Fisheries Management and Ecology, 2006, **13**, 329–335

Eradicating the invasive topmouth gudgeon, *Pseudorasbora parva*, from a recreational fishery in northern England

J. R. BRITTON

Environment Agency, National Fisheries Laboratory, Brampton, UK

M. BRAZIER

Environment Agency, NorthWest Region, North Area, Penrith, Cumbria, UK

Abstract An established population of the invasive topmouth gudgeon, *Pseudorasbora parva* (Temminck & Schlegel), was discovered in a recreational fishery in Northwest England in 2002. As the lake was seasonally connected to a river catchment, providing potential for dispersal, a containment and eradication programme was initiated. Containment involved screening of outfalls and preventing fish movements off site. Eradication involved the fishery being treated twice with a rotenone-based piscicide, in March and April 2005. The mean *P. parva* density prior to rotenone application was 6.1 m^{-2}; following the application, none were recorded. Non-target species in the fishery were removed prior to the application; following rotenone degradation, they were re-introduced and subsequently spawned, with recording of young-of-the-year. This contrasts with 2004 when only young-of-the-year of *P. parva* were recorded. As the eradication appeared to be successful, the method is considered suitable for use on other populations posing a similar threat of dispersal of the species into rivers and on other invasive fish populations in undesirable locations.

KEYWORDS: invasion, Lake District, non-native, rotenone, topmouth gudgeon.

Introduction

Topmouth gudgeon, *Pseudorasbora parva* (Temminck & Schlegel), has proved to be a highly invasive fish species in Europe following its initial introduction into Romania in 1960 (Bianco 1988; Wildekamp, Van Neer, Kucuk & Unlusayin 1997; Pinder, Gozlan & Britton 2005). Native to Japan, China, Korea and the River Amur basin, this small cyprinid species rarely achieves lengths above 8 cm and has broad environmental tolerance limits. In combination with the life history traits of early maturity, batch spawning and nest guarding (Bruton 1986; Rosecchi, Thomas & Catsadorakis 2001), the species has a number of characteristics that favour invasion success on introduction into new water bodies (Ricardi & Rasmussen 1998; Pinder *et al*. 2005). The potential impacts of *P. parva* invasion on native species include the adverse effects of inter-specific competition, facultative parasitism, disruption of ecosystem functioning and pathogen transfer (Libosvárský, Baruš & Sterba 1990; Rosecchi, Crivelli & Calsadozakis 1993; Xie, Zhenyu, Gregg & Dianmo 2001; Gozlan, St-Hilaire, Feist, Martin & Kents 2005).

The first record of *P. parva* in the wild in England and Wales was in 1996 (Domaniewski & Wheeler 1996), with four infected sites reported in 2002. However, by 2005, there were recordings from 25 sites (Gozlan, Pinder & Shelley 2002; Pinder *et al*. 2005). Whilst some of the infected waters are fully enclosed stillwaters that posed no immediate threat of dispersing *P. parva* into rivers, there were infected stillwater sites with hydrological connection to river systems that posed a direct threat of riverine dispersal (Pinder *et al*. 2005). For example, *P. parva* has dispersed in the Test and Itchen catchments of Southern England (Pinder *et al*. 2005).

One of the infected stillwaters is a recreational fishery on the southern edge of the Lake District in

Correspondence: Rob Britton, Environment Agency, National Fisheries Laboratory, Bromholme Lane, Brampton, PE28 8NE, UK (e-mail: robert.britton@environment-agency.gov.uk)

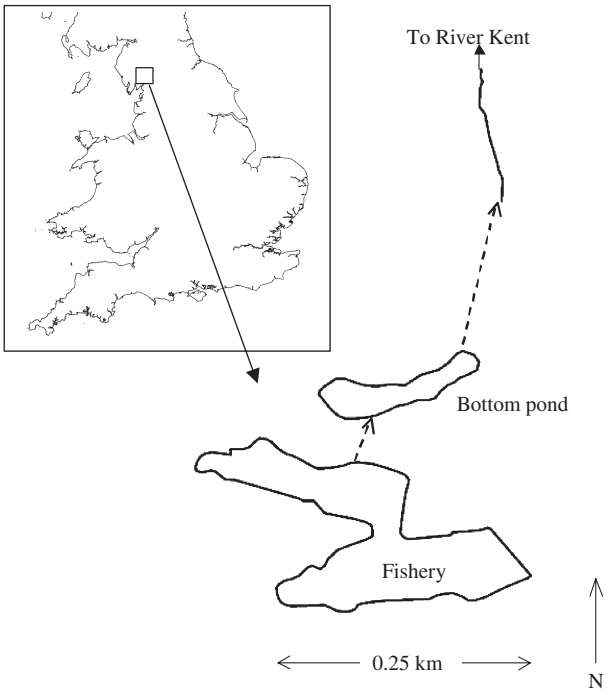

Figure 1. Location and overview of the *Pseudorasbora parva* infected site in North West England. The dashed lines represent a seasonal connection between the fishery and bottom pond, and the bottom pond and the River Kent catchment, according to precipitation levels.

Northwest England (Fig. 1). This lake was seasonally connected to a tributary of the River Kent, a catchment of high conservation status through the presence of Annex B species of the Habitats Directive, including the white-clawed crayfish, *Austropotambius pallipes* (Lereboullet) and bullhead, *Cottus gobio* L. (English Nature 2004). Furthermore, the Lake District National Park encompasses 14 major lakes of high nature conservation value. These are already highly vulnerable to the detrimental impacts of introductions of non-indigenous species, such as roach, *Rutilus rutilus* (L.), and ruffe, *Gymnocephalus cernuus* (L.), a result of the lakes' low species diversity and availability of vacant niches (Winfield & Durie 2004). There was a requirement, therefore, to protect the river catchment and the lakes from *P. parva* dispersal through a combination of containment and eradication. This paper describes and evaluates this containment and eradication exercise, with discussion of the wider implications for the management of invasive fishes in England and Wales.

Pseudorasbora parva *management plan*

The infected fishery is a shallow (< 2 m), 2.2-ha lake in North West England (Fig. 1). The presence of topmouth gudgeon was confirmed in October 2002 (I. Winfield, personal communication), although the initial, accidental introduction was believed to have occurred in 2000. The fishery is managed for recreational, catch and release angling; the other fish species present are roach, gudgeon, *Gobio gobio* (L.), common bream, *Abramis brama* (L.), tench *Tinca tinca* (L.) and common carp *Cyprinus carpio* L., the latter three species present only due to enhancement stocking. This lake is seasonally connected to a smaller lake of 0.75 ha (bottom pond), which then discharges into a tributary of the River Kent (Fig. 1). In March 2003, it was confirmed that the bottom pond also contained *P. parva*, a consequence of individuals being displaced from the fishery during periods of heavy rainfall and subsequent high lake levels.

Following confirmation that *P. parva* was present in the fishery, the risk of its dispersal into the River Kent catchment was determined to be high and unacceptable, so a management plan to prevent this was initiated. Whilst this comprised two main phases – containment and eradication – the initial step was to establish a legislative basis for the plan under the Import of Live Fish Act (ILFA) 1980 (Hickley & Chare 2004). The site was licensed under ILFA (Hickley & Chare 2004) in October 2003 for keeping *P. parva*, with conditions of containment and eradication.

The first phase of the management plan was *P. parva* containment. This involved prohibiting fish movements off the site and screening the main outfall. The screen, however, was shown to be ineffective in preventing the movement of all *P. parva* life stages from the fishery into the bottom pond, with passive movement of individuals of < 20 mm. Containment, therefore, was not successful, and eradication became a necessity to prevent further dispersal.

Prior to the eradication exercise, the method, its time-scale and its evaluation process had to be determined. The eradication method had to consider the small size of individual *P. parva* (12–70 mm) and their high abundance (> 10 m^{-2} in some areas), factors that meant conventional netting or electric fishing methods were not feasible. As a drain-down and fish removal operation was not possible because of the hydrology of the area, the application of a piscicide was considered the only realistic option available. The piscicide chosen was PW Rotenon that contained the active constituents of rotenone (2.5%) (CAS 83-79-4) and piperonylbutoxide (2.5%) (CAS 51-03-6). Fish are acutely sensitive to rotenone poisoning, with aquatic invertebrates less susceptible to its effects (Ling 2002).

The time-scale of the programme had to consider the recreational fishery. To have minimal impact on the

fishery, it was decided that the initial rotenone treatment would be applied in March 2005, with the second treatment only applied when the initial concentration had degraded to low, sub-lethal levels. This timing also ensured that the application commenced prior to any *P. parva* spawning (rotenone is not effective on fish eggs). To minimise losses of the angler target species in the fishery, *C. carpio*, *A. brama* and *T. tinca* > 250 mm, these were removed from the fishery prior to the first application and held off-site until they could be re-introduced at the conclusion of the exercise.

Evaluation of the eradication programme had to consider that two waters were being treated with rotenone, the fishery and the bottom pond (Fig. 1). In contrast to the fishery, access to the bottom pond was limited and marginal areas overgrown, making fish sampling very difficult. Therefore, it was decided that evaluation of the programme would concentrate on the fishery, with less intensive monitoring of the bottom pond. In the fishery, the principal evaluation method was comparison of *P. parva* density before and after the rotenone application.

Methods

The concentration of rotenone required to deliver eradication of *P. parva* was determined by laboratory toxicology tests following Allen, Kirby, Copp & Brazier in press. The recommended rotenone dosage of 0.125 mg L^{-1} for 4 h (Allen *et al.* 2006) was used as the target strength throughout the eradication exercise. To achieve this required concentration of rotenone throughout the water column, the degradation rate of rotenone in the fishery had to be considered, as its half-life is temperature dependent and it deactivates rapidly on binding with suspended solids and bottom sediments (Gilderhus 1982; Dawson, Gingerich, Davis & Gilderhus 1991). Volumetric calculations (Finlayson, Schnick, Cailteux, Demong, Horton, McClay, Thompson & Tichacek 2000) suggested application of 140 L of rotenone in a solution of 3 mg L^{-1} would be sufficient to achieve the rotenone target strength for the required duration in the fishery. In the bottom pond, however, as the water is shallower and there is a greater layer of silt, 30 L of rotenone solution was used at 4 mg L^{-1} to prevent rapid reduction in concentration to sub-lethal levels due to binding and degradation. The solution was applied using modified Oxyjet® equipment that enabled boat mounting, facilitating application to all open water areas and throughout the water column. The shallow, marginal areas and all wetted areas were treated using a back-mounted sprayer. The first application of rotenone in the fishery was on 21 March 2005, with application to the bottom pond the following day.

Following its application, the rotenone breakdown rate was determined from daily water samples, with a bioassay designed to measure active rotenone concentration (Ling 2002). Once the active rotenone levels were at sub-lethal levels and appropriate for fish re-introduction, fish were placed in a keep-cage in the fishery for 24 h to assess their response. If there was no adverse response, then the non-target fish were to be re-introduced and recreational angling re-commence.

To enable evaluation of the eradication exercise, pre-application fish samples were taken in August 2004 and February 2005, and post-application fish sampling was carried out in May and August 2005. All fish sampling was completed by taking samples from multiple points using a combination of micromesh seine netting and electric fishing. The effect of the rotenone application on the aquatic macro-invertebrates was monitored between February and April 2005 using kick and sweep sampling at eight sampling points around the fishery. Samples were taken to the laboratory for identification to at least family level. Their relative abundance was also estimated to enable comparison with samples collected following the rotenone application.

Prior to the initial application of rotenone, the angler-target coarse fish were removed from the fishery in February 2005 using a 100-m long, 20-mm mesh, seine net over a 5-day period. To minimise the chance of transferring *P. parva* to the holding facility and then back into the fishery, each removed fish was checked for *P. parva* presence (e.g. inspection of buccal cavity) a total of four times between their initial removal and subsequent reintroduction.

Results

Pre-eradication

A sample of 450 fish < 70 mm collected in August 2004 revealed that *P. parva* was the dominant species in these size classes in the fishery, with only two *R. rutilus* and one *G. gobio* also present. Electric fishing point samples in February 2005 determined the pre-application *P. parva* mean density in the fishery was $6.1 \pm 3.2\ m^{-2}$. Fork length ranged between 12 (young-of-the-year) and 61 mm (3+) (Fig. 2). No other species was recorded in these samples. The fish removal exercise in February 2005 resulted in 920 kg of *C. carpio*, 142 kg of *A. brama* and 76 kg of *T. tinca* being transferred to the holding facility.

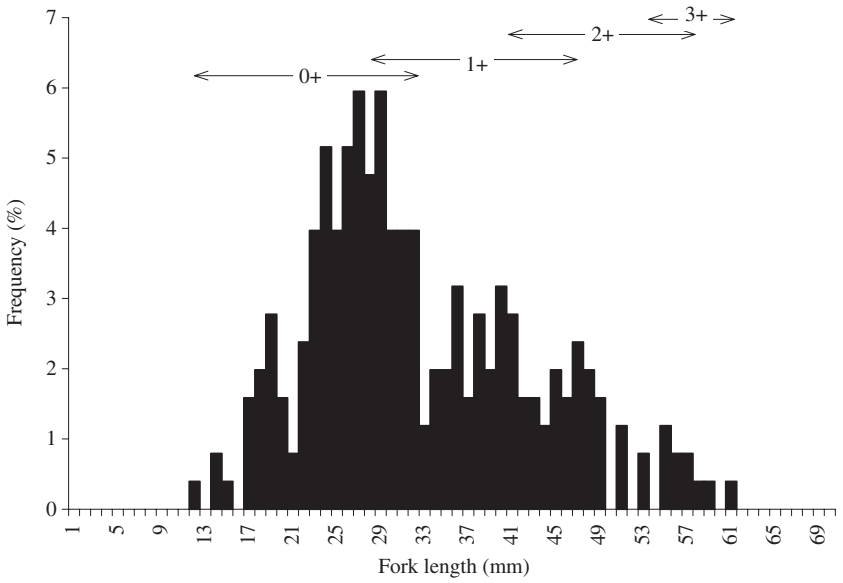

Figure 2. Length frequency of *Pseudorasbora parva* in the fishery, February 2005 ($n = 271$).

Application of rotenone solution

The initial impact (30 min post-treatment) of the application was the appearance of moribund fish in the marginal areas, followed by activity associated with rotenone toxicity and then mortality (> 60 min post-treatment). Although *P. parva* was numerically the principal species recorded, non-target species were also affected, with recovery of 110 kg of *C. carpio*, 36 kg of *T. tinca* and a combined total of 98 kg of *R. rutilus*, *G. gobio* and *A. brama*. Only low numbers of *P. parva* and *A. brama* were recovered from the bottom pond following the initial rotenone application.

Post-application water samples revealed that the rotenone concentration in the lake water exceeded 0.125 mg L^{-1} for 4 days, but only 24 h in the bottom pond, justifying the higher initial concentration of rotenone solution used in this application. Following rotenone degradation in both lakes, the second application was administered on 31 March (fishery) and 8 April (bottom pond). No fish were observed being affected by the rotenone during, and after, this treatment. Following this second application, rotenone levels in the fishery degraded to < 0.05 mg L^{-1} after 9 days; in the bottom pond, this only took 5 days (Fig. 3).

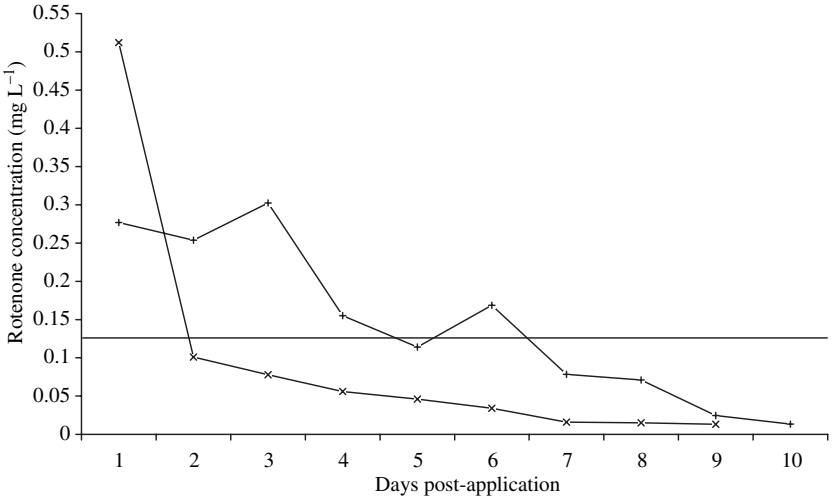

Figure 3. Rate of rotenone degradation in the fishery (+) and bottom pond (×) after the second application. The horizontal line denotes the target strength of rotenone concentration required to achieve full mortality in topmouth gudgeon after 4 h.

Following the rotenone application, there were some shifts in the invertebrate fauna of the fishery, with *Sialis* sp. and cased caddis of the Limnephilidae family most affected. As these species possess external gills, this may have facilitated uptake of rotenone and resulted in mortality of individuals. The group least affected was dipteran larvae, with rotenone application having little or no impact on their species diversity and abundance.

No fish was recorded from the first post-application fish sampling on 3 May 2005, suggesting that the rotenone doses had resulted in full mortality. The fish in the keep cage were then introduced into the fishery for 24 h and all survived, so the angler target species were re-introduced on 26 May 2005 and the fishery re-opened for recreational angling on 16 June 2005. No *P. parva* was recorded from the next fish sampling on 8 August 2005, although young-of-the-year of *C. carpio* and *A. brama*, as a result of spawning by the re-introduced stock, were caught. This represented the first evidence of successful spawning in these species since 2003. Sampling in the bottom pond on both occasions suggested that no *P. parva* was present.

Discussion

Initial evaluation of the exercise suggests that eradication of *P. parva* was achieved, with their removal facilitating the successful spawning of the resident *C. carpio* and *A. brama* in 2005. Anecdotal reports also suggested fishery performance in August and September 2005 was good and preferable to that during the same period in 2004 (G. McKee personal communication). This implies that the exercise was successful in both eradicating *P. parva* and enhancing the fishery for recreational angling due to the removal of this pest species. This apparent success did have a financial implication; although the capital costs of the exercise were not particularly high (e.g. cost of rotenone was only £20 L^{-1}), it required intensive manpower input during key stages. For example, the removal of the angler target species in February 2005 (5 days) and the initial rotenone application in March 2005 (2 days) required a team of at least 10 people to be present daily.

Eradication of alien species has been acknowledged as a valid management option for preventing and/or mitigating the adverse impacts of biological invasions (Genovesi 2005). In Europe, exercises to eradicate alien species are rarely completed, a result of poor legislative support, high cost and public opposition (Genovesi & Bertolino 2001; Genovesi 2005). Opportunities to achieve full eradication usually only coincide with rapid detection of a new alien (Genovesi 2005). In the case of *P. parva* in England and Wales, with at least 25 waters now infected (Pinder *et al.* 2005), it may take considerable effort and resources to even consider a full eradication programme. Strategies that aim to prevent *P. parva* dispersal from infested lakes into river catchments remain realistic management options, with this case study demonstrating that these can incorporate eradication of lake populations using a rotenone-based approach. However, as a result of time and budgetary constraints, economic and feasibility analyses would be required prior to the initiation of further *P. parva* eradication programmes to ensure the benefit of such exercises justifies their overall cost.

Fish removal and eradication exercises are frequently unsuccessful in achieving their aims, often a result of ineffective capture techniques or habitat complexity that provides areas of refuge for the target species that are inaccessible to these techniques. Even when capture techniques are successful, compensatory mechanisms in the population of the target species often buffer the impact of the removal. For example, a programme to reduce the depredation impact of zander, *Sander lucioperca* (L.), on prey fish populations in canals in England actually had the opposite effect, as juvenile recruitment increased after the removal (Smith, Leah & Eaton 1996). An exercise to remove a trout population from a mountain lake in California was also unsuccessful, as the chosen method – gill netting – was unable to capture trout < 110 mm (Knapp & Matthews 1998). Where rotenone has been used, it has not always been successful due to a marked variation in toxic sensitivity between different species and factors, such as water temperature and hardness, also impacting its effectiveness (Meadows 1973). Ponds cleared of undesirable fish species by rotenone are frequently re-infested as the population becomes resistant by directional selection (Orciari 1979). Therefore, the eradication programme discussed here must consider long-term evaluation, so it is recommended that regular monitoring of the fish population be continued for at least a further 3 years. If no *P. parva* is caught or observed in that timeframe, only then it may be said that the species has definitely been eradicated from the fishery.

The variation in rotenone sensitivity according to species and environmental parameters meant it was essential to test the toxicology of rotenone on *P. parva* prior to application, and in water taken from the fishery and at similar temperatures to those that would be experienced in the exercise. This testing successfully found concentrations that would result in full mortality over known exposure times (Allen *et al.* 2006).

However, a variable that also had to be considered was the concentration of rotenone that could actually be sustained in both lakes, given their characteristics and the factors that influence rotenone degradation (Gilderhus 1982; Dawson *et al*. 1991). Indeed, a faster rate of rotenone degradation occurred in the bottom pond than the fishery (Fig. 3), a result of this pond's increased siltation and concentration of suspended solids, despite application of a higher initial concentration of rotenone. Whilst laboratory experiments suggested that the duration of this concentration was sufficient to produce full mortality in *P. parva*, this demonstrated the difficulty of achieving precise rotenone concentrations over specified periods under field conditions. In similar eradication programmes, it is therefore recommended that the target strength of rotenone required to produce full mortality is used only as the minimum concentration to be achieved by the application, with higher concentrations preferable to maximise effectiveness, and to prevent rapid and unpredictable degradation to sub-lethal levels.

Although this eradication exercise appears successful, such programmes should always be viewed as the last control option for invasive fishes, rather than a principal control method, with pro-active protocols to prevent the invasion preferred. To minimise invasion opportunities for non-native fish, introduction control and dispersal prevention is essential. Hickley & Chare (2004) suggested a framework with the principal components of education, legislation, enforcement and audit/review. Non-native fish legislation in England and Wales already makes it an offence to introduce and keep alien fishes without prior consent, with some species also requiring licensing (Hickley & Chare 2004). Genovesi (2005) recommended implementation of policies that allow both early detection and rapid responses to new incursions. Had these been in place in England and Wales in the late 1990s, when *P. parva* was initially detected in a small number of waters, action may have already eliminated them from England and Wales. Instead, *P. parva* has dispersed and it is believed to be present at a number of aquaculture facilities from which fish movements have not been prohibited (Pinder *et al*. 2005), thus facilitating inadvertent movement within contaminated batches of fish. Therefore, implementing eradication exercises at infected sites with connectivity to river catchments may not be sufficient to prevent further dispersal of *P. parva* in England and Wales. Actions to prevent this dispersal should include:

- eradication of *P. parva* populations from infected aquaculture facilities and infected waters that have connectivity to river systems;
- increased auditing of fish introductions into sites with connectivity to river catchments, with screening for the presence of all *P. parva* life stages, from larvae to mature adults (Maitland 2004; Pinder 2005);
- increased public dissemination of information on *P. parva* identification and presence in England and Wales through appropriate national and angling media to facilitate early detection of newly infected waters.

Without implementation of actions such as these, the presence of *P. parva* in fisheries is likely to increase and result in the species becoming an addition to the permanent ichthyofauna of England and Wales. Notwithstanding this, eradication of *P. parva* from lacustrine fisheries does appear feasible using a rotenone-based approach.

Acknowledgments

The authors wish to thank the Windermere, Ambleside and District Angling Association for their co-operation throughout the programme, numerous colleagues in the Environment Agency (North-West Region, National Fisheries Laboratory and National Laboratory Service), Brian Finalyson and colleagues of the US Fish and Game Service for training in rotenone application and Gunnar Persson of InterAgro for technical and logistical advice. Also thanks to Ian Winfield for information on the initial positive identification of topmouth gudgeon in the fishery. The views expressed in this paper are those of the authors and not their parent organisation.

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