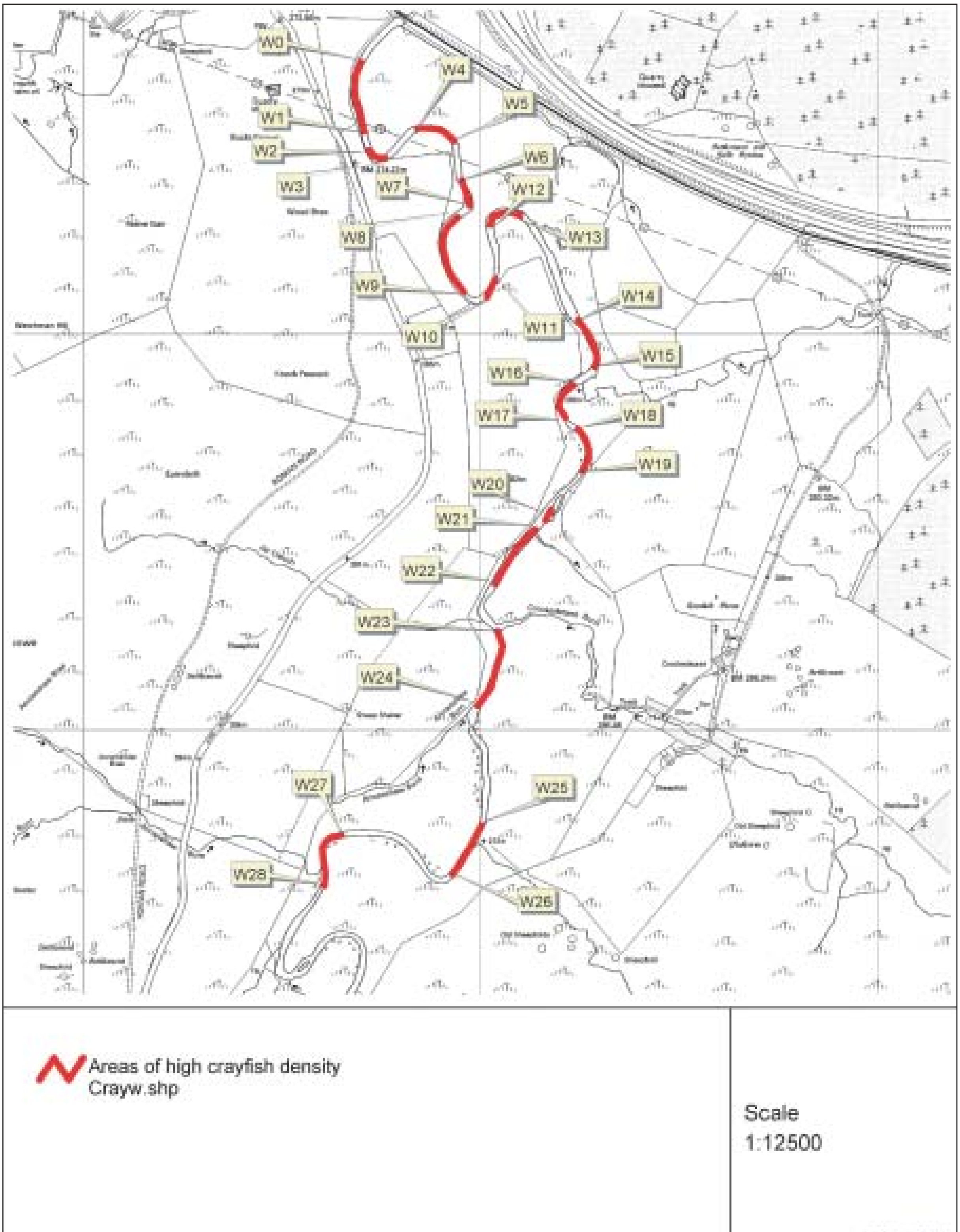


Figure 14a River characteristic sample points (0–50) with GPS labelled

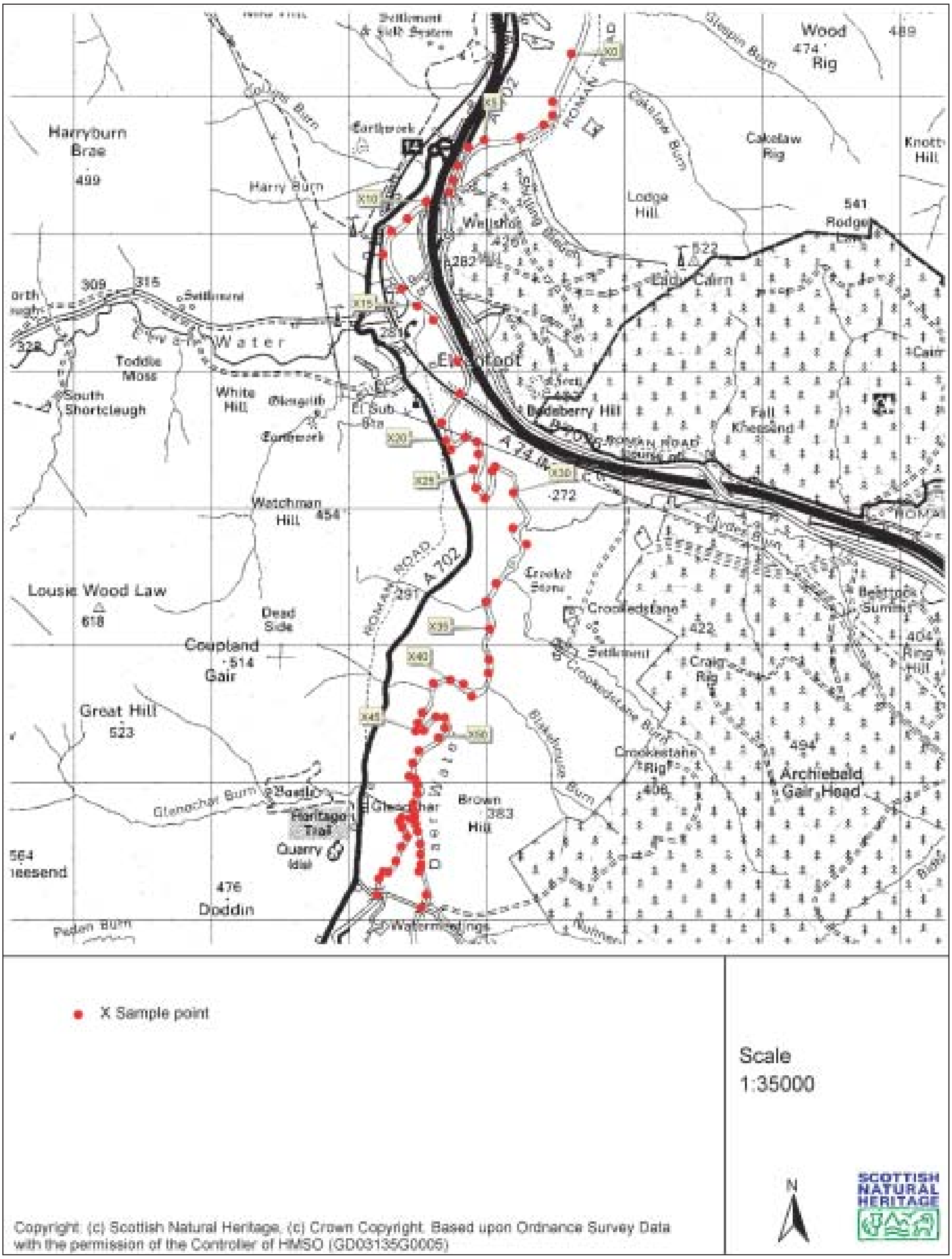


Figure 14b River characteristic sample points (50–78) with GPS labelled

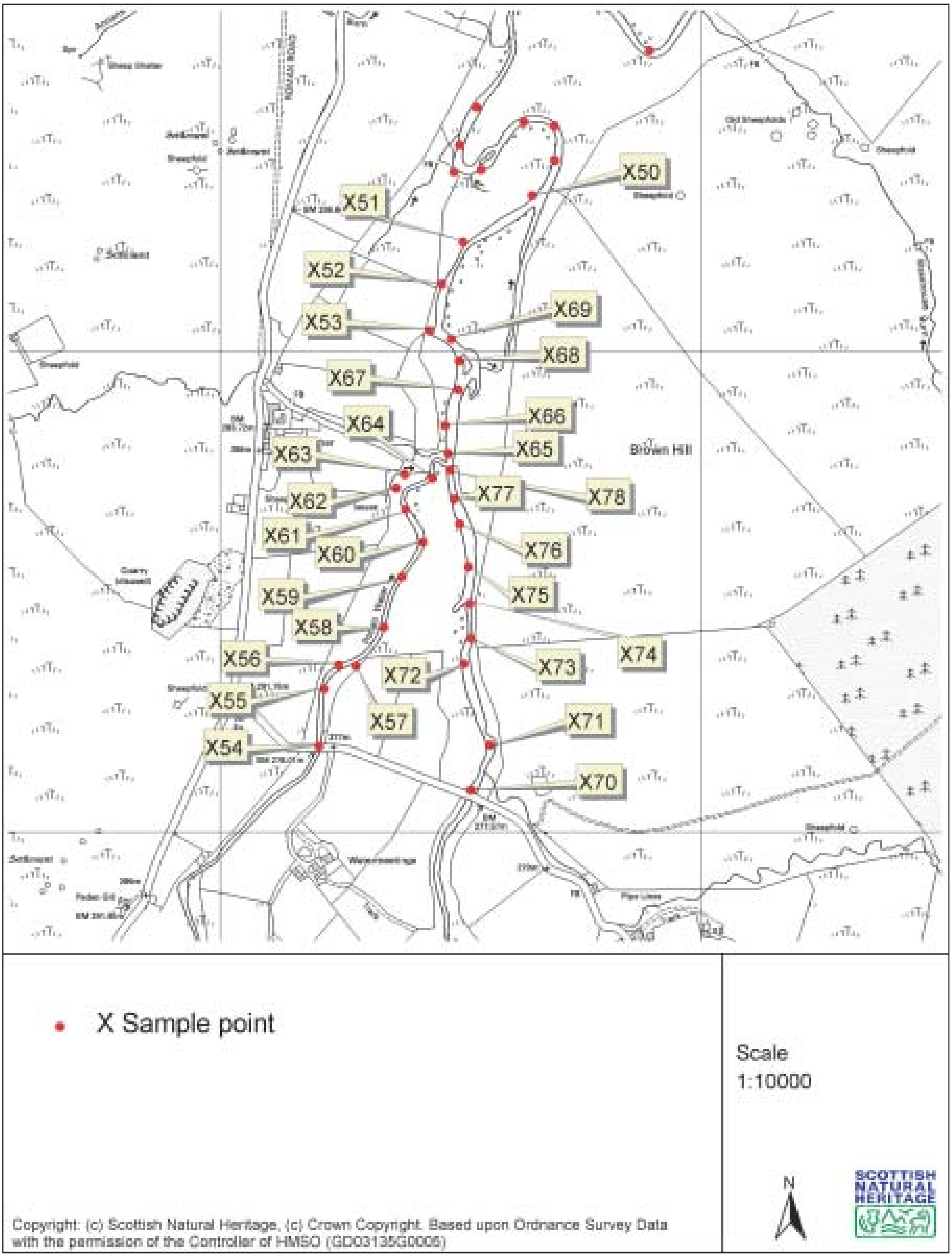
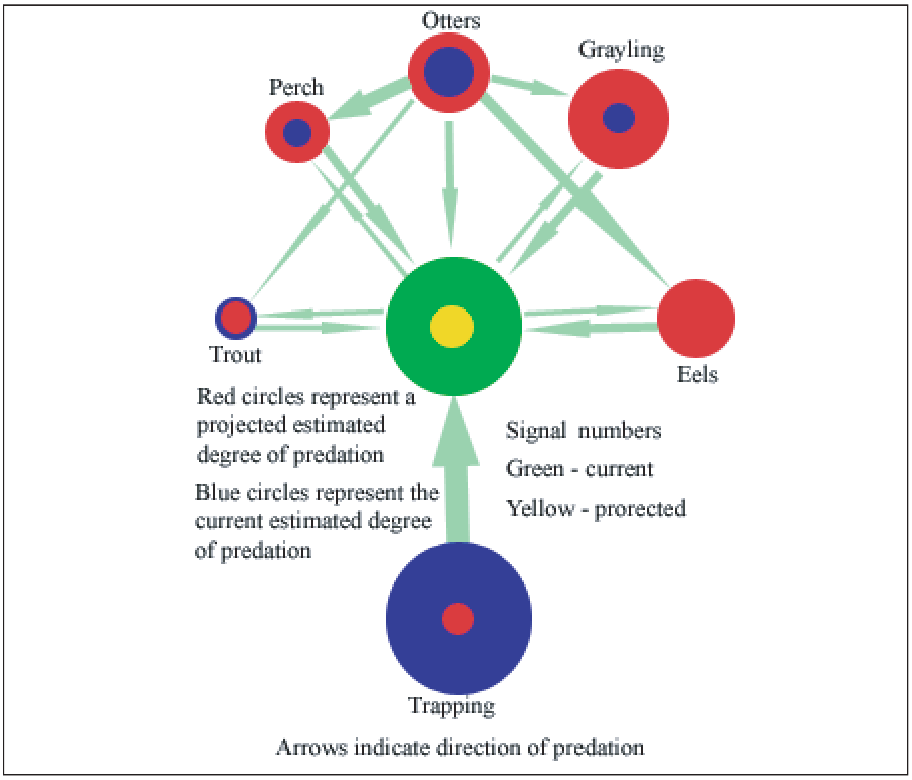


Figure 15 Schematic of current and projected signal predator/prey relationships



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APPENDIX 1 – Global positioning system data

X series, **X0–X78** (79 data points, see Figures 14a & 14b), 16/12/01 & 27/02/02.
The course and character of the Upper Clyde was mapped from 2km downstream of Telford Bridge to 1km upstream of the confluence between the Daer and Potrail, in total about 14km, and included information on the locations of large riffles and deep pools, extensive cover of submerged plants (good juvenile and sub-adult cover), confluences, and other information considered relevant, eg high boulder clay banking (good for burrow systems). For notes see Appendix 1.

Z and **Y** series, **Z1–Z6** & **Y1–Y10** (16 data points, see Figure 12), 12/12/01.
The locations were plotted of a sub-group of 34 traps (9 in the Z series and 25 in the Y) that have been working their way up river. The Z series were downstream of a large riffle which separated them from the Y series. Some data points refer to more than one trap, for that and other notes see Appendix 1.

V series, **V0–V28** (29 data points, see Figure 12), 15/11/02.
The locations of 69 traps that had reached the top end of the population were plotted and details of records of any crayfish taken. For notes see Appendix 1.

EF series (5 data points, see Figure 12), 12/5/02.
The five electro-fishing runs were mapped. For notes see Appendix 1.

W series, **W0–W28** (29 data points, see Figure 13), 16/12/01.
Iain Miller provided quite a detailed, accurate map of where he reckons there are or have been high densities of signals, 15 such areas in total, varying in size from 30m of one bank only to c.200m of both banks, which, after a few minor adjustments, were mapped (also using X series data points) and any relevant information noted. For notes see Appendix 1.

PHR series (6 data points), 21/8/02.
The locations of 6 traps containing were plotted and details of trapped crayfish taken.

BB series (3 data points), 21/8/02.
The locations of 3 baited buckets was plotted and details of any crayfish taken. For notes see Appendix 1.

PH series, **PH1–PH29** (30 data points, see Figure 11), 16/4, 15/5, 25/6, & 12/7, 13/8, 3/9, 24/9, all 2002.
pH readings were taken from the Clyde between Strathclyde Country Park (**PH1**) and its headwaters, ie the Daer Water (**PH18**) and Potrail Burn (**PH20**), including many of its tributaries, namely (starting downstream) the Medwin (**PH23**), Thankerton Burn (**PH24**), Coulter Burn (**PH25**), Wandel Burn (**PH26**), Roberton Burn (**PH27**), Duneaton Burn (**PH28**), Midlock Water (**PH29**), Elvan Water (**PH13**), Little Clyde (**PH21**), Crooked Stane Burn (**PH22**), Glenochar Burn (**PH15**), and the Peden Burn (**PH19**). For notes see Appendix 2.

Z and **Y** series, 12/12/01, summer flow.
One trap per data point unless otherwise stated.

Z1–Z5 average depth 0.5m and gravel banks, **Z5–Z6** fast riffle, **Z6** and upstream boulder clay banking.
Z1 – 1 male; **Z2** – 0; **Z3** (3 traps) – 1 male; **Z4** – 0; **Z5** – 0; **Z6** (2 traps) – 0.

Z1–Y2 riffle, **Y3** deep with boulder clay banking which continues to **Y4**, riffle downstream of **Y5**, **Y6** deep with boulder clay banking, **Y7–Y8** riffle.
Y1 – 0; **Y2** – 1 male; **Y3** (3 traps) – 0; **Y4** – 1 male; **Y5** (2 traps) – 0; **Y6** (7 traps) – 2 berried females, one of which appears to still be laying; **Y7** (3 traps) – 2 males; **Y8** (2 traps) – 2 males, 1 female; **Y9** (3 traps) – 1 male; **Y10** (2 traps) – 1 berried female.

V series, 15/11/02, water level dropping from spate two days previous.
V0–V15 left hand bank, **V16–V28** right hand bank; **V9** very deep pool.

V0 (2 traps) – 2 males, 1 berried female; **V1** (3 traps) – 3 males; **V2** – 2 males; **V3** – 1 male; **V4** (2 traps) – 1 male; **V5** (2 traps) – 0; **V6** – 0; **V7** (2 traps) – 1 male; **V8** – 0; **V9** (4 traps) – 10 males, 2 females; **V10** (3 traps) – 3 males, 1 berried female; **V11** (2 traps) – 3 females; **V12** (3 traps) – 4 males; **V13** (6 traps) – 6 males; **V14** (2 traps) – 1 male; **V15** (3 traps) – 6 males, 3 females, 2 berried; **V16** (2 traps) – 3 males, 2 females, 1 berried; **V17** (4 traps) – 2 males, 2 females; **V18** – 1 male; **V19** – 1 male; **V20** (2 traps) – 1 female; **V21** (2 traps) – 3 males, 3 females, 1 with unlaid eggs, 1 berried; **V22** (3 traps) – 5 males, 1 berried female; **V23** (4 traps) – 3 males; **V24** (3 traps) – 4 males, 1 female; **V25** (2 traps) – 1 male; **V26** (4 traps) – 6 males, 4 females, 2 berried; **V27** (3 traps) – 2 males, 3 females, 1 berried; **V28** – 2 males.

Total 81 males and 21 females, 11 of which, or 52%, were berried.
Male:female ratio of 1:0.26.

X and **W** series, 16/12/01 and 27/2/02.
X0–X8 shallow riffle, low bank, plenty of juvenile cover, getting steadily deeper downstream from **X8–X0**. Gabions on left hand bank (lhb) between **X6** and **X7**. Deep pool on right hand bank (rhb) between **X8** and **X9**, riffle on lhb. Riffle and pool by **X10**, riffle to **X11**, and then to **X12** and **X13**. **X15** by slow riffle and shallow pool, medium to shallow, ideal for juveniles and sub-adults, getting slowly deeper to **X16** with extensive beds of crowfoot, starwort, *Potamageton sp*, and freshwater moss, ideal for juveniles etc. Between **X16** and **X17**, medium to shallow riffle of uniform depth, extensive beds of crowfoot etc, ideal for juveniles etc. Between **X17** and **X18**, shallow riffle and pool with deep pool on lhb, some submerged macrophytes. Between **X18** and **W0** and **X19**, deep riffle and deep pool with rising boulder clay banks, deep pool at **W1**, and riffle at **X20** with extensive beds of crowfoot etc. **W2–W3**, including **X21**, deep pool on lhb with high boulder clay banking. Deep pool on rhb at **X22**. Between **W4** and **W5** rhb re-enforced with fast riffle and deep pool on rhb at **X23**. Shallow riffle between **X23** and **X24** getting deeper through **W6–W7** with fast shallow riffle to **W8**. High boulder clay banking at **X25** with riffle and pool stronger on lhb, upstream to **X26** pools deepen with occasional riffles. Extensive beds of crowfoot etc make this area good for all age classes of signals. To **W9** river is slow and deep with high boulder clay banking, although at **X27** is fast and deep on lhb of bend. Pool between **W10** and **W11** with long shallow riffle to **X28**. **W12–W13** rhb is more populated and is fast and eroding, with shingle banks on lhb between **X28** and **X29**. From here to **X30** lhb shallow, rhb high, and to **W14** is uniformly wide and shallow with extensive beds of crowfoot etc. **W14–W15** more populated on high rhb than shallow lhb with shingle beds. Fast riffle between **W15** and **W16**. Lhb more populated on higher banking between **W16** and **W17** with fast riffle to **W18**.

There are extensive beds of submerged plants, usually where the depth is even and flow moderate, between GPS data points **X15** and **X20**, **X25** and **X26**, **X30–W14**, **W21**, and **W22**, above which macrophyte cover is moderate at best. Deep boulder clay banking starts to rise between **X18** and **X19**, again at **X25** and **X27**, around **X30**, between **W14** and **W19**, **W23** and **25**, and **X39** and **X41** (see Figures 14a and 14b for GPS **X** series, and Figure 13 for GPS **W** series).

pH sample sites and readings

Date and pH readings							
	16/4	15/5	25/6	12/7	13/8	3/9	24/9
Sample site							
PH1	8.09						
PH2	8.13						
PH3	8.40						
PH4	8.35						
PH5	8.21						
PH6	8.25		7.72				
PH7	7.99		7.49	7.55	6.94	7.35	7.88
PH8	8.45		7.58	7.58	7.43	7.78	8.64
PH9	7.79		7.58	7.68	7.87	7.88	9.23
PH10	8.98	8.86	7.45	7.28	7.41	8.83	9.19
PH11	8.35	8.08	7.60	7.29	7.36	7.74	7.95
PH12	7.95	8.04	7.37	7.01	7.30	7.68	7.83
PH13		7.81	7.57	7.24	7.41	7.51	7.70
PH14		7.83	7.40	6.97	7.21	7.29	7.48
PH15		7.81					
PH16		7.86	7.44		7.13	7.29	7.42
PH17		7.63	7.11		6.98	7.10	7.22
PH18		7.58					
PH19		7.81					
PH20		7.73					
PH21		7.75					
PH22		7.67					
PH23				8.20			
PH24				7.63			
PH25				7.47			
PH26				7.26			
PH27				8.40			
PH28				7.83		8.78	9.03
PH29				6.68	7.25	7.38	7.42

GPS data points with OS grid references

X0	16/12/01	661 930	X40	09/01/02	573 474	W0	09/01/02	569 668
X1	16/12/01	647 895	X41	09/01/02	561 472	W1	09/01/02	569 650
X2	16/12/01	647 885	X42			W2	09/01/02	571 645
X3	16/12/01	641 878	X43	09/01/02	553 450	W3	09/01/02	576 643
X4	16/12/01	624 869	X44	09/01/02	549 443	W4	09/01/02	583651
X5	16/12/01	598 867	X45	27/02/02	548 437	W5	09/01/02	592 648
X6	16/12/01	586 862	X46	27/02/02	554 437	W6	09/01/02	594 638
X7	16/12/01	578 849	X47	27/02/02	563 447	W7	09/01/02	596 632
X8	16/12/01	575 838	X48	27/02/02	569 447	W8	09/01/02	592 630
X9	16/12/01	572 829	X49	27/02/02	569 439	W9	09/01/02	595 610
X10	16/12/01	556 823	X50	27/02/02	564 432	W10	09/01/02	602 608
X11	16/12/01	542 810	X51	27/02/02	550 422	W11	09/01/02	604 613
X12	16/12/01	530 801	X52	27/02/02	564 414	W12	09/01/02	603 627
X13	16/12/01	524 784	X53	27/02/02	543 404	W13	09/01/02	609 629
X14	16/12/01	538 759	X54	27/02/02	520 317	W14	09/01/02	624 603
X15	16/12/01	549 747	X55	27/02/02	521 329	W15	09/01/02	628 591
X16	16/12/01	561 736	X56	27/02/02	524 334	W16	09/01/02	622 587
X17	16/12/01	578 706	X57	27/02/02	528 334	W17	09/01/02	619 578
X18	16/12/01	580 683	X58	27/02/02	534 342	W18	09/01/02	625 576
X19	16/12/01	567 662	X59	27/02/02	537 353	W19	09/01/02	624 565
X20	16/12/01	570 648	X60	27/02/02	542 360	W20	09/01/02	615 555
X21	16/12/01	573 642	X61	27/02/02	538 367	W21	09/01/02	613 551
X22	16/12/01	584 651	X62	27/02/02	536 371	W22	09/01/02	602 537
X23	16/12/01	592 647	X63	27/02/02	538 374	W23	09/01/02	605 524
X24	16/12/01	593 639	X64	27/02/02	544 373	W24	09/01/02	598 507
X25	16/12/01	590 627	X65	27/02/02	547 378	W25	09/01/02	600 476
X26	16/12/01	591 614	X66	27/02/02	546 384	W26	09/01/02	593 464
X27	16/12/01	598 606	X67	27/02/02	549 392	W27	09/01/02	565 473
X28	16/12/01	603 626	X68	27/02/02	549 398	W28	09/01/02	561 460
X29	09/01/02	606 629	X69	27/02/02	548 402			
X30	09/01/02	619 610	X70	27/02/02	552 308			
X31	09/01/02	618 585	X71	27/02/02	556 318			
X32	09/01/02	628 573	X72	27/02/02	550 334			
X33	09/01/02	606 544	X73	27/02/02	552 340			
X34	09/01/02	599 531	X74	27/02/02	551 347			
X35	09/01/02	601 511	X75	27/02/02	551 355			
X36	09/01/02	601 489	X76	27/02/02	549 364			
X37	09/01/02	601 479	X77	27/02/02	548 369			
X38	09/01/02	589 462	X78	27/02/02	547 375			
X39	09/01/02	583 471						

GPS data points with OS grid references *(continued)*

V0	16/11/02	545 672	Y1	12/12/01	617 557	PH1	17/04/02	NS75	324 646
V1	16/11/02	567 663	Y2	12/12/01	625 567	PH2	17/04/02	NS75	361 648
V2	16/11/02	566 660	Y3	12/12/01	628 573	PH3	17/04/02	NS75	937 094
V3	16/11/02	568 653	Y4	12/12/01	618 584	PH4	17/04/02	NS84	278 644
V4	16/11/02	571 646	Y5	12/12/01	620 586	PH5	17/04/02	NS84	672 401
V5	16/11/02	576 643	Y6	12/12/01	628 592	PH6	17/04/02	NS94	150 144
V6	16/11/02	593 639	Y7	12/12/01	607 535	PH7	17/04/02	NS94	560 448
V7	16/11/02	591 629	Y8	12/12/01	609 629	PH8	17/04/02	NS93	786 822
V8	16/11/02	589 620	Y9	12/12/01	605 629	PH9	17/04/02	NT13	903 615
V9	16/11/02	591 614				PH10	17/04/02	NS93	710 026
V10	16/11/02	620 586	Z1	12/12/01	608 546	PH11	17/04/02	NS92	340 332
V11	16/11/02	609 547	Z2	12/12/01	606 544	PH12	17/04/02	NS91	575 837
V12	16/11/02	605 542	Z3	12/12/01	605 542	PH13	16/05/02	NS91	500 729
V13	16/11/02	603 540	Z4	12/12/01	602 537	PH14	16/05/02	NS91	576 677
V14	16/11/02	600 533	Z5	12/12/01	599 532	PH15	16/05/02	NS91	508 395
V15	16/11/02	601 510	Z6	12/12/01	600 510	PH16	16/05/02	NS91	520 316
V16	16/11/02	601 480				PH17	16/05/02	NS91	551 306
V17	16/11/02	599 476				PH18	16/05/02	NS99	702 494
V18	16/11/02	597 470				PH19	16/05/02	NS91	332 009
V19	16/11/02	591 463				PH20	16/05/02	NS99	371 955
V20	16/11/02	614 553				PH21	16/05/02	NS91	700 604
V21	16/11/02	624 565				PH22	16/05/02	NS91	643 503
V22	16/11/02	628 571				PH23	12/07/02	NS94	804 405
V23	16/11/02	629 594				PH24	12/07/02	NS93	781 844
V24	16/11/02	627 598				PH25	12/07/02	NT23	173 441
V25	16/11/02	624 603				PH26	12/07/02	NS92	481 768
V26	16/11/02	609 627				PH27	12/07/02	NS92	444 863
V27	16/11/02	604 629				PH28	12/07/02	NS92	344 599
V28	16/11/02	604 611				PH29	12/07/02	NS92	569 135

APPENDIX 2 – Invertebrate samples taken from downstream of Elvanfoot (NS 954181) between 1996 and 2000 (courtesy of SEPA)

	Date of sampling and taxa present							
Taxa	**5/96**	**1/97**	**5/97**	**5/98**	**10/98**	**3/99**	**8/99**	**3/00**
i Mayflies								
Heptageniidae	+	+	+	+	+	+	+	+
Baetidae	+	+	+	+	+	+	+	+
Caenidae	+	+	+	+	+	+	+	+
Ephemerellidae			+	+	+		+	
Ephemeridae	+							
Philopotamidae							+	
ii Stoneflies								
Leuctridae	+	+	+	+	+	+	+	+
Perlodidae	+	+	+	+	+	+	+	+
Perlidae	+	+	+	+			+	+
Chloroperlidae	+							+
Namouridae	+							+
Taeniopterygidae						+		
iii Caddis flies								
Leptoceridae	+		+	+				+
Lepidostomatidae	+		+	+	+	+		+
Sericostomatidae	+		+		+			+
Rhyacophilidae	+	+	+		+	+	+	+
Polycentropidae	+		+					+
Limneplilidae	+	+		+	+	+		+
Hydropsychidae	+	+	+	+	+		+	+
iv Molluscs								
Ancylidae	+	+	+		+	+	+	
Hydrobiidae								+
Lymnaeidae	+	+	+	+	+			+
Sphaeriidae	+							
v Crustaceans								
Gammaridae	+	+	+	+	+	+	+	+
Asellidae					+		+	
vi Beetles								
Dytiscidae								+
Hydrophilidae								+
Hydroptilidae	+							
Elmidae	+	+	+	+	+	+	+	+
vii Other flies								
Tipulidae	+	+	+	+			+	+
Simulidae	+	+	+			+	+	+
Chironomidae	+	+	+	+	+		+	+
viii Worms & Leeches								
Planariidae	+	+	+	+	+	+	+	+
Erpobdellidae								+
Oligochaetae	+	+	+	+	+	+	+	+
Total no. of taxa	27	18	22	18	19	14	18	27
BMWP score	181	108	148	120	121	96	109	172
ASPT score	6.7	6.0	6.7	6.7	6.4	6.9	6.1	6.4

APPENDIX 3 – Monthly trapping records

	males	females	male:female	Totals
Aug. 2001	710	512	1:0.72	1,231
Sept. 2001	1,560	1,176	1:0.75	2,736
Oct. 2001	1,059	289	1:0.27	1,348
Nov. 2001	638	503	1:0.79	1,141
Dec. 2001	433	258	1:0.60	691
Total	**4,400**	**2738**	**n.a.**	**7,147**
Av/month	**880**	**550**	**1:0.63**	**1,430**
Jan. 2002	90	115	1:1.28	205
Feb. 2002	70	20	1:0.29	90
Mar. 2002	245	86	1:0.35	331
April 2002	347	90	1:0.26	437
May 2002	332	79	1:0.24	411
June 2002	161	41	1:0.26	202
July 2002	544	426	1:0.78	970
Aug. 2002	692	800	1:1.16	1,492
Sept. 2002	869	1,236	1:1.42	2,105
Oct. 2002	890	346	1:0.39	1,236
½ of Nov. 2002	470	158	1:0.34	628
Total	**4710**	**3397**	**n.a.**	**8,107**
Av/month	**450**	**325**	**1:0.62**	**775**