Eur J Wildl Res (2008) 54:79–87
DOI 10.1007/s10344-007-0114-2

ORIGINAL PAPER

Estimating the relative abundance of American mink *Mustela vison* on lowland rivers: evaluation and comparison of two techniques

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Received: 25 January 2007 / Revised: 15 May 2007 / Accepted: 22 May 2007 / Published online: 13 July 2007

Abstract Monitoring elusive species, which are 'difficult to study', often relies on the use of indirect indices to estimate relative abundance. It is important to know the accuracy of such indices and factors affecting it. For the American mink *Mustela vison* (an invasive species of conservation concern in the UK), we compare two indices of relative abundance: sign surveys (based on the detection of scats) and a new method based on the use of tracking plates on rafts. We found that raft surveys consistently performed better than did sign surveys and that estimates of relative abundance derived from both raft and sign surveys were linearly related to the number of individuals captured (but statistically significantly so only for raft surveys). Although both indices were highly correlated, there was considerable unexplained variation in the relationship between them. No statistically significant seasonal effects were detected for either method. Costs of the two methods were comparable after the first 2 years (based on four surveys per year), although raft surveys were more economical than were sign surveys in the longer term. In areas where polecats *M. putorius* are sympatric with mink, it will be important to develop methods to minimise confusion between the tracks of polecats and mink.

Keywords Sign surveys · Scats · Tracks

Communicated by W. Lutz

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Introduction

Assessing and monitoring the abundance of species underpins much of conservation and wildlife management (Macdonald et al. 1998; McDonald and Yalden 2004). It is rarely possible to obtain robust estimates of absolute abundance for reasons including cost, time and practicality (Gibbs 2000). However, estimates of relative abundance may suffice (Eberhardt and Simmons 1987; Macdonald et al. 1998). The sometimes unwarranted assumption of such estimates is that they include some (unknown) error, but that the error is reasonably constant over time or among sites (Gibbs 2000). It is, therefore, important to understand which factors cause such estimates to vary and exactly how the estimates vary in response.

American mink *Mustela vison* are an introduced species in the UK and in many other parts of the world, including continental Europe, the former USSR and South America (Macdonald and Harrington 2003). Wherever they have been introduced, American mink are generally associated with declines in native species due to both predation and competition (e.g. water voles *Arvicola terrestris* in the UK, Macdonald and Strachan 1999; European mink *M. lutreola* in Eastern Europe, Macdonald et al. 2002), and thus, have recently become the subject of local control campaigns (e.g. in the Outer Hebrides, Moore et al. 2003). To monitor the spread of American mink, or indeed the efficacy of attempts to control them, it is important to have reliable methods to detect them and to monitor their abundance.

Due to the naturally low density of mink and their nocturnal and elusive nature, estimates of relative abundance for this species usually rely on indirect methods. The 'standard' survey method for mink is based on searches for scats (faeces) and footprints along riverbanks (hereafter 'sign surveys'; Bonesi and Macdonald 2004). Such methods are widely used, particularly for carnivores that leave scats in prominent places (e.g. foxes *Vulpes vulpes*, Webbon et al. 2004; Sadlier et al. 2004 and otters *Lutra lutra*, Strachan and Jefferies 1996). However, the method is time-consuming, labour intensive and depends on the observer both finding and correctly identifying scats, both of which may be subject to error. The detection of footprints on riverbanks is problematic insofar as it is dependent on substrate (Bonesi and Macdonald 2004), which may vary among sites and seasons; thus, inter-site variability may be reduced by restricting surveys to scats alone (the method adopted in this study; hereafter 'scat surveys'; Barea-Azcon et al. 2007).

A second method is based on recording footprints on tracking plates on rafts at the rivers' edge (hereafter 'tracking rafts'). Described by Reynolds et al. (2004) as a presence/absence indicator to guide and evaluate mink population control, this method has been widely adopted by wildlife practitioners in the UK to target mink trapping. Tracking rafts also offer a further potential use to biologists in indexing the relative abundance of mink populations (cf. tracking stations used, for example, for forest carnivores, Zielinski and Stauffer 1996).

Mink scats are generally assumed to be easily distinguishable from otter spraints by their distinctive smell and morphology, which is important because both may be found at the same marking places along the waters' edge (Dunstone 1993). However, both species eat fish, so identification based on gross morphology (which will vary according to prey type consumed) can be uncertain (Hansen and Jacobsen 1999). Furthermore, distinguishing mink scats from polecat *M. putorius* scats in the field may be impossible due to their similar shape, size and odour (Maran et al. 1998). Polecats are widely believed not to leave scats in obvious marking places, in contrast to mink (Birks and Kitchener 1999). Nonetheless, there is obvious potential for confusion with polecat scats, and indeed those of foxes, stoats *M. erminea* and hedgehogs *Erinaceus europaeus*.

Davison et al. (2002) tested the reliability of experienced naturalists in identifying the droppings of marten *Martes martes* and found that up to 30% of scats collected were incorrectly identified. In low-density areas, errors were even higher, with 97% of 30 scats identified as 'marten' scats actually belonging to fox or polecat. These results clearly demonstrate the need for stringent quality controls on survey methods reliant on identification of droppings. Analysis of mitochondrial DNA offers a simple solution and has been used successfully to distinguish among riparian mustelid species (Hansen and Jacobsen 1999; Gomez-Moliner et al. 2004). Mitochondrial DNA can be reliably extracted from old rain-washed samples (Davison et al. 2002) and is, therefore, appropriate for genetic identification of samples of unknown age and variable condition (e.g. scats).

There are clear size differences among the tracks of mink, otter and stoat (Strachan 1995), but mink and polecat tracks are similar in size. Identification of tracks may, therefore, also be problematic. Sidorovich (1999) describes the qualitative differences between the tracks of these two species, but there is currently no quantitative method for reliably distinguishing between them. Furthermore, it is not yet known to what extent polecats will be attracted to tracking rafts, and therefore, whether or not track identification will be a significant problem.

In this paper, we compare the performance (and relative costs) of two methods (scat surveys and tracking rafts) used to assess the relative abundance of American mink on lowland rivers. The ability of tracking rafts to detect the presence of mink, in comparison with other methods, has been documented by Reynolds et al. (2004). However, there has been no wide-scale evaluation of the method compared with extensive scat surveys; neither has there been an assessment of seasonal effects on this method. Bonesi and Macdonald (2004) found that the number of mink signs detected by observers vary among months according to seasonal changes in the minks' behaviour. Deposition of tracks on rafts may also be affected by seasonal changes in movements (for example, during the breakdown of the territorial system amongst males in the mating season, Yamaguchi and Macdonald 2003). We therefore assessed the correlation between the two methods as well as the seasonal variation in both. DNA analysis of scats was used to check our identification of mink scats. Finally, both indices were compared with estimates of numbers of individuals obtained by trapping.

Materials and methods

Study sites

The study was carried out between 2003 and 2006 on six 20 km stretches of river within the Upper Thames Valley, England: the River Thames (Bablock Hythe to Radcot Lock, Ordnance Survey grid reference SP435042-SP298002); the Lower River Windrush (Standlake to Witney, OS grid ref. SP404031-SP359089); the Upper River Windrush (Taynton to Bourton-on-the-water, including ca 3.5 km of the Sherborne Brook, OS grid ref. SP231134-SP176194 and along the Sherborne Brook to SP151152), the Upper River Evenlode (Chadlington to Daylesford, OS grid ref. SP339205-SP243255), the Lower River Evenlode (Fawler to Cassington, OS grid ref. SP444107-SP376166) and the River Cherwell (Adderbury to Northbrook, OS grid ref. SP493338-SP489219). All of these rivers are slow-flowing, between 1–2 and 20 m wide and between <20 cm and up to 3 m deep. Rivers were fringed with trees (e.g. willow *Salix fragilis*), and vegetation (e.g. nettles *Urtica dioica*, bramble *Rubus fruticosus*, blackthorn *Prunus spinosa* and hawthorn *Crataegus monogyna*). Bands of vegetation (e.g. common reed *Phragmites australis*) emerged from the water in summer. Adjacent land use was mainly grazed pasture; arable land and woodland also occurred.

Otters were present at all sites, and polecats were present in the vicinity of the R. Thames, the R. Windrush and probably the R. Cherwell. Foxes, stoats and hedgehogs were all present in all the study sites.

Temperatures in the area over the period of the study varied between 0.8 and 25.5°C (data collated per month: lowest mean minimum–highest mean maximum; Oxford weather station: http://www.metoffice.gov.uk/climate/uk/stationdata). Average monthly rainfall was 40.9 mm (max. 93.4 mm in June, min. 16.6 mm in January).

Survey methods

Scat surveys Scat surveys were carried out on foot by searching the entire length of both banks of the river (up to 5 m from the waters' edge) of each site for mink scats. Scats were identified as belonging to mink on the basis of size, shape and smell (Dunstone 1993). All scats found were removed to avoid double counting between successive surveys, but a small portion of the scat was left in place to retain some scent at the site to minimise potential effects on subsequent marking behaviour. To make our search effort relatively constant, we aimed to cover approximately 1 km/h. A GPS location to the nearest 10 m was recorded for all scats found.

Tracking rafts Tracking rafts (described in detail in Reynolds et al. 2004) consisted of a wooden platform (ca 1,200× 600 mm), supporting a tunnel (660×185×250 mm), beneath which was placed a clay plate (recessed into the floor of the raft). The clay plate was kept moist and receptive to footprints by a wicking layer beneath the clay that drew water up from the river. Rafts were placed throughout each site at approximately 1-km intervals and were left in place throughout the duration of the study. The surface of the clay was smoothed at the beginning of each survey period and the rafts checked for tracks 2 weeks later. Data were recorded as the presence/absence of mink tracks on rafts. The use of 1-km spacing ensured that there was at least one raft present in even the smallest mink territory (minimum mink home range on the R. Thames, 2004–2005=1.71 km, n=11, L. Harrington, unpublished data).

Survey strategy Surveys (complete coverage of a single site within one survey period) were carried out four times annually at key periods in the minks' year, i.e. during the mating season (January–early April), the summer or 'kit-rearing' season (late April–July), juvenile dispersal (August–early October) and the winter when populations are generally stable (late October–December; as defined in Yamaguchi and Macdonald 2003). The actual survey dates were: March, July, September and November.

To compare the performance of the two survey methods, at least four sites were surveyed at each of the four survey periods over 2 years (n=8 survey periods, with the exception of March 2005 when all six sites were surveyed and the final survey period when only two sites were surveyed) between September 2003 and July 2005. Two additional surveys were carried out on the R. Thames and R. Cherwell in September and November 2005, and one further survey in March 2006 on the R. Cherwell to allow comparison with concurrent live-trapping (below), giving a total of 37 surveys for analysis.

Genetic identification of mink scats

Sixty-one of the scats collected during field surveys were selected at random, preserved in 96% ethanol and sent to the Department of Haematology, Royal Infirmary of Edinburgh for genetic analysis. In the laboratory, DNA was extracted from scat material using the QIAamp DNA stool mini kit (QIAGEN, Crawley, West Sussex, UK). Extracted DNA was amplified with consensus polymerase chain reaction (PCR) primers capable of amplifying a portion of the mitochondrial cytochrome b gene from stoat, weasel, polecat, mink, pine marten and otter. The resultant amplified DNA fragments were sequenced using the reverse oligo sequencing primer, using ABI 'Big-Dye' dye terminator chemistry and an ABI Prism 377 instrument (Applied Biosystems, Foster City, CA, USA).

Trapping

Live trapping Live trapping was carried out at two sites (the R. Thames and R. Cherwell) concurrently with scat and raft surveys for four survey periods over 1 year (2005 and for the R. Cherwell, 2005–2006). We used single-entry, wire mesh cage traps (A. Fenn, Redditch, Worcestershire, UK) set on the tracking rafts positioned within the tunnel (placed on top of the tracking plates). All traps were used with otter guards fitted directly to the traps (Albion Manufacturing, Wymondham, Norfolk, UK) or situated behind otter exclusion bars on the raft itself (see Reynolds et al. 2004) to prevent the capture of young otters. Traps were secured to the raft with electrical ties and provisioned with hay (for insulation and to prevent damage to teeth and gums, Birks and Kitchener 1999) and either sardines or rabbit (for food). All traps were checked daily, early in the morning. Traps were set on *all* 20 rafts (i.e. this differed from removal trapping, below, where traps were set only on rafts where tracks were detected) at each site over two consecutive 5-day trapping sessions (ten traps were set per session).

Note that because animals were trapped on the same rafts used to detect tracks (albeit at separate times within the same ‘season’), trapping did not provide a completely independent assessment of numbers of individuals to compare with raft survey indices. However, our aim was to investigate how tracks on rafts relate to numbers of individuals using the rafts over a range of densities and over different seasons, as well as to assess how scats detected compare with numbers of individuals in comparison.

Animals caught were transferred to a wooden box ($0.15\times0.15\times0.48$ m) with a Perspex window for the induction of anaesthesia (Yamaguchi et al. 2002). Animals were anaesthetised using isoflurane (IsoFlo: Schering-Plough Animal Health, Welwy Garden City, Hertfordshire, UK) delivered via a vapouriser attached to a portable oxygen cylinder (Mathews et al. 2002). After induction, animals were transferred to a face mask for anaesthetic maintenance during the handling procedure.

Under anaesthesia, individual sex was identified, and all animals were uniquely marked by implanting a PIT tag (MID Fingerprint, UK). Procedures were usually completed within 10–30 min, and animals were transferred to a plastic holding box for recovery before being released at the site of capture. Animals recovered from anaesthesia within 10–25 min.

Removal trapping On the R. Windrush (Lower and Upper) and the Lower R. Evenlode, mink removal was carried out over the months of March 2004 and 2005, respectively, providing three independent estimates of numbers present (i.e. numbers of mink removed) comparable with March scat and raft surveys.

Removal trapping was carried out by setting cage traps (as for live trapping) on every raft where tracks were detected. Captured mink were shot. Traps were set for 2 weeks or until an animal was captured. After the removal of the trap, the raft was monitored at 3- to 5-day intervals (‘negative’ rafts were also checked repeatedly for the appearance of new tracks) and new traps set, in both cases, as necessary (as in Reynolds et al. 2004). Thus, rafts were continually checked and traps set for the duration of the month of March.

Analysis

River sites were divided into contiguous 500-m sections during data analysis using ArcMap in ArcGIS 9.0 (http://www.esri.com; 34–46 sections per site, both banks included in a section). Scat locations were plotted on digital river maps and the number of scats falling within each 500-m section calculated. Individual river sections were scored as ‘positive for mink presence’ if at least one mink scat was found there. The relative abundance of mink, for each survey at each site, was quantified as the proportion of positive sections (percent of occupancy) for scat surveys and the proportion of rafts with tracks for raft surveys. Numbers of individuals were estimated as the total number of mink captured per trapping session.

The distributions of scat and raft survey indices were highly skewed; we therefore report medians and means in data summaries. We used arcsine–square root transformations of these variables as recommended for proportional data (Zar 1996) in all statistical tests. For ease of interpretation, plots of untransformed variables are presented in figures.

We used one-way analysis of variance (ANOVA) to investigate differences in abundance indices among sites. Pearson’s correlation coefficients and regression analyses were used to examine the relationship between the two different indices (and other potentially explanatory variables: season, observer, recent weather, year and site) and between the two indices and estimates of numbers of individuals. The effect of season on both indices was examined using mixed model GLMs, with arcsine-transformed percentage sections/rafts as the response variable and season as a single (fixed) factor blocked by site (random factor). Graphical analysis of residuals was used to check for conformation with the assumptions of normality and homoscedasticity for regression and ANOVA tests (Kleinbaum et al. 1988). Normality of residuals was further tested by the Kolmogorov–Smirnov test; in all cases, we concluded that our data conformed with these assumptions (Kolmogorov–Smirnov test, $p>0.09$).

All statistical analyses were carried out in MINITAB 13 (http://www.minitab.com). Statistical significance was accepted at $p<0.05$.

Results

Genetic identification of mink scats

DNA was successfully extracted from all 61 scats and PCR successfully performed in all cases. Amplified DNA fragment sequences were compared to an alignment of known cytochrome b sequences for the species listed in the “Materials and methods”. In every case, the sequence was consistent with the source DNA being American mink.

Survey methods

Scat surveys We recorded 512 mink scats over 37 surveys (median per survey=11.0, mean=14.9, range 0–84, n=33 ‘complete’ surveys). The percentage of positive river sections (hereafter ‘percent positive sections’) per survey ranged

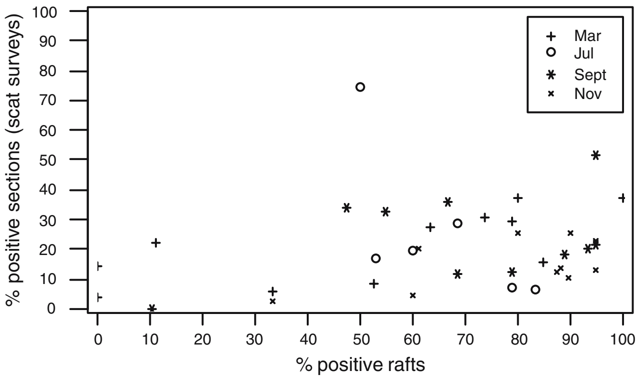


Fig. 1 Correlation between indices of relative abundance for mink based on scat surveys and raft surveys. Surveys were carried out at six independent 20-km sites for four survey periods per year (in March, July, September and November) over 3 years (September 2003–March 2006; not all sites were surveyed during all survey periods, see text for details). Plot shows outlier, which was removed for subsequent analyses

between 0 and 74.3 (median=19.5, mean=21.0, n=37), excluding one outlier where we recorded a particularly high number of scats (R. Cherwell, July 2004); percent positive sections ranged between 0 and 51.4 (median=18.9, mean=19.5, n=36). This outlier was excluded from all further analyses of scat surveys on the basis that in contrast to all other sites and survey periods, otters were found at very low densities at this site during this survey period, which may have affected the marking behaviour of mink (Crawford 2003). Percent positive sections differed significantly among sites (one-way ANOVA: F=6.21, df=5,30, p<0.001).

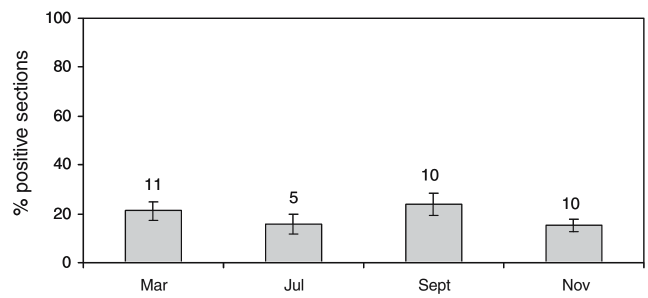
Raft surveys The percentage of positive rafts (hereafter 'percent positive rafts') ranged between 0 and 100 (median =73.7, mean=66.2, n=37) and differed significantly among sites (one-way ANOVA: F=4.89, df=5,31, p=0.002).

Comparison of scat and raft surveys The percent positive sections was significantly positively correlated with the percent positive rafts (r=0.373, p=0.025, n=36, excluding outlier; Fig. 1), although detection of the presence of mink by rafts usually exceeded that by scat surveys (slope of the best-fit line <0). Regression of percent positive sections against percent positive rafts as a predictor variable was statistically significant (F=7.99, df=1,34, p=0.008), although R^2 was low (19.0%). The addition of season to this model resulted in some improvement to R^2 (26.7%) although season, as a predictor of percent positive sections, was not quite statistically significant (overall regression with two factors, percent positive rafts and season: F=6.03, df=2,33, p=0.006; t tests for significance of coefficients, percent positive rafts: t=3.37, p=0.002, season: t=−1.86, p=0.071), and the amount of unexplained variation remained high. The addition of observer, year, recent weather and site were all non-statistically significant and resulted in negligible improvements in R^2.

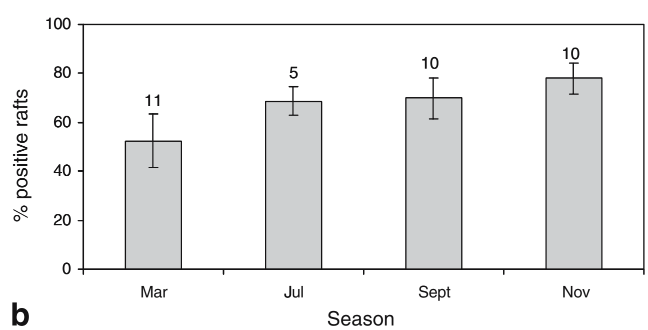
Seasonal variation Although there was some evidence of a weak seasonal effect on the relationship between percent positive sections and percent positive rafts, we could find no consistent seasonal pattern in either variable (Fig. 2). General linear models of either percent positive sections or percent positive rafts, including season as a single fixed factor, blocked by site (random factor) were not statistically significant in either case (percent positive sections, season: F=2.10, df=3,27, p=0.123; percent positive rafts, season: F=1.79, df=3,28, p=0.172).

Trapping

Live trapping Over four live trapping sessions, we captured 19 (10 male, 9 female) and 22 (12 male, 10 female) mink on the R. Thames and R. Cherwell, respectively. Of these, approximately 60% of individuals (68.4 and 63.6% on the Thames and Cherwell, respectively) were captured in more than one trapping session. Total captures per trapping session were high, as were recapture rates both *among* and *within* sessions (Table 1). Numbers of individuals captured per trapping session varied among seasons, but not consistently between sites (Table 1), whilst numbers were



a



b

Fig. 2 Seasonal variation in **a** percentage of 500-m river sections with mink scats and **b** percentage of rafts with mink tracks. All sites (n=6) are combined. Surveys were carried out over 3 years (September 2003–March 2006); therefore, some seasons include repeat surveys within the same site over different years (not all sites were surveyed every season, every year, see text for details). Data are presented as mean±SE, n (number of surveys) is shown above the error bars. Outlier (R. Cherwell, July 2004) is excluded. Seasonal differences were not statistically significant for either variable (see text)

Table 1 Capture rates, recapture rates, numbers of individuals captured, sex ratios and numbers of rafts used per individual for mink trapped on the R. Thames (2005) and R. Cherwell (July 2005–March 2006)

Site	Trapping session	Total captures	No. individuals no. (m, f, m/f ratio)	Percent of individuals captured in previous sessions	Percent of recaptures within session	No. rafts used per individual (mean, max)
Thames	Mar 05	32	12 (5, 7, 0.71)	N/A	62.5	2.8, 5
Thames	July 05	17	11 (6, 5, 1.20)	54.5	30.8	1.2, 2
Thames	Sept 05	9	7 (2, 5, 0.40)	85.7	35.3	2.5, 4
Thames	Nov 05	15	6 (3, 3, 1.00)	100	50.0	2.0, 3
Mean		18.3	9.0 (3.3, 5.0, 0.83)	80.07	44.65	2.1
Cherwell	July 05	13	9 (5, 4, 1.25)	N/A	22.2	2.1, 4
Cherwell	Sept 05	18	9 (5, 4, 1.25)	77.8	60.0	1.2, 2
Cherwell	Nov 05	32	15 (7, 8, 0.88)	46.7	53.1	1.7, 3
Cherwell	Mar 06	28	11 (9, 2, 4.50)	72.7	60.7	1.5, 3
Mean		22.8	11.0 (6.5, 4.5, 1.97)	65.73	49.00	1.6

Each trapping session is based on 20 raft traps at 1-km intervals set for 5 days each (trapping carried out in two consecutive 5-day sessions with ten traps set per session).

highest on the R. Cherwell in November; on the R. Thames, they were lowest at this time of year (although it is noteworthy that in November on the R. Thames, we did not catch several individuals that we knew to be present from a parallel radio-tracking study in the area). Sex ratios were similarly highly variable, but also showed no consistent seasonal pattern (Table 1). Individual male mink used a maximum of five rafts, females generally one or two, three at most. There appeared to be a slight tendency for an increase in the number of rafts used per individual in March and September (Table 1). From the number of captures, we estimated that the density of mink was ca 0.26–0.52 mink per kilometre on the R. Thames and ca 0.5–0.83 mink/km on the R. Cherwell.

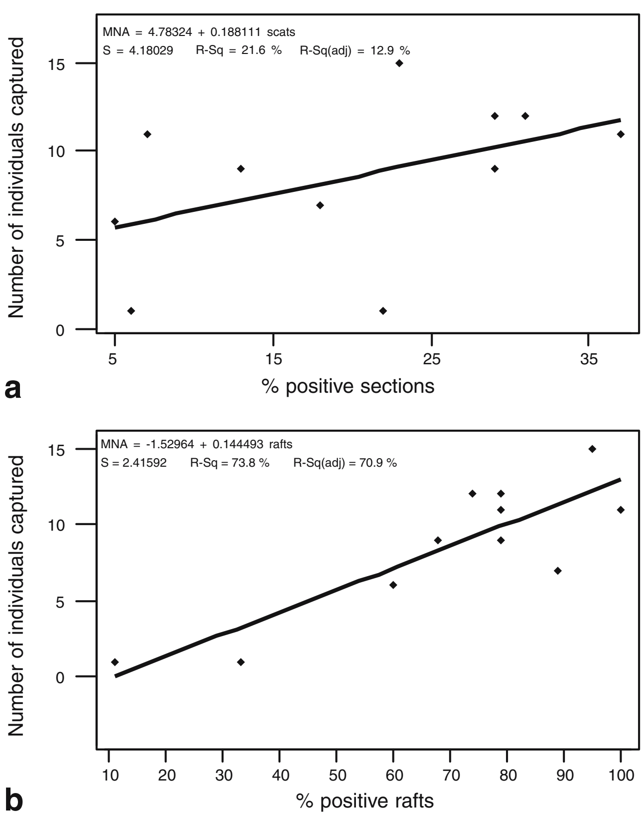


Fig. 3 Relationship between **a** percentage of river sections with mink scats and **b** percentage of rafts with mink tracks and number of individuals captured. Numbers of individuals captured were obtained from live trapping (n = 8) on the R. Thames (2005) and R. Cherwell (2005–2006) and removal trapping (n = 3) at three mink control sites (L. and U. Windrush, March 2004 and L. Evenlode March 2005). Note that in **b**, the number of individuals captured is not independent of the percentage of positive rafts (as an index of relative abundance; see text)

Removal trapping Numbers removed on the Lower and Upper Windrush (March 2004) and the L. Evenlode (March 2005) were 12, one and one, respectively. Approximate density of removed mink on the L. Windrush in March 2004 was estimated to be 0.62 mink per kilometre.

Relationship between survey methods and numbers of individuals captured Both indices were positively and linearly related to the number of individuals captured (Fig. 3), although only percent positive rafts were statistically significantly correlated with numbers of individuals (‘individuals’; r=0.858, p=0.001, n=11). Percent positive sections were weakly positively correlated with ‘individuals’, but the relationship was not statistically significant (r= 0.463, p=0.151, n=11). Similarly, R^2 was high (regression analysis, adjusted R^2=61.7%, F=17.10, df=1,9, p=0.003) for the relationship between ‘individuals’ and percent positive rafts, but was very low for the relationship between ‘individuals’ and percent positive sections (adjusted R^2= 13.2%, F=2.52, df=1,9, p=0.147), suggesting that there was a large amount of unexplained variation in the latter relationship (Fig. 3).

Discussion

Relative performance of the two methods

One potentially serious problem with indirect survey methods that are based on identification of scats (for any species) is misidentification (e.g. Davison et al. 2002). Genetic analysis in this study, however, demonstrated that highly accurate identification of mink scats is possible in the field. Our identification of mink scats was not, however, completely error-free. During a separate study on mink diet (Windham 2007) using a separate sub-sample of 198 of the same scats collected during surveys, nine of the scats analysed (4.5%) were found to contain groomed polecat hair, suggesting that they were polecat, and not mink, scats, and a further three scats (1.5%) were deemed not to belong to mink on the basis of unlikely dietary remains (predominantly fruit), suggesting an actual error rate of approximately 6%. This value is still low and unlikely to have a significant effect on estimates of relative abundance derived from such indices, but it does suggest that identification may be problematic where polecat density is higher.

Nevertheless, despite high success in the identification of mink scats that were detected in the field, we found that scat surveys consistently performed poorly in relation to raft surveys in that, in almost all cases, the percentage of positive rafts was higher than the percentage of positive sections (scat surveys). The two indices were positively correlated, but the relationship between them included substantial (81%) unexplained variation (Fig. 1). Although season had some effect on the relationship, we were unable to find additional explanatory variables and could not define any consistent seasonal pattern in either of the indices (Fig. 2).

The fact that several fieldworkers participated in the scat surveys may have contributed to the variation in this index, but statistically, the effect of 'observer' was not significant. Our survey strategy was not designed explicitly to reveal differences in observers, but it is noteworthy that Bonesi and Macdonald (2004) found no differences in field sign survey results among observers with similar training and abilities. Variation in scat survey indices may also be due to unknown longevity of scats and variation in longevity. In his circumstances, Robinson (1987) found that most scats persist for up to 2 months, but it is likely that longevity is highly variable and dependent on habitat and weather conditions (Parry et al. 2006). Although we did not detect an effect due to recent rain or flooding (that may result in loss of scats), we included rain and flooding only in the days immediately before the survey, not over the weeks preceding the survey.

Conversely, a potential problem with raft surveys is misidentification of tracks. If a small number of polecat tracks on rafts had been identified as belonging to mink, for example, the result could be an overestimation of abundance by raft surveys. Live trapping on the rafts, however, suggested that the use of rafts by polecats, in this study, was low: We caught only two polecats and one feral ferret (compared with a total of 19 individual mink captured) during one of four trapping sessions at one of the two live trap sites (R. Thames, September 2005). Thus, this source of error is unlikely to have been significant.

Despite previous reports in the literature of seasonal variation in mink signs (e.g. Bonesi and Macdonald 2004), we did not detect statistically significant seasonal effects in either scat or raft surveys (Fig. 2). Bonesi and Macdonald (2004) described minima in mink signs during the gestation period and in December, with peaks during the mating season (January to March) and the 'kit-rearing' season in June. We did not carry out surveys during the gestation period precisely because few signs tend to be found then, and so, we cannot compare the methods during this seasonal trough in signs. Although there was a slight tendency towards a higher number of positive sections in March as compared to 'November', the difference was not statistically significant. Furthermore, we found a slight tendency for the proportion of river sections with mink scats to be lower during the 'kit-rearing' season. Robinson (1987) also found very low numbers of scats in June and July in Scotland, although he did find particularly *high* numbers during the mating season. Differences between our study and that of Bonesi and Macdonald are most likely due to the fact that in our study, we excluded 'natural' tracks that are occasionally found on riverbanks and included only scats in our observations of 'fieldsigns' (cf. Barea-Azcon et al. 2007). We found a high proportion of tracks in March which, had we included them in an overall 'sign index', might have resulted in significant differences between this season and others. Similarly, high numbers of 'signs' in June, in Bonesi and Macdonald's study were mostly due to the presence of tracks rather than scats (L. Bonesi, personal communication). Nevertheless, although the seasonal patterns in mink sign described by Bonesi and Macdonald (2004) in relation to behavioural changes in mink through the year are logical (for example, an increase in signs during the mating season when movements, particularly by male mink, increase substantially, Yamaguchi and Macdonald 2003), there is little evidence that such behavioural changes are reflected in patterns of scats detected. Whilst the lack of detection of a statistical effect of season on the abundance of mink scats may be due to small sample size in this study, data for individual sites showed considerable variation (and no consistent trend) in seasonal patterns among sites and among years. Raft surveys, similarly, revealed only a slight tendency (and statistically non-significant) for the proportion of tracks to increase from March to November. As for scat surveys, variation among sites was high, and no consistent trend was apparent among sites or among years within a site.

The high numbers of American mink trapped and the high recapture rates suggest that their populations on the R. Thames and R. Cherwell were relatively stable over the period of the live trapping study. In contrast to the male bias commonly found in mustelid trapping studies (Buskirk and Linstedt 1989), we found a high proportion of females in our trapped samples during some trapping sessions (although sex ratios over the entire year did not appear to be sex-biased in either direction at either site; Table 1). Furthermore, although previous studies have reported particularly high numbers of individuals trapped during the mating season (Dunstone 1993 and references therein), we did not detect any such effect. High numbers trapped in March are ordinarily due to an increase in the male trapping bias due to increased movements of males during the mating season. As the rafts appear to be particularly efficient at catching females, trapping data based on raft traps are likely to provide a more consistent approximation of the resident population size, being less affected by the sector of the population that fluctuates and is transient.

Both indices were positively correlated with the number of individuals trapped, although in the case of the scat survey indices, the relationship was not statistically significant and contained much scatter (Fig. 3a). Similar levels of variation have been reported previously (Robinson 1987; Bonesi and Macdonald 2004). Given the non-independence of the raft surveys and the trapping method used to estimate number of individuals, one might expect a close relationship between these two variables; what Fig. 3b demonstrates is that the relationship is consistent over a range of densities and seasons.

At very low densities, both methods were capable of detecting the presence of mink. At two of our mink-removal sites in March 2005, however, although none of the rafts had tracks, scats were found in one and five sections of the upper and lower Windrush, respectively. Scats detected, in this case, may reflect mink that had moved through the site during the mating season (at some time during the previous 2 months), but that were no longer present (and thus, not detected by the rafts). Reynolds et al. (2004) also found a small number of cases (2 of 22) where mink were detected by scats but not by rafts, although in general, mink were more often missed by scats (at 10 of 22 sites tracks were found on rafts, but no scats were found).

Relative costs of two methods

Scat surveys are time-consuming: Each 20-km site in this study required five full survey days to cover the entire site. Raft surveys involve initial investment of time and money, but once the rafts are in place, the same 20-km stretch can be surveyed in 2 days (1 day to set the tracking plates and a second to check for tracks), and this 2-day process can be repeated for subsequent sessions for as long as the rafts are left in place.

Assuming a cost of £30 per raft, £50 per day wages for a surveyor and £3 for petrol per day (based on an estimated 20-km drive to drop rafts at 1-km intervals along the river; obviously this distance may vary greatly), it would cost £856 to set up 20 rafts at a 20-km site (assuming ten rafts were put out per day by two people, and one person spent a day in preparation, e.g. mixing clay used as a tracking medium). 'Set-up' costs for scat surveys are limited to the purchase of a hand-held GPS unit (ca £100). Subsequent surveys, however, based on the same £50 per day for surveyor wages, would cost £106 for the raft survey (2 days at £50 each, assuming that raft checks require only one person, plus £3 petrol per day, for 2 days) and £250 for the scat surveys (5 days for one person at £50 each). Thus, for six or more surveys, the cost of raft surveys is comparable to the cost of sign surveys (£1,492 vs £1,600, respectively) based on approximate set-up costs and per-survey costs as detailed above. Furthermore, as the number of surveys increases, the cost of raft surveys in relation to scat surveys will become progressively cheaper (assuming that no rafts require replacement). The rafts used in this study have been in place for 3 years. Nevertheless, some replacement and maintenance will be necessary, and we estimate it at £200 per year.

Conclusion: recommendations for assessing the relative abundance of American mink

American mink scats can be identified reliably in the field (i.e. without recourse to expensive DNA methods); however, this may hinge on the local abundance of polecats. Nevertheless, rafts consistently perform better than scats, there is a consistent relationship between the number of rafts with tracks and the numbers of individuals using the rafts over a range of densities and in different seasons, and raft surveys are, at least, comparable in cost to scat surveys and potentially cheaper in the longer term. In contrast with previous studies, we found that although season caused some fluctuations in both indices, no clear seasonal pattern was evident. There is a risk with raft surveys of confusion among medium-sized mustelids (e.g. in our case, polecats), and we recommend further work to determine whether the tracks of the two species can be reliably differentiated. This will become particularly important in the UK with the current expansion there of the polecat's range.

Acknowledgements We thank all the landowners for allowing us access to their land, all the volunteers who helped with field surveys, especially Anna Renwick, Penelope Whitehorn, Bernadette Higgins and Amanda Bassett, Mike Short for his advice on raft construction, David Stirling for carrying out the DNA analysis, Merryl Gelling for assistance with animal anaesthesia and Steven Lead for his help with the GIS analysis; we also thank Paul Johnson, Rob Strachan, Laura Bonesi, Jonathan Reynolds, Johnny Birks and two anonymous reviewers for helpful comments on an earlier version of this manuscript. The river maps were kindly supplied by the Environment Agency; the study was funded by the Esmee Fairbairn Foundation. The study complies with current UK laws: Animal trapping and handling was conducted under DEFRA licence WCA/06/4 (under Section 16 of the Wildlife and Countryside Act 1981), Home Office project licence PPL 30/1826, and personal licences PIL 30/6917 and PIL 30/6530.

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