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SHORT COMMUNICATION

A method test of the use of electric shock treatment to control invasive signal crayfish in streams

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ABSTRACT

1. Invasive crayfish exert adverse impacts on native biodiversity in Europe. This field study investigated the scope for use of electric shock treatment to eradicate signal crayfish in a small headwater stream.

2. High intensity (96 kW, direct current 1600 V, 57.8 A, at 7 Hz) repeated shocks were delivered via electrode tapes to two sections of stream. Both had 98 min as 2-min shocks. Section 2 had additional 15-min shocks to a total of 308 min.

3. Crayfish mortality was 86% and 97% in the two sections respectively, based on the number recovered when the channel was subsequently dewatered. The survivors found were in the banks. Mark–recapture indicated that 72% of the total population was captured, hence the minimum mortality was 77% of the total population after the longer treatment.

4. All sizes of crayfish were affected, but small individuals (<30 mm carapace length) were more susceptible.

5. Test cages showed increasing mortality with exposure. A fitted model showed 50% mortality with 17 min shock time, 75% mortality with 30 min (distance to electrode in the range 10–50 cm).

6. The treatment is a possible non-selective method of control for invasive crayfish in small watercourses, rather than an eradication method, because some crayfish survived in the stony banks. Periodic treatment downstream of a physical barrier would potentially keep the crayfish density low and may therefore reduce the risk of the barrier being overcome by upstream invasion. Options for further investigation to improve the method are discussed.

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KEY WORDS: stream; biological control; new techniques; invertebrates; alien species

INTRODUCTION

Invasive alien species are a major cause of global biodiversity loss (Millennium Ecosystem Assessment, 2005). Invasive crayfish species have adverse effects on native species and habitats through competition, predation, grazing and burrowing, and transmission of disease (Gherardi, 2007). Dense populations of invading signal crayfish (*Pacifastacus leniusculus*) can

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reduce diversity and abundance in macroinvertebrate communities (Crawford *et al*., 2006). Fish eggs may escape predation in gravel (Gladman *et al*., 2012), but are vulnerable near the surface and when larvae emerge (Edmonds *et al*., 2011). Although adult fish prey on juvenile crayfish, overall reduction of salmonid fish in headwater streams has been reported in the presence of dense populations of crayfish (Peay *et al*., 2009).

Land managers often seek to eradicate local populations of invasive crayfish (see Reynolds *et al*. (2012) for a review of methods used). Trapping is commonly used, but has not eradicated any invasive crayfish populations, although some localized reduction is possible. Non-selective biocides have been used effectively in small stillwater sites, but controlled treatment of running water is challenging. This study investigated a possible alternative in small streams: electric shock treatment. Non-lethal electrofishing surveys use shocks at very low power to stun fish (Beaumont *et al*., 2002) or crayfish (Westman *et al*., 1979). Electrical equipment can be used to stun or kill crustaceans before boiling for human consumption (Neil, 2010), or for killing individual invasive crayfish caught in surveys (Ducruet *et al*., 1993). Here, a new portable high-power apparatus was field-tested for its effectiveness in eradicating an invading population of signal crayfish in a stream in England.

METHODS

The study site was a shallow, stony headwater stream in North Yorkshire, England (54° 02′ 33.16″ N, 2° 14′ 05.50″ W), *c*. 1.5 m wide, without vegetation, except some mosses. Water conductivity was 105–220 μS cm^{-1} during the study. Signal crayfish had already replaced the fish population in the study site (Peay *et al*., 2009).

Portable electrical equipment (designed, built and operated by Electro Fishing Services Ltd) comprised: 1. power supply (a portable 5 kW frame generator and a 230 V generator for the pulse unit); 2. capacitor unit to deliver power, and 3. pulse unit, to control power, frequency, and duration of DC (direct current) pulses (Figure 1). Metallic tape electrodes, laid in three flexible strips along the bed of the stream, delivered shocks in the water (Figure 2). A ‘high power’ unit produced *c*. 96 kW output, typically 1600 V, 57.8 A, at 7 Hz, with square pulses of width (duration) 4.4 ms. A ‘low power’ prototype, *c*. 20 kW, produced 500 V pulses. In comparison, conventional electrofishing equipment would produce *c*. 0.5 kW, 300 V in this type of stream, briefly stunning fish and crayfish.

Authorization was obtained from the Environment Agency. Treatment (shock followed by dewatering) was carried out during a dry week in August 2011 in two *c*. 7 m consecutive sections of stream, with a similar (15 m) length used as a control (dewater only)

Figure 1. Equipment set-up for electric shock treatment of a stream: (a) flume pipe for flow bypass; (b) pulse unit and laptop computer for programming; (c) capacitor unit; (d) 5 kW generator; (e) pump for dewatering after treatment; (f) stop net; section under treatment.

Figure 2. Stream bed set for shock treatment, with electrode tapes and test cages (6 mm plastic mesh, base 30 × 45 cm, with gravel and 15 signal crayfish).

and an untreated section between (Figure 3). Stop-nets were set at both ends of each section to prevent movement of crayfish into or out of the section.

Before treatment, baited crayfish traps were set for one night in each section and all crayfish caught were marked (using a yellow Dykem Brite-Mark® paint-marker) and then released into the enclosed section from which they had been caught. This was to estimate efficiency of capture when the sections were subsequently dewatered and searched. Compared with a manual search in running water, crayfish are much more readily seen and caught when the channel of a stony stream is fully dewatered and all moveable refuges of crayfish can be thoroughly searched (Peay, unpublished data), giving a better estimate of the total population. Even so, some refuges in banks are inaccessible. The number of marked crayfish recaptured as a proportion of the total (live and dead) crayfish found in the manual search indicates the proportion of the total population captured in the search and, conversely, the proportion missing. Where all refuges in the channel have been searched, the missing proportion is likely to be in the banks.

Starting at night, when crayfish were active, the two sections were treated concurrently with cycles of 2-min high-power shock and 25 min rest (total 49 shock cycles, cumulative shock time 98 min). The rest periods were to allow crayfish to leave their refuges if they received only a non-lethal shock. Some longer breaks of several hours were made during a 72-h period, for safety reasons and maintenance. Section 1 was dewatered, the crayfish were removed by thorough hand-searching, then flow was restored. Crayfish sex, size (measured as

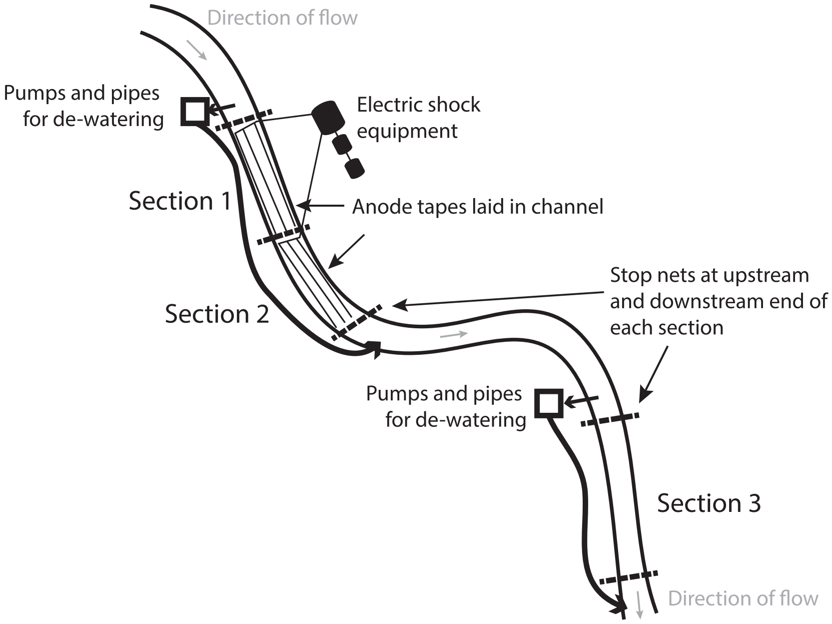

Figure 3. Schematic diagram of the study site (not to scale) and equipment, with sections given electric shock treatment (Section 1 and 2) and control (Section 3).

carapace length (CL) to 0.1 mm), damage (including loss of chelae), condition and mark were recorded. Section 2 was then given a further 14 cycles of 15-min high-power shocks during the next 24 h (total 63 cycles, 308 min). Section 2 and the control section were each de-watered and crayfish recorded, then flow was restored. Both electric-treated sections were dewatered again, this time at night, to observe whether surviving crayfish emerged from the banks after the experimental treatment.

In addition, shock treatment was applied to caged crayfish to investigate the effects of fewer shock cycles. Crayfish were obtained from traps set *c.* 50–100 m downstream of the study area. Batches of 15 crayfish were put into each of 17 cages (Figure 2) and given one or more shock cycles at high or low power, with cumulative time varying between 2 and 30 min. Crayfish were held in the stream (no shocks) for 48 h and their condition was recorded.

Non-parametric tests (G-tests with Williams' corrections) were used to compare mortality between sections, sexes and size classes and the incidence of chelae loss between treatments and between live and dead crayfish in shock-treated sections. To investigate the mortality of crayfish in the cages, a generalized linear model with a binomial distribution was fitted to the dataset (using SPSS 20.0), to test the effects of cumulative shock time (2 to 30 min) shock power (high or low) and duration of shock cycles (2 or 15 min) on crayfish mortality in cages (expressed as number dead from 15). A scale parameter (Pearson Chi-square value/df = 2.269) was used to correct for over-dispersion. As the terms of shock power and duration of shock cycle were not significant, they were dropped from the model.

RESULTS

Section 2, which had the longer treatment, had significantly higher mortality (97.4% of a total of 410 individuals found) than section 1 (86.4%, of 278 total), (G = 10.92, df = 1, $P < 0.001$). There was no mortality in the dewatered control section. The average catch density per section ranged from 29.6 to 31.4 crayfish m^{-1}.

As mortality was similar for both sexes (G = 0.30, df = 1, *P* = NS), results were pooled. Juvenile crayfish <30 mm predominated in both sections (80% and 85% in sections 1 and 2 respectively). Crayfish were aggregated into two size classes (5–29 mm and 30–54 mm CL) for a test of difference (as the number of survivors was too low to allow analysis with more size classes). Mortality was greater in smaller crayfish (Figure 4). In section 1, mortality in the larger crayfish was only 66%, significantly lower (G = 3060, df = 1, $P < 0.001$) than the 92% mortality in smaller crayfish. In section 2, where overall mortality was higher, the difference in mortality between large and small sizes (90% and 99%, respectively) was not significantly different (G = 8.66, NS). Following dewatering, manual removal retrieved 72% (31/43) of the marked crayfish, indicating that 28% of crayfish (live or dead) were inaccessible in crevices in the banks. One crayfish emerged from a bank in section 1 during the dewatering at night, i.e. after manual removal.

In the shock-treated sections, more crayfish were missing chelae (70%) than in the control section (17%) (G = 371, df = 2, $P < 0.001$). The incidence of chelae loss did not differ between crayfish that survived shocks and those that died (G = 0.29, df = 1, *P* = NS), suggesting that loss of chelae was an effect of treatment, rather than due to autotomy as a voluntary escape response.

Cage tests were used to investigate the effects of total shock time on mortality. Total shock times in the range 2–30 min produced mortality in the range 0–100% and the mortality of the caged crayfish increased with total shock time (Figure 5). The fitted model indicated 50% died within 17 min shock time (6–52 min, 95% confidence limits) and 75% in 30 min (14–76 min). With only 17 tests carried out, the model was not extrapolated to calculate the time to maximum mortality.

DISCUSSION

Electric shock treatment caused high mortality of the invasive crayfish; however, complete eradication was not achieved. The recorded mortality was 97.4% in section 2, but incomplete recapture of marked crayfish (live and dead) showed that part of the population was inaccessible in the banks and the proportion of survivors is unknown. If all survived, the proportion of live crayfish (recorded and

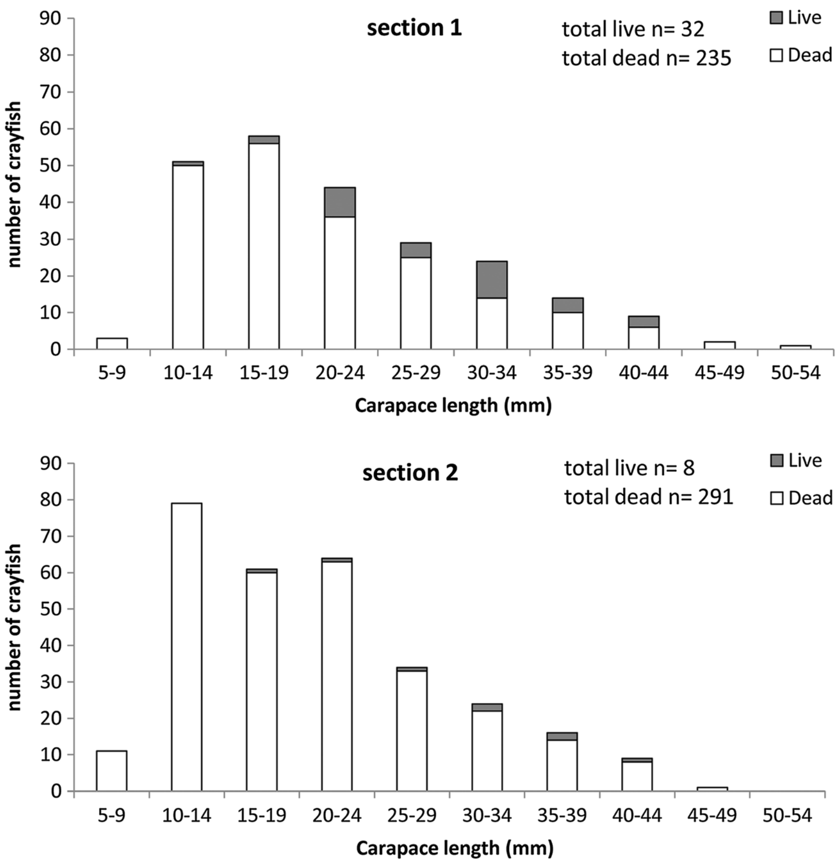

Figure 4. Mortality of signal crayfish in two stream sections given high intensity treatment (section 1 high power: 96 kW, total shock time 98 min; section 2: 96 kW, total shock time 308 min); total mortality by size class (carapace length, mm).

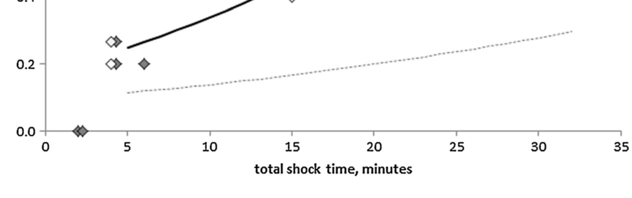

Figure 5. Mortality of crayfish (as a proportion of 15 crayfish per cage) in 17 cages exposed to different cumulative shock times in a stream at either high power (96 kW, dark grey diamonds) or low power (20 kW, white diamonds). The fitted generalized linear model was $y = 0.089$ $(x - 1.555$, where $y = \ln (p/1{-}p)$, p = proportion dead, x = total shock time (Wald chi-squared = 14.862, df = 1, $P < 0.001$). The fitted model is shown (black line) with 95% confidence limits (dotted lines).

assumed) in the total population would be 23%, i.e. the minimum mortality in the total population would be 77%. Even in the accessible areas, the only surviving crayfish were found under large stones against the banks. Some were in tetanus when found, but recovered later, indicating lower effectiveness of treatment there. Chelae are often lost during fights, or in defence against predators, but tetanus is likely to have caused the (70%) loss during the shock treatment. Chelae loss has also been reported during conventional electro-fishing (Westman *et al*., 1979).

Small crayfish (<30 mm CL) had higher mortality than large ones. This is in contrast to conventional electro-fishing for fish, in which large individuals are more susceptible than small ones, owing to the greater potential difference in the voltage between head and tail in large fish. The power or field strength increases with the conductivity of the water compared with that of the fish. Although there is some information on the conductivity of fish

(Beaumont *et al.*, 2002), there is little information available about the conductivity of whole crayfish and the extent to which susceptibility to electric shock may be influenced by factors such as body size, shape and the condition of the exoskeleton. Cage tests showed that mortality increased with the cumulative shock time and reached 75% within *c.* 30 min, but with variation in the distance to electrode tapes (range 10–50 cm), within and between cages, it was not possible to determine the maximum achievable mortality for the lowest shock time. Field strength increases in a non-linear relationship with proximity to the electrode, which would lead to variations in the shock power at different points in the channel. Neil (2010) showed that lower power (110 V, 5–10 A, 50 Hz, 12 s) killed crabs and lobsters when they were in contact with an electrode. In contrast, in this field trial, with wider-spaced electrode tapes, much higher power input was required.

Two options for improving treatment efficiency are increasing the power and improving treatment of the banks so that all crayfish in refuges are lethally shocked. An increase in power could be achieved by (a) using additional, more closely spaced, electrode tapes, (b) higher power equipment (c) reducing the water level, provided refuges remain submerged, or (d) increasing conductivity (e.g. by addition of an electrolyte). The treatment of the banks by electric shock would be influenced by the substrate, its water retention and ion content. Further investigation would be required to assess the scope to use electrodes in the banks, or other measures to improve treatment. Unless the issue of treatment of refuges in banks can be addressed successfully, electric shock treatment seems unlikely to achieve eradication of populations of invasive crayfish species, but it could be used as a control measure. Effectiveness may be greater in streams where there is little available habitat in the banks and hence better exposure to treatment.

Unlike trapping, which is selective for large crayfish (Abrahamsson, 1981), electric shock treatment is effective against all sizes of crayfish, especially those <30 mm CL, which are rarely caught in traps but represent at least 80% of the total population. Young of the year <10 mm CL were all dead in the treated sections (Figure 4).

A disadvantage of electric shock treatment is that, like biocide treatments, it has impacts on non-target fauna. Accidental mortality in fish can occur, even with conventional electro-fishing (Beaumont *et al.*, 2002), so unless fish were removed in advance, high mortality would be expected with this high-power treatment. Biocide treatment is the only successful eradication method so far against signal crayfish populations (Peay *et al.*, 2006 and unpublished data). The main advantage of electric shock treatment over biocide treatment is that it has no impacts outside the treated area, but in contrast to biocide treatment it is only suitable for very shallow waters. It may have some potential as a pre-treatment for a high density population, before using a longer-term control measure that has lower impact. Electric shock could also be considered for periodic treatment of a localized area in conjunction with a physical barrier. In principle, repeatedly reducing the population to very low density downstream of the barrier may reduce the risk of the barrier being overcome by crayfish invading upstream.

Electric shock treatment does not provide a simple solution to the problem of non-native crayfish in the increasingly invaded catchments across Europe, but it does offer a new tool that may have some specific local applications in the management of invasive crayfish. It may also have greater potential for eradication of invasive aquatic species that are not as refuge-dependent; for example, invasive fish in shallow water bodies.

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REFERENCES

Abrahamsson SAA. 1981. Trappability, locomotion, and diel pattern of activity of the crayfish *Astacus astacus* and *Pacifastacus leniusculus* (Dana). *Freshwater Crayfish* **5**: 239–253.

Beaumont WRC, Taylor AAL, Lee MJ, Welton JS. 2002. Guidelines for Electric Fishing Best Practice. Environment Agency R&D Technical Report W2-054/TR. http://publications.environment-agency.gov.uk/pdf/SW2-054-TR-e-e.pdf.

Crawford L, Yeomans W, Adams CE. 2006. The impact of introduced signal crayfish *Pacifastacus leniusculus* on stream invertebrate communities. *Aquatic Conservation: Marine and Freshwater Ecosystems* **16**: 611–621.

Ducruet S, Rojat G, Nicholas L, Laurent PJ. 1993. A new device for electrocution of crayfish. *Freshwater Crayfish* **9**: 154–157.

Edmonds NJ, Riley WD, Maxwell DL. 2011. Predation by *Pacifastacus leniusculus* on the intra-gravel embryos and emerging fry of *Salmo salar*. *Fisheries Management and Ecology* **18**: 521–524.

Gherardi F. 2007. Understanding the impact of invasive crayfish. In *Biological Invaders in Inland Waters: Profiles, Distribution, and Threats*, Gherardi F (ed). Springer: Dordrecht; 507–540.

Gladman ZF, Adams CE, Bean CW, Long J, Yeomans WE 2012. Investigating the threat of non-native North American signal crayfish (*Pacifastacus leniusculus*) to salmon redds. *Aquatic Conservation: Marine and Freshwater Ecosystems* **22**: 134–137.

Millennium Ecosystem Assessment. 2005. Ecosystems and Human Well-being: Biodiversity Synthesis. World Resources Institute, Washington, DC. http://www.maweb.org/documents/document.354.aspx.pdf [26 May 2012]

Neil D. 2010. The effect of the Crustastun™ on nerve activity in crabs and lobsters. Research Institute of Biodiversity, Animal Health and Comparative Medicine, University of Glasgow, Glasgow. http://crustastun.com/assets/files/Neil_2010_Glasgow_Report.pdf [9 Nov 2012]

Peay S, Hiley PD, Collen P, Martin I. 2006. Biocide treatment of ponds in Scotland to eradicate signal crayfish. *Knowledge and Management of Aquatic Ecosystems* **380–381**: 1363–1380.

Peay S, Guthrie N, Spees J, Nilsson E, Bradley P. 2009. The impact of signal crayfish (*Pacifastacus leniusculus*) on the recruitment of salmonid fish in a headwater stream in Yorkshire, England. *Knowledge and Management of Aquatic Ecosystems* **394–395**: 12. DOI: 10.1051/kmae/2010003.

Reynolds J, Souty-Grosset C, Gherardi F. 2012. Control and management of non-indigenous crayfish. In *Management of Freshwater Biodiversity Crayfish as Bioindicators*, Reynolds J, Souty-Grosset C (eds). Cambridge University Press: Cambridge; 197–297.

Westman K, Sumari O, Pursiainen M. 1979. Electric fishing in sampling crayfish. *Freshwater Crayfish* **4**: 251–256.