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ORIGINAL PAPER

Empirical development of strategy for the control of invasive American mink by trapping

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Abstract American mink (*Neovison vison*) are an ecologically damaging invasive species in Europe and Iceland where attempts to control them typically rely on trapping. The focus and efficiency of trapping can be improved by using track-recording mink rafts to identify where mink are present before traps are deployed. This paper describes development of operating strategy for the use of mink rafts with traps, to optimise capture efficiency against costs. We worked sequentially on two unconnected chalk streams in central southern England. On 17 km of the River Itchen, we operated a very high density of rafts (5.9 per km) through spring and summer to generate multiple detections of each mink present. All rafts recording mink tracks were armed with traps, and captured mink were euthanased. After removal of mink until no further detections were made, we calculated that each mink was detected 5.3 times at 5.1 raft sites, and on this basis, rationalised raft density to a standard one per kilometer of river. We set a trap deployment time (10 days) that encompassed the longest observed lapse from detection to capture (7 days), and extended the check interval for rafts in monitoring mode from 1 week to 2 weeks to further reduce costs. These operating rules were then deployed for 12 months on the 44-km River Wylye beginning in autumn. Rafts indicated that the river was cleared of mink through the capture of seven individuals, each of which was detected 3.6 times at 2.7 raft sites, on average, and was trapped within 6 days of detection giving a response time of less than 20 days. Although these operating rules may need refinement for other environments, we believe this is a sound basis for effective mink control.

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Introduction

The negative impact of American mink (*Neovison vison*) as an introduced species on native ground-nesting birds, rodents, amphibians, and European mink (*Mustela lutreola*) in Europe and Iceland has been widely acknowledged (see reviews by Bonesi and Palazon (2007) and Macdonald and Harrington (2003)). In the UK, the most dramatic documented impact has been on the water vole (*Arvicola terrestris*), which has been in steep decline due to predation by mink and habitat loss. National water vole surveys in 1989–1990 and 1996–1998 (Jefferies 2003) showed a 67% decline in occupied sites and an estimated 88% decline in abundance during this period. This decline has been the impetus for many of the local mink control programs in the UK (Strachan and Jefferies 1993; Strachan and Moorhouse 2006).

Trapping has been regarded as the most effective way to reduce mink numbers (Macdonald and Strachan 1999). In conventional practice, traps are set speculatively using knowledge of the habits of mink to anticipate where they would travel and what features would provoke investigation and capture (Dobbins 1991; Harding 1906; Melero et al. 2008; Moore et al. 2003). Catches from trapping in this way were highest in early spring (mating season) and autumn (dispersal season); it was found to be relatively unsuccessful in late spring and summer (Bonesi et al. 2006; Moore et al. 2003). When traps caught no mink, the operator faced a dilemma. Was the trap in the wrong place, was the trap avoided or visited but not triggered, was the bait unattractive, or was there no mink in the vicinity to catch? In any of these cases, the only animals caught would be non-targets. In the UK, potential non-targets include species of conservation concern (e.g., water vole, otter [*Lutra lutra*], polecat [*Mustela putorius*]). The use of too many traps, deployment for too long a period, poor trap placement or an unattractive bait could all create situations in which some or all traps were unlikely to catch mink. There was also uncertainty about how many mink might be present on a given stretch of river and whether it was possible to remove them faster than they could be replaced. Little or no advice was available on how much trapping effort was needed to achieve an impact on mink numbers that significantly reduced predation on prey species, although on the basis of simulation models, Bonesi et al. (2007) recommended trapping for at least 3 months per year, coordinated at a regional scale. Harrington et al. (2009) found that for local control, 3 months was indeed the minimum to ensure water vole persistence and that a rapid response to immigration outside the main trapping seasons was essential. In many European countries, legislation requires that traps are checked daily, so the use of too many traps or lengthy deployment carries unavoidable cost implications.

The GWCT Mink Raft (Reynolds et al. 2004; Reynolds et al. 2009) leads naturally to a focussed control strategy in which traps are set only in response to detection of a mink at a site. The raft was designed to house either a recording medium (a clay-based mixture irrigated by capillary action) or a trap. Reynolds et al. (2004) showed that the mink raft was a more efficient detector of mink presence than were field sign surveys, speculative trapping or incidental sightings of mink, and this was confirmed experimentally by Harrington et al. (2008). Precise location of the raft was not an important determinant of detection rate (Reynolds et al. 2010), implying that specialist skills are not required to deploy rafts. Repeated visits to rafts were observed at sites occupied by mink with the probability of a visit equal to 0.4–0.6 per mink raft and 2-week check period (Reynolds et al. 2010). This suggested that having detected a mink on a raft, the raft itself is a good place to locate a trap. Furthermore, provided rafts were deployed at a density that ensured multiple opportunities (i.e., rafts or check periods) to detect any mink present, trapping could be suspended with confidence while there were no detections of mink. This would substantially reduce trap use and hence operator costs and non-target impacts.

In this study, we sought to develop recommendations for the use of mink rafts to guide trapping, specifically (1) the distance at which mink rafts should be spaced apart, (2) the number of days between raft checks in monitoring mode, and (3) the maximum duration of each trap deployment. We did this through two sequential mink removal projects on unconnected chalk streams in central southern England. Both projects were funded and undertaken as conservation actions to protect water vole populations, but this paper concentrates on mink control methodology rather than the response of water voles. In the first project, we used a very high raft density to ensure multiple detections of each mink. Data from this project allowed us to determine more parsimonious raft spacing and rules for raft and trap management. We then implemented this strategy on a longer river to verify efficiency in depleting mink numbers. This study did not aim to determine whether trapping in this way could have a sufficient impact on mink numbers to benefit prey species.

Study area

The study took place on two unconnected chalk streams in central southern England: (1) the lower reaches of the River Itchen, a 17-km stretch with braided channels (43 km total channel length) having an average channel width of 12 m between Tumbling Bay (51°02′N, 1°19′W) and Woodmill (50°56′N, 1°22′W); (2) the River Wylye, a 44-km stretch with an average channel width of 8 m from Brixton Deverill (51°09′N, 2°12′W) to the confluence with the River Nadder at Quidhampton (51°04′N, 1°50′W). The river had two small tributaries: the River Till (12 km) and the Chitterne Brook (7 km). Rafts were set only on lower reaches of these tributaries as the upper reaches were dry for much of the year. Both rivers flow through unimproved grazed floodplain meadows and are designated as Special Areas of Conservation under the EU Habitats Directive due to abundant instream water crowfoot (*Ranunculus* spp.) communities (Harrison and Harris 2002; Ladle and Westlake 1995). In comparison to the Wylye, the Itchen is more intensively managed for fly fishing with riverside habitat typically protected by fencing from livestock grazing and trampling allowing more abundant marginal macrophyte communities. Some mink trapping by river keepers was known to have taken place on both rivers prior to this study; this was mostly unrecorded, but eight mink were known to have been trapped on the Wylye between November 2002 and March 2003.

Materials and methods

River Itchen

We constructed and deployed rafts as described in Reynolds et al. (2004). Between 24 March and 16 April 2003, we deployed 101 rafts sequentially from south to north so that we could maintain a consistent rolling programme of weekly raft checks when in monitoring mode (Fig. 1a). We were able to check approximately 24 rafts per day. We selected sites that were convenient for access at approxi-

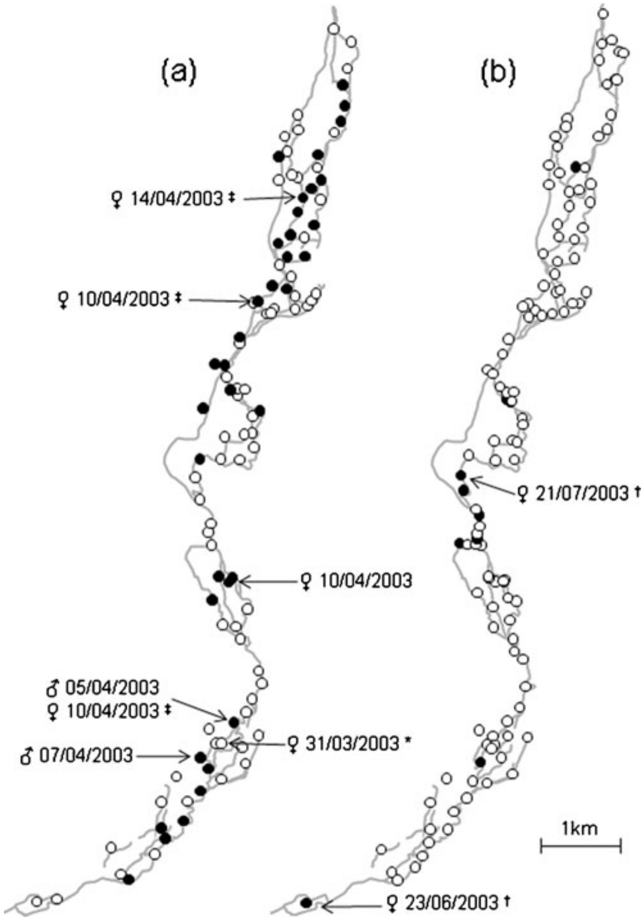

Fig. 1 Positions of mink rafts in 2003 on the lower River Itchen in southern England: **a** weeks 1 to 4 inclusive 31 March to 25 April and **b** weeks 11 to 18 inclusive 1 June to 1 August. *Filled symbols* indicate rafts on which tracks identified as mink were detected during each period. No mink were detected in weeks 5 to 10. Capture locations are *arrowed* with sex and date indicated. *Asterisk* indicates shot nearby, *double dagger* indicate pregnant female, and *dagger* indicate lactating female

mately 300-m intervals along all river channels where these were likely to retain water during the summer. This spacing was chosen by reference to published literature on summer home-range size for female mink (Dunstone 1993: females average 2.1 km of linear riverine habitat, range 1.2 to 3.2 km; males average 2.5 km, range 1.6 to 4.4 km) to make several rafts available to each mink present. All animal tracks on a raft were recorded under the categories: mink, otter, water vole, other mammal, Gallinule (i.e., coot [*Fulica atra*] or moorhen [*Gallinula chloropus*]), or other bird. Any other field signs (e.g., faeces) on rafts were also recorded. Following each check, the tracking substrate was smoothed over or replaced if dirty, and the raft base was cleaned using a metal scraper and a stiff brush with water to remove field signs.

The start date was taken as the 24 March 2003, and the first raft check (of seven rafts) took place on 31 March 2003 (start of check week 1). Between 1 May and 5 June 2003 (weeks 6 and 10), 43 of the rafts on the main river channel were moved approximately 150 m downstream, with the aim of detecting any mink that had exceptional local activity (Fig. 1b). From 5 May 2003 (week 6), we deployed 19 rafts at additional intermediate sites following mink detections (tracks or sightings) to increase the probability of capture. On 16 June (week 12), three more rafts were added in an attempt to catch a detected mink; traps were run at these sites for 2 weeks before being removed. Raft density was two to seven per kilometer depending on the stage of the study and on how eligible channels were defined. On the principal river channel, 55 rafts were initially deployed at a density of 3.2 per km (average 312 m apart, range 131–983 m). By the end of June 2003, 120 rafts had been used at 163 sites on multiple channels, sampling them at an average of 265-m intervals (range 95–983 m); average straight-line separation was 170 m (range 50–860 m). The study ended on 1 August 2003 (week 18).

On detecting mink at a raft site, we replaced the tracking cartridge with a single-entry live-capture cage trap measuring 60×18×15 cm (Rhemo Products Ltd., New Milton, Hampshire, UK). No bait or other attractant was used. Physical excluders consisting of two vertical wooden dowels defining a central aperture of 17.5×6 cm and two smaller side apertures were fixed in the tunnel entrance to exclude non-target species larger than mink (Reynolds et al. 2009). Traps were checked daily until removed and were set for a maximum of 28 consecutive days at a given site. If a mink capture occurred, we replaced the trap with a tracking cartridge and weekly raft checks were resumed at that site. From May 2003 (week 9), we reduced trap deployment to a maximum of 14 days to improve efficiency and reduce non-target captures in the light of accumulating data on capture times and post-capture detections of mink.

Captured mink were confined and immobilised at the end of the cage trap by means of two plywood partitions with long slots allowing them to be inserted through the mesh of the trap from above and were then shot in the head at point-blank range using an air pistol (.177 Webley 'Hurricane', nominal muzzle velocity 420 fps; Webley and Scott Ltd., Birmingham, UK) loaded with steel-pointed pellets (Prometheus®, Pax Guns Ltd., London, UK). After dispatch, mink were sexed, and females were examined for signs of lactation. In the case of three lactating females, we operated traps for a week following each capture in case dependent young followed their mother's scent. Captured mink were classified as juvenile (in their birth year) or adult (in their first adult year or older) on the basis of pulp cavity occlusion (both sexes) and baculum weight (males).

River Wylye

We initially selected 46 raft sites in the same way as on the Itchen but spaced at approximately 1-km intervals along river channels (average = 1.0 km, range 0.2 to 2.6 km). We intended this spacing to minimise effort while creating at least one opportunity to detect each mink present on each check occasion guided by results from the Itchen (Fig. 2). Three extra sites were added on 15 October (week 8) near existing raft sites showing high mink activity. In week 35, a further raft was added. Near the end of the study, in an attempt to catch a detected mink while avoiding dense colonies of water voles, six more rafts were added in weeks 44 to 48. We followed the same raft-checking protocol as on the Itchen but with a longer 2-week check interval. The start date was 25 August 2003 and the first check took place on 8 September (check week 2). At each site, we deployed two rafts approximately 25 m apart to allow a concurrent paired trial of two alternative trap types (one of each trap type deployed at each site). Rafts this close together are not independent (Reynolds et al. 2010); hence, detections were consolidated by site. As the two trap types proved equally likely to catch, we terminated the trap comparison study in April 2004 when one raft from each pair was removed. All remaining rafts were removed during September 2004. The final layout of 52 rafts could be checked by two fieldworkers in 2 days.

We used the same trapping procedures previously employed on the Itchen except that traps were set for ten consecutive days at a given site, after which we returned the raft to monitoring mode. Some trap deployments were continued for up to 12 days to allow the reset raft to fit into the same check schedule as nearby rafts; the impact of this on mink detections was considered to be negligible provided the probability of a mink visit was equal whether the raft was in monitoring or trapping mode. We set traps on both rafts of a pair if mink tracks were found on either raft. Similarly, if a mink was caught on either raft of the pair, we replaced both traps with tracking cartridges. Because adult females may be accompanied by their young in late summer, we checked rafts 1 and 3 days after returning them to monitoring mode following trap deployment. If mink were not detected at this stage we resumed two weekly checks. All mink caught were euthanased as on the Itchen.

Results

River Itchen

Mink detections and captures

The history of mink detections and captures is summarised in Fig. 3a and mapped in Fig. 1a. Most detections and captures occurred in weeks 1 to 4 when we found mink tracks (Fig. 4) at 36 out of 96 raft sites (38%) leading to the capture of six mink. Another mink was shot by a river keeper on the first day of raft checks; this mink could have left tracks on rafts and is, therefore, included in relevant calculations.

During weeks 4 to 10 inclusive, there were no mink detections at any of the raft sites (Fig. 3a). None of the raft sites established during weeks 6 to 10 detected any mink during the first four weekly checks after moving. There were three subsequent detection events separated in time (Fig. 3a) involving ten out of 118 (8%) raft sites (Fig. 1b). The first two of these ended with the capture of a mink; the third occurred on the last day of the study and was left unresolved.

By the end of week 18 (31 July), there had been 48 separate detections of mink (i.e., rafts × check occasions

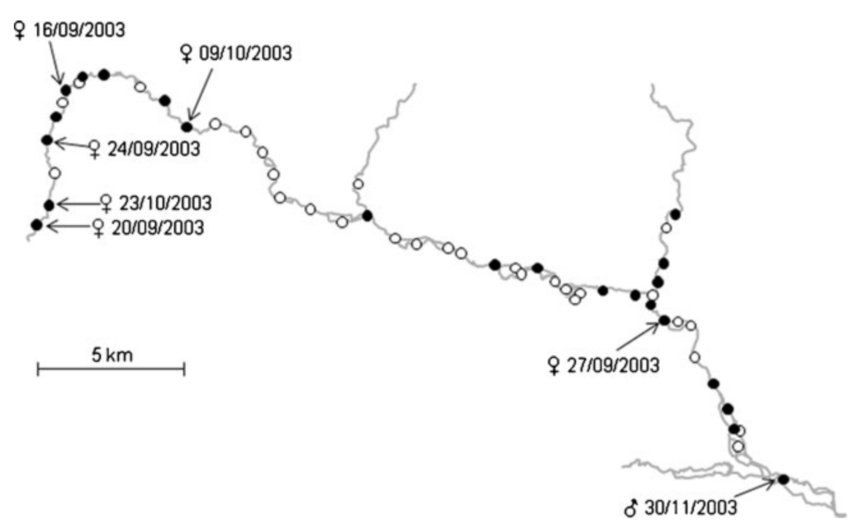

Fig. 2 Positions of mink rafts on the River Wylye in southern England, 8 September 2003 to 26 August 2004. *Filled symbols* indicate rafts on which tracks identified as mink were detected during each period. Capture locations are *arrowed* with sex and date indicated

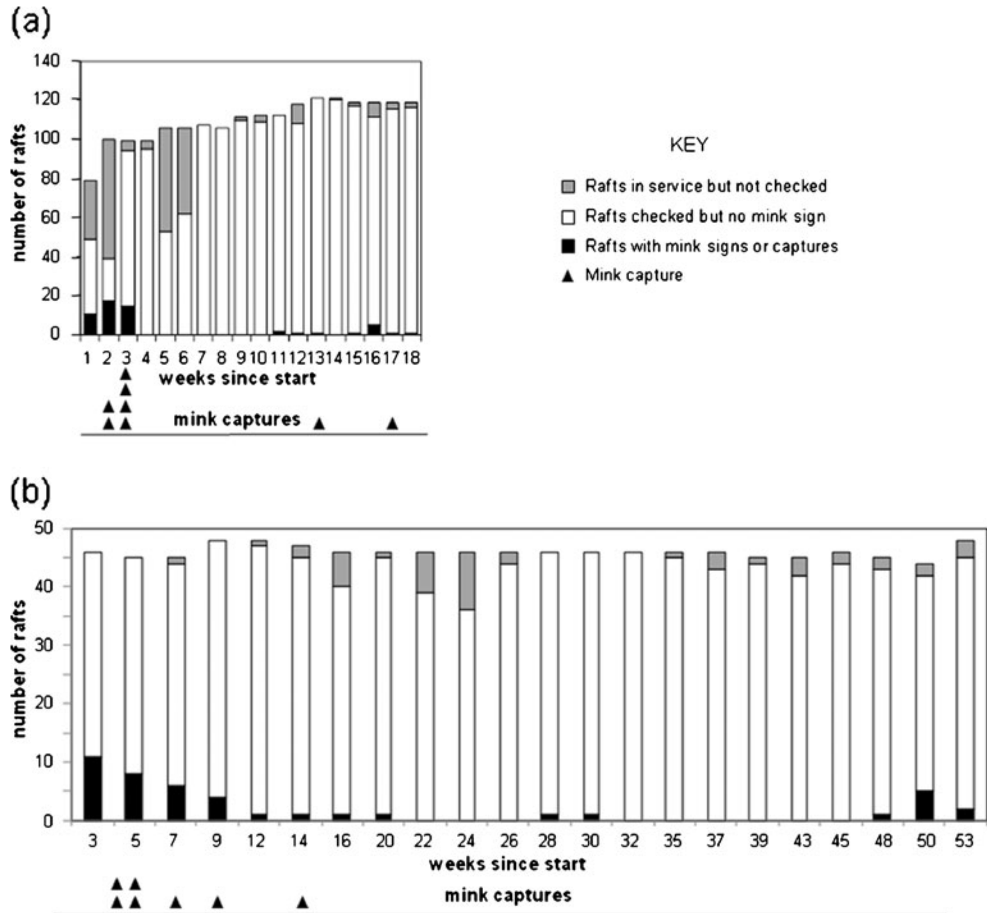

Fig. 3 The percentage of raft sites with mink detections (either tracks or captures) in each check period during two projects in southern England: **a** the River Itchen during March through August 2003, and **b** the River Wylye during August 2003 through August 2004. Mink captures are indicated below the horizontal axis by *triangles* (one per capture). In certain weeks when manpower was diverted to other tasks (e.g., to establish new raft sites), not all rafts in service (i.e., capable of recording mink tracks) were checked, but any tracks recorded by rafts would have been logged against the following week

excluding captures), and mink tracks had been recorded at 46 out of 163 raft sites (28%). Nine mink were killed, eight of which were trapped and one shot by a river keeper. Assuming all mink responsible for the tracks had been killed (see "Discussion"), each of the nine mink had been detected on 5.1 different rafts and 5.3 times before capture on average. Traps were deployed on 52 occasions for a total of 1,016 trap-days (1 trap-day = 1 trap set for 24 h) averaging 127 trap-days per mink capture. Two cases where tracks were misidentified caused additional 13 deployments (263 trap-days).

Fig. 4 Mink tracks accumulated over 7 days on the tracking medium of a mink raft on the River Itchen, southern England, photographed on 10 April 2003. The track-recording area measures 24×15 cm

For successful traps, the average number of days between detection and capture was 4.9 (range 2 to 7). All mink trapped were adults. The six mink trapped during the first 3 weeks were four females (three lactating; one pregnant) and two males. Two mink trapped later were both female (both pregnant). The average distance between captures was 2.9 km for female captures and 0.7 km for male captures.

Non-target captures

Non-target captures in the trapping period 31 March 2003 to 1 August 2003 (with numbers caught) were water vole (5), grey squirrel (*Sciurus carolinensis*; 3), moorhen (1), brown rat (*Rattus norvegicus*; 1), and mallard (*Anas platyrhynchos*; 1).

River Wylye

Mink detections and captures

The history of mink detections and captures is summarised in Fig. 2b and mapped in Fig. 3b. Mink tracks were recorded on 19 out of 49 raft sites (39%) by week 9, which led to the capture of seven mink by week 14. Between weeks 15 to 44, mink tracks were found on three out of 50 (6%) raft sites, but no mink were caught on these rafts when traps were placed in response. These instances were both spatially isolated (average distance between detections = 14.2 km) and temporally isolated (detection at each raft site only occurred in a single check period) and it seemed likely that the mink had moved on before traps were deployed. During weeks 46 to 52, eight further detections occurred at seven raft sites. No mink were caught despite four extra rafts deployed and traps run for between 6 and 8 days after which traps on these 11 rafts were removed due to frequent captures of water voles. In summary, through the 12 months from 25 August 2003 to 26 August 2004 (weeks 1 to 52), mink tracks were recorded on 23 out of 52 sites (44%). Raft position at each site (i.e., upstream or downstream member of the pair) had no influence on mink detections ($\chi_1^2=0.0636$; $P>0.05$).

Seven mink were caught, six female mink during the first 9 weeks and one male mink at week 14. Captures were made at seven out of 32 (22%) trap sites. Traps were set for 510 trap-days (counting traps on paired rafts at each site as one trap deployment) averaging 73 trap-days per capture. Out of 40 trap deployments, four were run for 11 days and four for 12 days; average deployment time was 7.6 days. For successful traps, mink captures were made on average 3.3 days after deployment (range 1 to 8). As all captures were made after the end of the breeding season during September to November, no attempt was made to classify these mink as juvenile or adult. No mink were detected or caught in a central section of river (Fig. 3b), where eight mink had been killed in the 12 months prior to our study. For the five females caught upstream of this section, the mean distance between captures was 2.8 km.

Non-target captures

Non-target captures (with number caught) were water vole (39), stoat (*Mustela erminea*) (2) and water rail (*Rallus aquaticus*) (1). Thirty-one of the water vole captures occurred during weeks 49 and 50. Three water vole fatalities (one of which had been predated from outside the trap) and one stoat fatality were recorded.

Effort

Results of the two studies are summarised in Table 1. Despite a higher proportion of sites detecting mink, the revised operating strategy used on the Wylye reduced trapping effort per mink caught by 53% compared with the 'scoping' strategy on the Itchen. In both studies, with their different operating regimes, manpower costs made up the highest proportion of total cost (between 35% and 39%). Vehicle running costs and fuel were the next highest cost (22% to 26%), while the cost of the raft materials accounted for less than 5% of the total cost (Tables 2 and 3). The revised operating rules (lower raft density and two weekly check intervals) reduced the cost of monitoring and trapping (per kilometer of river corridor per week) from £203 on the Itchen to £14 on the Wylye (Table 3). On the Wylye, 113 man-days were expended in making 25 checks of the entire raft layout in the course of 12 months plus associated daily visits to traps while set.

Discussion

The intention of the raft-guided mink control strategy is to improve the focus of trap use, reducing the redundancy that occurs in any trapping program. In a conventional speculative trapping program, there are three conceivable causes of redundancy:

(1) The trap is not within the activity range of any mink.
(2) The trap is within the activity range of a mink but is not visited because of poor location or an unattractive trap 'set'.
(3) The mink that might have visited the trap has already been caught elsewhere.

All of these are reduced through the guidelines developed in this study.

Table 1 Summary statistics for mink control on two rivers in central southern England using mink rafts

	Itchen	Wylye
Length of river corridor (km)	17	44
No. of raft sites	163	52
No. of sites detecting mink	47 (29%)	23 (44%)
No. of mink captures	8	7
Trap-days per mink caught (mean)	155	73
Raft check interval (in monitoring mode; days)	7	14
Response time[a] (mean in days)	12	20

[a]Response time is the maximum possible lapse between the first visit of a mink to a raft and its capture

Table 2 Breakdown of unit costs incurred using GWCT mink rafts for control of American Mink on a river in central southern England in 2003–2004 using the operating rules developed in this paper

Staff costs (per person)	£
Salary (£)	15,000
Daily staff cost[a,b] (£/day)	62.50
Hourly staff cost[c] (£/h)	7.81
Vehicle costs	
Provision of vehicle (£/day)	9.37
Running costs (£/mile)	0.63
Raft construction (£/raft)	17.58
Raft materials (£/raft)	16.00
Replacement of clay mix (£/raft)	0.22
Cage trap (£/trap)	15.00

[a] Daily costs based on 300 working days per year

[b] Including empolyer's costs at 25% of salary

[c] Hourly cost based on an 8-h working day

Raft spacing and positioning

Following the high density scoping strategy used on the Itchen, we reduced the number of rafts from approximately 5.9 per km of river corridor to 1 per km. This was still dense enough to result in multiple detections of each mink on the Wylye. On the Itchen, 36 rafts recorded mink tracks in weeks 1 to 4, but none of these recorded or caught mink during weeks 5 to 18 after six mink were removed. Thus, on average, each of these mink had made tracks on six rafts, given spacing (at that time) of six rafts per kilometer. On the Wylye, 19 rafts recorded mink tracks in weeks 1 to 9 leading to the removal of six mink; thus, on average, each mink had made tracks on 3.2 rafts given a spacing of one raft per kilometer.

This empirical progress towards optimal spacing makes the assumption that all mink detected were caught. This seems reasonable for the 36 raft sites and six mink in weeks 1 to 4 of the Itchen study and for the 19 raft sites and six mink in weeks 1 to 9 of the Wylye study. Later detections on the Itchen (in July 2003, weeks 16 to 19) were widely scattered and not clearly related to the subsequent two captures, although the number of detections rose from zero before each capture and fell again following it. Similarly, on the Wylye, only three detections occurred in the 30 weeks between 27 November 2003 and 2 July 2004. These occurred in weeks 19, 28 and 30 and were separated spatially by eight and 22 rafts that made no detections. Sixteen hounds from the visiting Border Counties mink hounds were used on 31 March and 6 April 2004 to draw a total of 20-km river channel and surrounding meadows in two continuous areas surrounding raft sites where mink had been detected. No mink were detected by the hounds. Hence we believe that these detections on rafts were made by transient individuals. Eight mink detections late in the study (14 July through 26 August, weeks 46 to 52) were more coherent but were not resolved before the end of the study at week 52.

Table 3 Overall costs for American Mink control in central southern England: on the River Itchen from March 2003 through July 2003 and on the River Wylye from October 2003 through August 2004. The Itchen study used an intensive 'scoping' strategy, the results of which led to revised operating rules for the Wylye. Costs per kilometer of river for the Wylye are indicative of a typical mink control campaign using mink rafts and employed fieldworkers working from a single base

River		Itchen	Wylye
Operating strategy		Scoping	Revised
Raft density (per km)		5.6	1.0
Raft check interval (days)		7	14
Max trap deployment (days)		28[a]	10
Number of weeks		18	52
Number of rafts running		120	50
Manpower costs:	*Office and meetings (£)*	*4,090*	*3,020*
	Making rafts (£)	*2,109*	*879*
	Setting and monitoring rafts (£)	*7,531*	*5,970*
	Trap checking (£)	*3,492*	*1,803*
	Sub-total (£)	17,223	11,671
Vehicle fixed costs (£)		2,033	2,061
Vehicle running and fuel costs (£)		9,674	8,440
Raft materials (£)		1,920	800
Replacement of clay mix (every 8 weeks) (£)		58	70
Traps (£) at £15 each		450	165[b]
Institutional overheads at 40% (£)		12,520	9,255
Total cost (£)		43,878	32,462
River corridor length (km)		17	44
Total cost per km per week (£)		203	14

[a] Reduced to 14 days for weeks 9–18

[b] The cost of traps needed will clearly depend on the initial density of mink. If initial site occupancy had been 100%, trap costs would have been £750 increasing mink control costs by £0.55 per km per week

Given a position at the margin of the river channel, raft location is apparently not critical for mink detection. Reynolds et al. (2010) showed that two rafts less than 50 m apart were not independent: visits to either raft were equally likely, and a visit to only one of the two was less common than expected. In effect, the pair acted like a single detector. Our later experience on the Itchen and Wylye supports this understanding because (a) within the main river channel, detections tended to be made on 'chains' of adjacent rafts; (b) on each river, only a few mink were apparently responsible for tracks left at a large number of rafts; (c) shifting raft positions by 150 m on the Itchen did not generate a sudden increase in mink detections; and (d) the mink detected were captured swiftly without the addition of bait or other attractant to the raft. Thus, redundancy due to poor technique is largely avoided by the use of rafts.

Furthermore, using rafts, we were able to efficiently capture female mink during the summer kit-rearing season, a time of year when trapping was previously considered ineffectual (Moore et al. 2003; Bonesi et al. 2007). By starting the Wylye study in autumn, we also showed that the strategy was no less effective in the main dispersal season when individual mink are expected to be less sedentary and therefore, less likely to revisit rafts.

Raft check interval

On the Itchen, rafts in monitoring mode were checked once per week to ensure that any mink present were quickly removed. Because captures occurred on average 5 days after trap deployment, the whole process from raft deployment (or mink arrival) to capture took on average 12 days. On the Wylye, the raft check period was increased to 2 weeks. The resulting increase in response time to 20 days did not apparently affect the achievement of depopulation.

Flexibility over check interval length would nevertheless be advisable to respond to more challenging circumstances. For instance, towards the end of the Wylye study, water vole densities were locally very high and we noticed that mink tracks could be obscured within a few days by water vole tracks and latrines. Territory-holding water voles scent-mark at latrines by stroking their hind feet across lateral scent glands on their flanks and then drumming them on the latrine (Macdonald and Strachan 1999). On mink rafts, this rapidly obliterates any other tracks, and in such circumstances, a shorter 1-week check interval seems advisable.

Bait

We used no bait or other attractant in our traps because repeated detections on the same raft suggested that mink re-visited unbaited rafts. An earlier experiment had shown that a commercial mink attractant did not increase the probability of detection at a raft (Reynolds et al. 2010). In this study, the speed with which mink were caught once traps were deployed (most commonly within 24 h, mean = 4.3 days) and the following drop in detections showed that, in general, detected mink were easily caught without bait or scent attractant.

Maximum duration of each trap deployment

There is no need to run traps where there is no mink to catch so logically a trap that has made a capture can be removed and the raft returned to monitoring mode until it indicates that other mink are present at the site. However, where a trap set in response to mink tracks fails to catch a mink within a reasonable time frame, some operating rule is needed to determine when the trap deployment should be terminated. This is because the mink responsible for the tracks on that raft may have been caught on another raft or died from another cause or may have moved away. Limiting the duration of each trap deployment is desirable to reduce manpower costs and non-target captures.

Preliminary work in 2001 using a camera system triggered by a passive infrared detector had shown that at natural sites with mink field signs, the interval between mink visits could be 2 to 3 weeks (Reynolds et al. 2004). This determined our initial decision to run traps for up to 4 weeks on rafts where mink had been detected. As with the initial raft spacing, this was intended to minimise the risk of failing to catch mink that were, in fact, present.

All captures on the Itchen were made within 7 days of trap deployment (mean = 4.8 days). Although there was the possibility that the individual caught was not the one that left tracks on the raft, this finding—together with the density of mink tracks on some rafts—suggested that mink re-visited rafts at intervals of just a few days. Hence, to reduce the risk of non-target captures and to reduce effort, trap deployment was limited to a maximum of 10 days on the Wylye. If any mink remained uncaught at these sites, they would be detected in turn and trapped later. On the Wylye, all mink captures were made within 8 days of trap deployment (mean = 3.3 days) supporting the operating rule.

Non-target captures

Most of the trapping on the Wylye took place between September and March, and non-target capture rate in this period was very low (six per mink on the Wylye in weeks 1 to 47). In weeks 49 to 50, this record was spoiled by 31 captures of water voles in 98 trap-days at 14 adjacent raft sites within a 9-km stretch of river during unsuccessful attempts to catch a mink detected at 11 of these sites shortly before the end of the project. Intensive use of rafts by water voles, whose latrines and tracks could obscure mink tracks, made this especially difficult. The exceptionally high water vole activity around these rafts at this time followed a 32-week period without mink detections during which water vole detections on mink rafts became increasingly frequent with field encounters suggesting a considerable population increase during spring and summer 2004. In the light of subsequent experience, we would now shorten the raft inspection interval to 1 week during peak mink dispersal periods (mid February to mid April, mid July to end September) giving a shorter response time and reduced risk of mink tracks being completely over-printed by water vole tracks.

Cost efficiency

In our raft-guided strategy, efficiency is improved by first identifying sites in current use by mink and then by limiting each trap deployment to a maximum of 10 days. Trap use is, therefore, suspended while there is no evidence of mink at the site. This reduction in trap use led to a mink capture rate of 73 trap-days per mink on the Wylye. Combining visits to rafts in monitoring mode and in trapping mode, the overall 12-month effort on the Wylye amounted to 293 site visits per mink capture. Had we been running single rafts at each site (rather than pairs for experimental reasons), the number of trap-days would have been halved at 255; if catch rate was unaffected, this would have meant only 26.5 trap-days per mink capture.

We can reasonably compare our findings with what might have happened if we had operated traps speculatively at every raft site. Bonesi et al. (2007) concluded that if trapping gave an average probability of capture of 0.5 per mink per month, at least 3 months of trapping per year were necessary for effective control. There were 52 raft sites on the Wylye. If seven mink were caught within 3 months (4,680 trap-days), the efficiency would be 669 trap-days per mink. Assuming a non-target catch rate of 0.0824 per trap-day as observed, an estimated 386 non-target captures might also have been made. Four man-days were required to visit all rafts on the Wylye; daily trap inspections at each site would, therefore, have required four fieldworkers daily or 480 man-days to cover 3 months of the year. In our study, 113 man-days were expended in checking rafts and traps through 12 months despite the extra burden of running two rafts at each site.

It is arguable that if 52 traps had been operated for 3 months (i.e., 4,680 trap-days rather than 510 trap-days as on the Wylye), they might also have caught mink that in our study were detected but not caught because of the delay between detection and trap deployment. There were 11 unresolved detections on the Wylye. These mink were clearly not regular users of the raft array, and we believe that they were most likely transients dispersing through the river system. If (in the worst interpretation) each detection represented a different mink and if all could have been caught in 3 months of trapping, the total catch by speculative trapping might perhaps have been 18 mink suggesting an efficiency of 260 trap-days per mink. In terms of minimising trap use, this still compares poorly with the 73 trap-days per mink in our study. If indeed these mink were transients, their capture may not have contributed as much towards the ecological aims as the capture of residents, particularly breeding females.

While Bonesi et al. (2007) recommended a minimum of 3 months trapping from computer simulations, Melero et al. (2008) recommend setting traps at five times our raft density. Furthermore, in the context of water vole conservation, Harrington et al. (2009) stressed that a rapid response to mink presence was critical, requiring continual monitoring outside main seasonal trapping periods. Our strategy gave year-round monitoring and the response to mink detections averaged 20 days (14-day inspection interval plus average number of days between detection and capture).

Compared with speculative trapping, it seems likely that where mink density was high, a raft-based strategy would be slower to catch the same number of individuals, though ultimately no less successful. Where mink density is low, e.g., as the result of successful trapping, the raft approach inevitably becomes more efficient by avoiding daily visits to traps. Critically, the raft-guided strategy indicates effectiveness in terms of mink presence or absence on a continuous basis.

Financial costs

The financial cost of effective control is rarely reported, but this information is valuable to guide management choices. It is difficult to evaluate the cost of effective mink population control by conventional speculative trapping because typically its effectiveness is unknown. Declining catch or catch-per-unit-effort are usually the only measures available to suggest a reduction in population size, but both are ambiguous and may be unreliable when population density is low (e.g., as a result of trapping). Trapping effort is usually limited by resources, but operators may also be unwilling to increase effort, knowing from experience that this is met by lower catch per unit effort. Once mink numbers become low and survivors hard to find, it is especially hard to devise a strategy that ensures effectiveness while minimizing financial and non-target costs.

By contrast, a raft-guided mink trapping strategy provides continuous re-assessment and can be costed per unit time and space. Daily site visits are not necessary while trapping is suspended, although the savings incurred in this way are compromised if the operator must nevertheless make a similar journey to check a trap that is set at a nearby site. For this reason, costs cannot be divorced from field logistics and mink population density so the optimal strategy will depend on circumstances. However, our intention was to develop guidelines to serve as a starting point, and in this spirit we have costed the overall effort of both our 'scoping' study (Itchen) and of the 'guideline' study (Wylye) to serve as illustrations. The deliberately over-intensive 'scoping' strategy first used on the Itchen was expensive at £203 per kilometer per week. Once raft density and check interval had been rationalised, the cost of mink removal and control over 12 months on the Wylye was reduced to £14 per kilometer per week. Thus, effective mink control remains expensive. Around 70% of costs were manpower-related (salaries and employer's costs), with transport the next most significant cost.

Conclusions

This work has defined valuable guidelines for the control of American mink as an invasive species using mink rafts. Although we anticipate that these guidelines might be refined for other situations following experience, we believe they offer a realistic starting point in most rivers. For any wildlife control operation to be justifiable it should be cost-efficient, target-specific and humane, and be demonstrably effective in achieving its aims. By focusing trapping effort on sites where mink have been detected and by reverting to monitoring mode once a mink capture has been made, mink rafts reduce trap redundancy compared with conventional speculative trapping. Redundancy inflates economic cost and non-target involvement and is an important variable in many other population control or research situations where wild animals must be efficiently addressed by traps, monitoring devices, or baits. Besides reducing costs, the mink raft provides a continuous measure of the impact that trapping is having on local mink presence. A later study using the working guidelines developed in this study to control mink numbers on a larger geographical scale for conservation benefit will be described elsewhere (Reynolds et al., unpublished). Detection methods have been used previously to guide population eradication on islands by poisoning (e.g., Taylor and Thomas 1989; Taylor et al. 2000), but we believe this is the first example of a detection method being used to guide systematic trapping, especially in a mainland context. The approach used here to develop operating guidelines—a deliberately over-intensive perturbation study—is likely to be useful in other population control contexts.

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