Successful eradication of signal crayfish (*Pacifastacus leniusculus*) using a non-specific biocide in a small isolated water body in Scotland

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Abstract The North American signal crayfish (*Pacifastacus leniusculus*) has been present in Scotland since at least 1995 and the species is now known to be present in a number of catchments. Once established, few opportunities for containment exist and eradication can often be impossible to achieve. However, in small, isolated water bodies, the application of a non-crayfish-specific biocide has provided the opportunity to remove this species permanently. In July 2011, signal crayfish were discovered in a flooded quarry pond at Ballachulish in the Scottish Highlands. This is an isolated site located ~100 km from the nearest known population and it is likely that the population was established as the result of a deliberate release of these animals 10 years previously. Experience gained from using the eradication technique at other sites in the UK led to the site being treated with a natural pyrethrum biocide (Pyblast®) in June 2012. Post treatment monitoring from 2012–2017 indicates that eradication has been successful. Monitoring of native species affected by the biocide suggests that both invertebrates and amphibians quickly recolonised the quarry pond. Eradication of crayfish using biocide is only feasible in water bodies where the entire population of crayfish can be exposed to a lethal dose and the impact on non-target species can be accepted. The technique is not appropriate for large, connected water bodies, although it may be possible to treat short stretches of canals where biocide exposure can be controlled and isolated populations of crayfish can be effectively treated.

Keywords: invasive species, natural pyrethrum, ponds

INTRODUCTION

Invasive species are the second largest cause of biodiversity loss globally through species extinction and habitat destruction (EEA, 2012). Their impact can be dramatic and often irreversible, so it is important that their spread is contained and that eradication is achieved wherever practicable. As a function of their isolation, islands may offer the best hope of locally eradicating an invasive species. Conventionally we think of islands as areas of land which are surrounded by water. However, for obligate aquatic species the reverse may be true, and it is the land which can form an effective barrier to invasion. In freshwater ecosystems, invasive non-native species can pose a major threat to native species through competition, predation and transmission of diseases (EEA, 2012) and their control in these 'freshwater islands', is therefore of particular importance.

Newly introduced species can establish rapidly and it is important to detect their presence, and take action, as early as possible. This is often not possible because, unlike terrestrial habitats, freshwaters are not easily surveyed (Boon & Bean, 2010). This means that invasive species in these habitats may not be detected until they have become fully established, often making it more expensive to remove them (Simberloff, et al., 2013).

Signal crayfish (*Pacifastacus leniusculus*) have been introduced to over 20 European countries since the 1960s. After escaping from farms in the 1970s they are now widespread across parts of England and Wales (Bean, et al., 2004). The species was first discovered in Scotland in 1995 (Maitland, 1996). In just over 10 years it had been illegally introduced into at least eight river catchments (Gladman, et al., 2009). Signal crayfish are omnivores and, through increased grazing pressure and predation, they can reduce the diversity of aquatic invertebrates and significantly alter food webs (Holdich, et al., 2014). As well as direct predation of eggs and young fish, they compete with Atlantic salmon (*Salmo salar*) and trout (*S. trutta*) for food and space and can mobilise sediment, causing silting of spawning beds (Gladman, et al., 2012; Bean & Yeomans, 2016).

Controlling signal crayfish has proved difficult and, in most situations, impossible to achieve. Several approaches have been attempted, ranging from the physical removal of animals using techniques such as trapping and electrofishing, to the construction of barriers to prevent their spread (Bean & Yeomans, 2016). Of these, trapping is often perceived as being the easiest and most effective option. In reality, however, the removal of crayfish by trapping has proved ineffective at eradicating signal crayfish because it does not remove the entire population (Freeman, et al., 2010). Where trapping has been allowed to take place on a commercial basis, either as a management tool or for the establishment of legal fisheries, it has been associated with the detection of an increased number of illegal introductions (e.g. Alonso, et al., 2000; Diéguez-Uribeondo, 2006; Arce & Alonso, 2011; Bohman, et al., 2011).

The use of biocides to control or eradicate crayfish populations is a relatively recent development. Early attempts to eradicate signal crayfish using chlorinated lime (Kozak & Policar, 2003) were not successful. However, later trials using natural pyrethrum (as Pyblast®) (Peay, et al., 2006) showed more promise in trials in Scottish freshwaters without being totally effective. O'Reilly (2015) provides a comprehensive review of the toxicity of Pyblast® and other organophosphates for signal crayfish control.

There is no single biocide available that is selective for signal crayfish only. This means that any attempted eradication using a biocide treatment would be expected to kill some, or all, of the non-target invertebrate and vertebrate fauna in the area being treated.

Signal crayfish were first detected in north-west Scotland in an artificial waterbody, a flooded slate quarry, near Ballachulish, in 2011. This species is thought to have been present within the pond for approximately 12 years prior to its discovery there (P. Madden, pers. comm.). The nearest signal crayfish population to that discovered at Ballachulish is located over 100 km south in the River Kelvin near Glasgow. This reinforced the initial view that this species was introduced to the Ballachulish quarry pond by people; in addition, it has footpaths and a recreational area adjacent so is readily accessed by the public. The pond, and therefore the crayfish population, was isolated with no source of natural re-infestation. However the proximity of the pond to local rivers, and the potential impact that this species may have on species of conservation and recreational value, such as Atlantic salmon and trout, made it essential that the signal crayfish population was removed as soon as possible.

Study site

Ballachulish quarry pond (Ordnance Survey Great Britain National Grid Reference NN08525824) is located immediately west of the town of Ballachulish on the west coast of Scotland (Fig. 1). The area contains a large pond and a smaller waterbody located 25 m to the north (NGR NN08435835). The affected waterbody has a surface area of 18,776 m^2 and a volume of 46,000 m^3. Whilst it is relatively shallow over much of its surface area (approximately 0–5 m deep), a smaller area of deeper water, extending to a maximum depth of 13 m, is present.

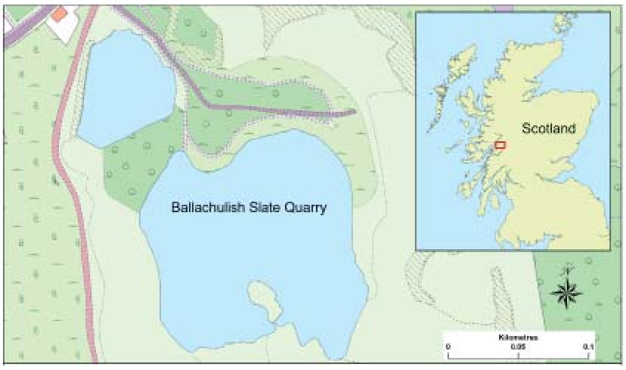

Fig. 1 The location of Ballachulish and the quarry pond relative to western Scotland.

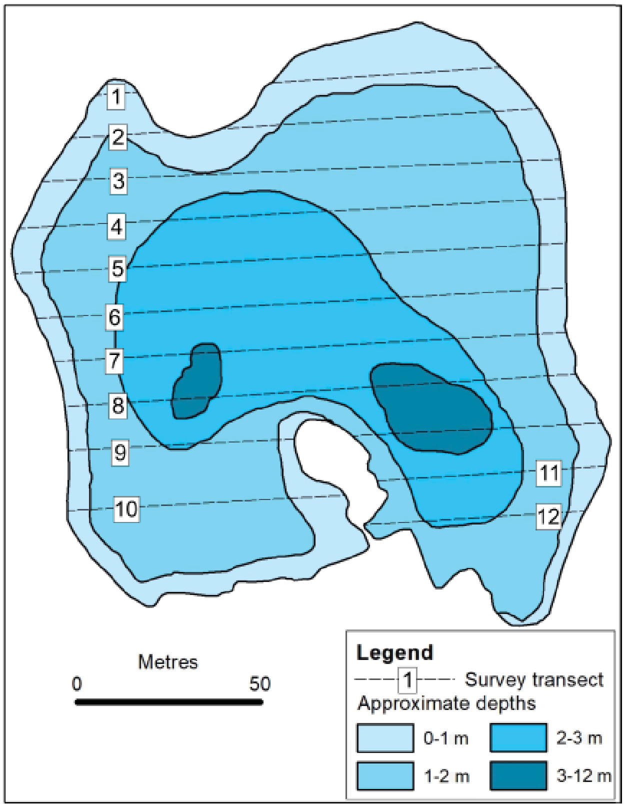

Fig. 2 Ballachulish quarry pond bathymetry.

Survey prior to any management action revealed that signal crayfish were restricted to the larger of the two ponds. The large pond also hosted a number of invertebrate and vertebrate species. Vertebrates found during the survey included fish (trout and European eel (*Anguilla anguilla*)) and amphibian species such as common toad (*Bufo bufo*) and palmate newt (*Lissotriton helveticus*).

METHODS

It was deemed acceptable, given the absence of any conservation priority species, that some mortality of native fauna would occur as a result of biocide application. The risk of inadvertently transferring juvenile crayfish in the act of translocating rescued animals to new locations meant that no attempt was made to rescue non-target species prior to the treatment taking place.

Bathymetric transects of the pond were obtained by the use of a plumb-line at 100 sample points (Fig. 2). These were used to divide the pond into compartments of equal volume. A total volume of 620 l of Pyblast® was applied to the surface of the pond by boat-mounted sprayers (Fig. 3) to achieve a target dose rate of at least 0.3 mg/l, on 12 June 2012. Water pumps and a boat with an outboard motor were used to ensure thorough mixing throughout the entire water column. In addition, backpack sprayers treated a 1 m band around the edge of the pond and the shallow margins of the pond to prevent signal crayfish leaving the water (Fig. 4). The following day, deep water sections of the pond were re-treated by spraying Pyblast® down 6 m-long rigid hoses, increasing the dose rate in the deepest areas of the pond to at least 0.4 mg/l. Mixing was achieved, as far as possible, using an outboard engine and shore-based pumps.

The effectiveness of the treatment was monitored by placing 13 sentinel cages, each containing 10 signal crayfish, of mixed sex, into the pond at different positions and depths and monitoring their mortality once the biocide had been applied. Bioassays using the freshwater shrimp (*Gammarus pulex*) as a test organism, were conducted according to the methodology described by Peay, et al. (2006). These were run on the pond water to monitor its toxicity at the point of treatment and to monitor the breakdown of the Pyblast® over subsequent days and weeks. Natural pyrethroids break down quickly when exposed to sunlight and their toxicity should reduce

Fig. 3 Pyblast® being applied to the surface of the pond from boat-mounted sprayers.

Fig. 4 Using a backpack sprayer to deliver biocide to the quarry pond edge.

Fig. 5 Dead signal crayfish in the margins of the pond following Pyblast® treatment.

rapidly. During this eradication exercise, toxicity levels, sufficient to kill *Gammarus*, persisted for 34 days.

The effectiveness of the signal crayfish removal attempt was monitored through baited Fladen-style traps set in the pond for a total of 195 trap nights in August/ September each year for five years post-treatment (975 trap nights in total). Traps were set in a range of habitats and depths throughout the site to maximise the potential of capture. The ability of invertebrates to recover very quickly, in as little as 24 days, was already known from other studies (e.g. Peay, et al., 2006), therefore recovery of the pond ecosystem was assessed through amphibian surveys carried out using sweep netting and kick-sampling in late June, August, September and October 2012. Larval common toad and palmate newts were measured, aged and their general behaviour assessed to determine whether it deviated from that normally expected in undisturbed sites.

RESULTS

During, and immediately after the Pyblast® application, signal crayfish held in sentinel cages were checked intermittently to assess mortality levels and the efficacy of treatment. By the end of the first day (12 June 2011) most of the signal crayfish were dead (Fig. 5), however, those in deep water sections (as determined from the use of sentinel crayfish) were still active. Effort was focused on increasing the concentration of Pyblast® in these areas and by the third morning (14 June 2011) all signal crayfish, even in the deep sections, were dead. The annual post-treatment monitoring found no signal crayfish in the pond for five years after the treatment and in August 2017 the eradication was declared successful.

Bioassay monitoring indicated that after one month the concentration of Pyblast® in the pond was below the lethal limit for *G. pulex* and it was judged safe to re-open the pond to the public. Fig. 6 shows the speed at which the reduction in toxicity of water samples taken from the surface and 5 m depth in the pond took place following Pyblast® treatment. These data show that biocide toxicity in deeper waters took longer to drop below lethal levels than those near the surface, but confirmed that toxicity levels dropped to levels non-lethal to signal crayfish in all areas within 20 days post-treatment.

The amphibian surveys found larval stages of common toad and palmate newt in late June 2012, which strongly suggested they had survived the Pyblast® treatment. There was no difference in size or development stage between tadpoles from the treated pond and a nearby untreated pond. All amphibian larvae behaved normally and showed no physical abnormalities (see O'Brien, et al., 2013). A low level of fish mortality was observed and this included one brown trout plus a very small number of European eels and three-spined sticklebacks (*Gasterosteus aculeatus*).

DISCUSSION

Post-treatment monitoring demonstrated that the application of Pyblast® at a target dose rate of 0.3 mg/l was successful in removing signal crayfish from the pond. Monitoring also showed that a number of non-target species survived the treatment, or were able to recolonise quickly (O'Brien, et al., 2013). The pond is artificial and the presence of signal crayfish would have significantly altered its ecology, meaning that there is no recent, or pre-crayfish, baseline against which to measure ecosystem recovery. However, five years after the biocide treatment an abundant invertebrate and amphibian fauna is present within the pond, and no lasting chemical effect of the treatment is visible.

The risk of signal crayfish being spread to new waterbodies within the local area by natural or anthropogenic means has been reduced as a result of this successful eradication. There are now no known populations in the north-west Highlands which pose a threat of re-introduction to this site. This project has shown that full eradication is achievable in small, isolated waterbodies where the entire signal crayfish population can be exposed to a natural pyrethroid biocide, and the impact on non-target species is deemed an acceptable risk.

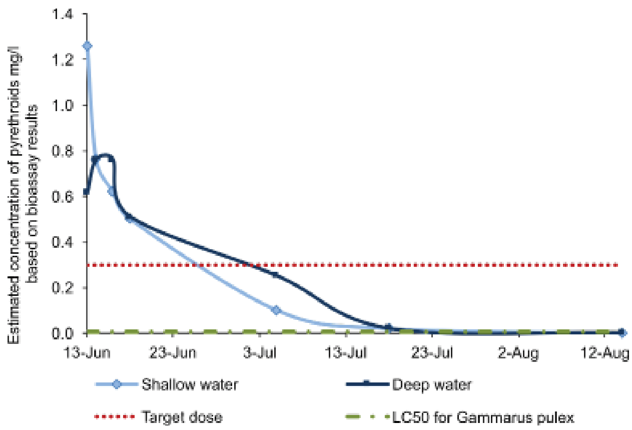

Fig. 6 Graph showing the reduction in toxicity of water samples taken from the surface and 5 m depth in the pond following Pyblast® treatment on 12t June 2012. Toxicity was estimated through a bioassay exposing *Gammarus pulex* to diluted samples and comparing to previous reference data collected on their mortality rates.

A partnership approach to dealing with signal crayfish in this location was a significant component of its success. Buy-in from public agencies and the local fisheries management sector provided the financial and physical resources required to provide adequate materials to carry out this work effectively. Ongoing promotion of a national biosecurity campaign aims to prevent future reintroductions. At an operational level, careful monitoring of sentinel signal crayfish and having a sufficient contingency of Pyblast® to supplement concentrations in the deepest areas of the pond proved crucial. The quarry pond at Ballachulish is the largest water body in the UK to date where signal crayfish have been eradicated using a natural pyrethroid. The main limitations to the wider application of this method to large waterbodies are the financial cost of the biocide (in 2012, Pyblast® cost over £50 per litre), the manpower required, the collateral damage to native biota and connectivity to outflowing rivers and streams. This trial accounted for biocide costs of >£30k alone, and with additional costs in terms of staff time and equipment hire (pumps, etc.) the total estimated figure was £73.1k. Additional costs associated with post-treatment monitoring are not included within this total. In Sweden and Norway, less expensive synthetic pyrethroids have been used (Sandodden & Johnsen, 2010), but these have the disadvantage of being more toxic and persistent in the freshwater environment. O'Reilly (2015) showed, using laboratory-based acute toxicity tests, that signal crayfish were most sensitive to Detamethrin, a synthetic pyrethroid, used in the aquaculture industry, and that juvenile signal crayfish were significantly more sensitive to Pyblast® than adult conspecifics at concentrations far lower than those used in this study (57.95 µg/l versus 0.3 mg/l). It may be possible, therefore, to use alternative biocide approaches in some situations, or lower the costs of treatment in populations which are detected at an earlier stage in their establishment. Recent advances in the detection of invasive species by environmental DNA may allow for earlier, and cheaper, identification of new populations through the expansion of surveillance networks to include a larger number of waterbodies. Environmental DNA assays have already been developed for signal crayfish (Larson, et al., 2017; Harper, et al., 2018) and a wide range of other biota (e.g. Ficetola, et al., 2008) which will allow for cheaper, and possibly more reliable, pre-and post-treatment monitoring of signal crayfish and other species to take place in future years.

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