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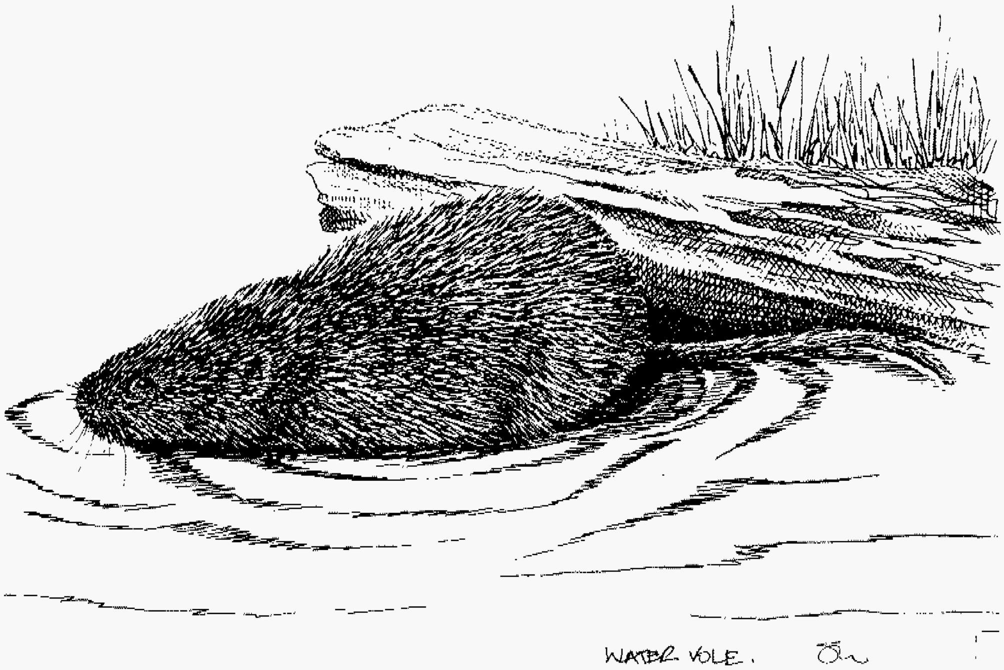
Halting the decline: Refuges and national key sites for water voles



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Halting the decline
Refuges and national key sites for water voles

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Summary

The water vole is continuing to decline rapidly. The reasons for this were clearly diagnosed over 10 years ago, yet a concerted conservation remedy has yet to be found – as evidenced by continued decline.

We show that water voles still thrive at large reedbed sites, even where mink (a predator of voles and a principal cause of more recent decline) have been present for many years. To assess whether reedbeds are likely to offer a sustained refuge from mink predation, we studied over-winter mortality in a sample of 70 radio tagged voles at three sites. Predation by mustelids accounted for 84% of mortality. Mink were unequivocally responsible for up to 46% of mortality at a site, though this was probably an under estimate. However, predation rate declined steeply with the distance water voles nested from main water channels; voles 150m from a main channel experienced only 30% predation. This effect is sufficient to allow water vole populations to grow by about one-third per year. Reedbeds thus offer a refuge from mink predation and potentially a rich source of dispersers to recolonise surrounding sites and maintain metapopulations. Reedbeds support large, apparently robust populations. This is in very marked contrast to most linear water vole habitats, where conservation efforts have been concentrated to date.

We recommend that reedbeds are made a focus of landscape scale conservation for the water vole. This National Key Sites strategy would complement, not replace, existing local key sites and other conservation approaches. To this end a programme of work is recommended, priorities being to secure habitat management beneficial to water voles at proposed National Key Sites and to determine whether reedbeds offer a long term refuge from mink. National Key Sites should be used to promote the recolonisation of surrounding landscapes by water voles and the refuge potential of other types of sites should be investigated.

Introduction

It is now clear that the water vole *Arvicola terrestris* has undergone a recent catastrophic decline, following a more gradual distributional attrition throughout the last century (Jefferies, Morris and Mulleneux 1989; Strachan and Jefferies 1993). Preliminary findings of the most recent national survey indicate that it has been lost from two thirds of sites that were occupied in 1989-90 (Strachan *et al.*, 2000). The causes of the decline are now generally accepted as loss and fragmentation of suitable habitat, leading to isolation of water vole populations. These are then highly vulnerable to extinction, especially through predation by introduced American mink (Lawton and Woodroffe, 1991; Barreto *et al.*, 1998). These problems were incisively diagnosed by Lawton and Woodroffe in the late 1980s, yet a concerted conservation remedy has still not been found – as evidenced by continued loss of water voles.

Against this background of continuing widespread decline, some sites in England still support large and apparently robust populations of water voles. These include reedbeds, which provide extensive, non-linear habitat. Reedbeds have seldom been surveyed for water voles, not least because the standard survey technique involves searching linear, not extensive, habitat. Large, dense networks of narrow ditches, for example on grazing marshes, may also support large numbers of water voles. Such types of sites often appear to provide superb water vole habitat and this has obviously been a crucial factor in allowing population survival. So too, may be the absence or very low frequency of mink in some areas, such as much of the Norfolk Broads. However, large water vole populations have persisted at some sites where mink have also been present for many years. For example mink have occurred at Stodmash NNR in Kent for 30 years, yet water voles there still thrive. It may be that mink are having a chronic effect on water vole populations in such places, slowly pushing them to local extinction. Alternatively, reedbeds and similar sites may offer refuges from mink predation allowing mink and water voles to coexist. Refuge sites could be source populations, helping to sustain water vole metapopulations in surrounding landscapes where conditions for water voles are less favourable.

There is now an urgent need to identify sites where national conservation effort for water voles can be targeted in the first instance, to ensure that at least some populations survive. These would be National Key Sites for water voles, complementing more local conservation foci. This does not mean abandoning water voles elsewhere, or sacrificing the principle of landscape scale conservation management. However, it is vital to ensure that sites where water voles are currently thriving are managed to maximise the chances of populations surviving. The intention is to use National Key Sites as a foundation for conservation in the wider landscape.

The aims of the work reported here were to determine whether reedbeds are likely to offer a refuge for water voles from mink predation and subsequently to identify potential refuges sites in England. These could form the basis for a network of National Key Sites, which can be managed to stabilise or improve water vole status. We also outline recommendations for the management of reedbeds, where the ecology of water voles is little known.

Methods

Study sites

The study was conducted during winter 1999–2000 at three reedbed sites (Fig. 1): Stodmarsh NNR, Kent (managed by English Nature); North Warren, Suffolk (Royal Society for the Protection of Birds); and Ham Wall NNR, Somerset (RSPB). These sites were selected because they had large water vole populations, despite the presence of mink often for many years. The sites were also selected because mink control, which would have confounded our results, was not being undertaken.

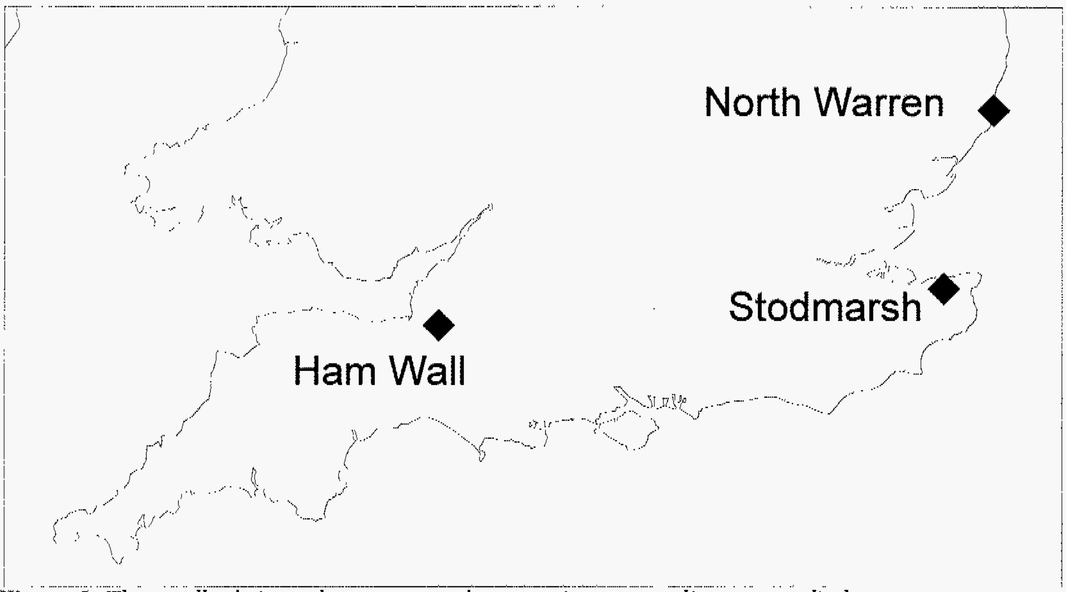

Figure 1. *The reedbed sites where water vole over winter mortality was studied.*

Measuring water vole perception of predation risk: giving-up densities

Foraging theory predicts that an animal should spend less time feeding where it perceives a higher risk of predation (Fig. 2; Lima and Dill, 1990). This can be tested experimentally using giving-up densities (GUDs) *i.e.* the amount of food remaining in a patch following a period of foraging (Brown *et al.*, 1992). This method has been employed successfully for a variety of terrestrial rodents in different habitats (Blumstein, 1998; Brown, 1988; Brown *et al.*, 1992; Thorson *et al.*, 1998).

To quantify how water voles may perceive predation risk in reedbeds we carried out GUD experiments at Stodmarsh in August 1999. We used experimental feeding stations consisting of pairs of plastic trays on floating polystyrene platforms. Each station was provisioned with 400g of chopped carrots. We carried out simultaneous experiments in main channels (>10m wide) at the edge of the reedbed and within the reedbed, at least 50m from the nearest main channel. Within each type of site, pairs of feeding stations were placed 1m and 5m from bankside cover where there was evidence of water vole activity (main channel) or occupied water vole nests (reedbed). An additional platform with the same amount of carrots but covered by fine wire mesh was placed away from each station. This was used to calculate the amount of weight loss of the chopped carrot due to desiccation and correct GUDs accordingly. We replicated each treatment eight times at intervals of 200m to ensure different water voles were sampled. Feeding stations were exposed for 48hr.

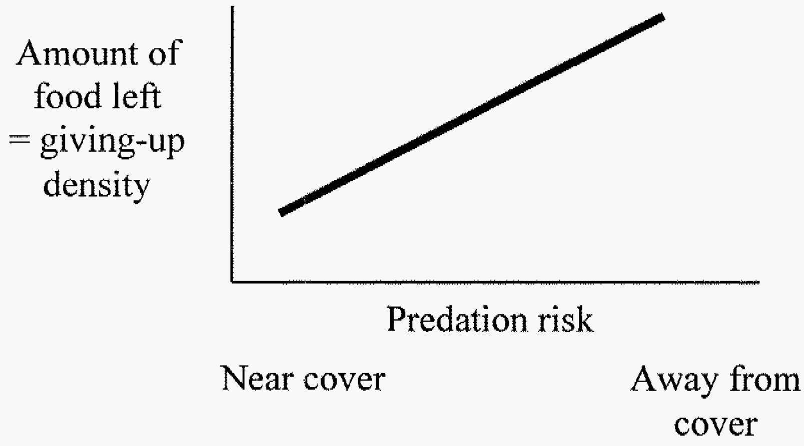

Figure 2. *The relationship between predation risk and the amount of food in a patch that a forager leaves uneaten (giving-up-density, or GUD), as predicted by foraging theory. We used this hypothesised relationship to assess how water voles perceive predation risk.*

Determining the rate and causes of over-winter mortality

A total of 70 water voles were captured in live-traps and fitted with radio transmitters (Biotrack, UK) between 20 September and 30 November 1999. Approximately half of these were captured adjacent to main channels at the periphery of reedbeds and half within reedbeds. Approximately equal numbers of adults and juveniles, and males and females were collared at each site. Traps were baited with chopped carrots and placed by water vole latrines or on floating platforms. Wooden nest boxes containing fresh straw were used with all traps left overnight. Captured voles were fitted with radio transmitter collars equipped with mortality switches. These were temperature sensitive, resulting in transmission of a rapidly pulsed signal if a water vole died. Dead voles could thus be identified from a distance and corpses quickly located.

Radio-collared voles were monitored at twice-weekly intervals over winter from commencement of trapping to April 2000, with the help of trained local volunteers. Cause of death of water voles was determined from the condition of corpses and associated field signs. Detailed field records were completed for each dead vole and the corpse was frozen for later examination. Water vole predators were identified using a combination of the following: toothmarks to collars and corpses; the extent and manner in which a corpse had been eaten; scats and tracks close to the corpse; and location of the corpse.

Assessing mink activity

Linear waterways, pathways and dykes throughout each site were systematically searched for evidence of mink, and the number of scats and/or sets of tracks recorded during each site visit. This gave us an index of mink activity/abundance for sites as a whole.

Statistical analyses

Differences in giving-up densities were analysed using a split plot design ANOVA. Generalised linear models with binomial errors and a logit link were used to model the proportion of water voles dying or being predated over winter in relation to potential explanatory variables. Response variables (mortality, predation) were offset by the number of weeks a water vole was radio tagged, since not all voles were tagged in the same week so their period of exposure to risk of mortality differed. The 95% confidence limits for fitted binomial relations were calculated using the method given by McCullagh and Nelder (1989). Explanatory variables considered were: site, water vole sex, age (adult or juvenile), month of death, distance from woody cover and distance from main channels. The latter two variables were measured as the distance of burrows or nests most used by individual voles to the stated habitat features (voles were very sedentary during winter).

The rationale for examining these potential explanatory variables was as follows. Mortality among juveniles is reported to be very high (Macdonald and Strachan, 1999). Most dispersal occurs in autumn and spring and may be sex biased (Stoddart, 1969), suggesting that there might be differences in mortality related to sex, age and month. Mature trees, especially willows, are important den sites for mink (Mason and Macdonald, 1983) and mink are often associated with woodland or scrub cover adjacent to aquatic habitats (Dunstone, 1993). Woodland cover may also be important for other predators. Mink, in common with other mustelids, typically forage along linear features. Also, surveys suggest that mink have a more detrimental effect on water vole populations living along main rivers 10m or more in width, than along smaller watercourses that may be peripheral to their home range (Strachan and Jefferies, 1993). Distance to main channels greater than 10m wide was therefore considered as a potential explanatory variable in mortality models.

A generalised linear model with Poisson errors and a square root link, offset by the number of days spent surveying at each site visit, was used to compare mink activity between sites. Analyses were conducted in GENSTAT.

Selection of potential national key sites

We used published sources and direct contacts with site managers, owners and conservation bodies to draw up a preliminary list of potential National Key Sites. Following field studies at reedbed sites, the criteria used for selection were: presence of extensive highly suitable habitat at a clearly defined site; water voles abundant or frequent at a site that was thus likely to support a large population; assured tenure and management of the site, and surrounding area if possible; ease with which management beneficial to water voles might be instigated or incorporated into existing management plans.

Results

Water vole behaviour in relation to predation risk

There was a significant difference between giving-up-densities (GUDs) at the two distances from cover ($p = 0.018$). GUD 5m from cover was significantly higher for experiments carried out both in wide channels and in the reedbed. There was no significant difference between the two treatments *i.e.* between channel and reedbed (Table 1, Fig. 3).

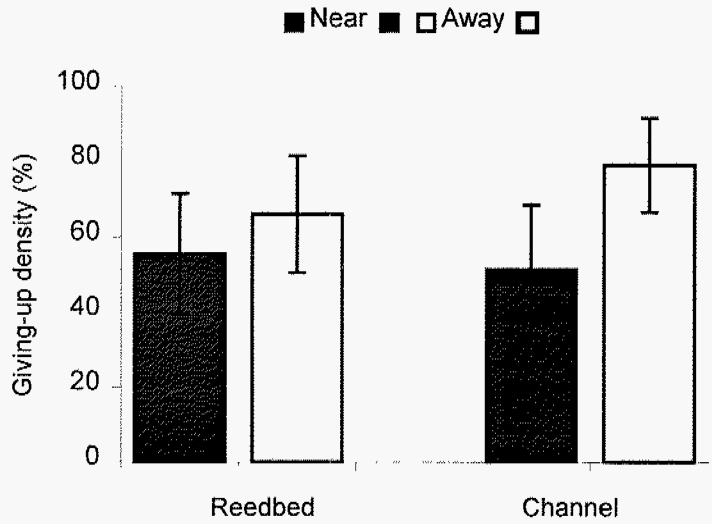

Figure 3. *Mean (±SD) percentage of food remaining (giving-up-density, GUD) at floating feeding stations in different situations, after 48hrs exposure to feeding water voles. Feeding stations were near (1m) and away (5m) from reed cover, within a reedbed and along main water channels on the edge of a reedbed. There was a significant difference in GUD between near and far stations (p=0.018), but not between the reedbed and main channels.*

Table 1. *Split plot design analysis of variance testing for differences in giving-up-density (GUD, arcsine transformed) between feeding stations in reedbeds and main channels, and near and away from cover.*

Source of variation	d.f.	F	*p*
reedbed *vs* channels	1,7	0.13	>0.1
sites within reedbed or channels	7,7	0.78	>0.1
near *vs* away within sites within reedbed or channels	1,15	7.10	0.018

Water vole winter ecology in reedbeds

Radio tracking confirmed important aspects of water vole behaviour in reedbeds. At the onset of winter, coinciding with rising water levels and reeds becoming dormant, water voles that had been living in above-water nests among reed stems moved to nearby banks or other higher ground. These places were on the edge of reedbeds, or within it. Water voles spent the winter in underground burrows. They were seldom found above ground during winter, but observations suggested they remained active underground and fed on plant roots. In spring water voles returned to nest within reedbeds.

Water vole mortality

In total 70 water voles were radio collared post breeding, 30 at Stodmarsh, 20 at North Warren and 20 at Ham Wall. Nine voles (13%) slipped their collars or disappeared during the first week of study (suggesting transmitter malfunction or dispersal); data for these water voles was excluded from analyses. Of the remaining 61 voles, 33 (54%) died before the end of winter. Twenty-two voles were known to be alive at the end of winter and a further six were missing. The known mortality rate is therefore at least 54% and if it is assumed (pessimistically) that the missing voles also died, mortality rates were: overall 63%; Stodmarsh 63%; North Warren 77%; Ham Wall 50%.

Table 2. *Causes of mortality of water voles at three reedbed sites over winter 1999–2000, as revealed through radio-tagging (n: total in each category; N: total voles that died).*

	predation								
	mink		mustelids*		other**		other mortality		
site	%	n	%	n	%	n	%	n	N
Stodmarsh	47	7	47	7	0	0	7	1	15
North Warren	20	2	60	6	20	2	0	0	10
Ham Wall	12.5	1	62.5	5	12.5	1	12.5	1	8
Total	30	10	55	18	9	3	6	2	33

*Mustelids included stoat, otter and, probably, unverified mink kills. **Other includes heron predation (1), compaction by heavy machinery (1) and unknown cause (1).

Causes of mortality

Of 33 water voles that died, 31 were predated; predation thus accounted for 94% of mortality (Table 2). Mustelids, including mink, were by far the most important predator being responsible for 84% of mortality. Confirmed mink kills accounted for 30% of overall mortality, 46% of mortality at Stodmarsh. However, we did not assign mortality to mink predation unless there was unequivocal evidence of such *e.g.* mink scats on a corpse, mink odour on a corpse, mink canine puncture marks on a water vole cranium. The mustelid category therefore probably includes unverified mink kills. Mink predation was thus probably higher than our figure suggests, and might account for most of the mortality. However, field evidence shows that there was some predation by non-mink mustelids, including stoats, though these were not common at any of the sites (Table 2). Mustelid kills that could not be assigned with certainty to a particular predator were typically water voles found killed and partly eaten in their home burrow. These could well have been due to mink, but it was not possible to separate them from, in particular, stoat kills.

Correlates of predation

In a model of the proportion of water voles predated, none of the following potential explanatory variables were included since they were not related to predation: study site, water vole age, sex, month of death and distance from woody cover. Distance from main channels could not be included into a model for all sites as virtually all animals at North Warren and Ham Wall spent the winter adjacent to main channels (there were no dry areas within these reedbeds). In a model using data from Stodmarsh only (where there were more banks and other areas of high ground away from main channels), the distance from main channels was found to be a strong predictor of predation probability (p=0.002; Table 3). The model fitted the data very well and using it we can predict the probability of a water vole being predated in relation to distance from a main channel (Fig. 4). This declines steeply with distance and water voles 150m from a main channel escape with less than half the risk of predation than voles near main channels.

Table 3. *Generalised linear model examining whether water voles were predated or not at Stodmarsh (response variable in GENSTAT with binomial errors and logit link), offset by the number of weeks each vole was radio-collared (staggered entry design). Parameter estimates and s.e.s are in logits.*

explanatory variable	parameter estimate	s.e.	d.f.	p
Distance from main channel	1.487	0.601	1	0.002

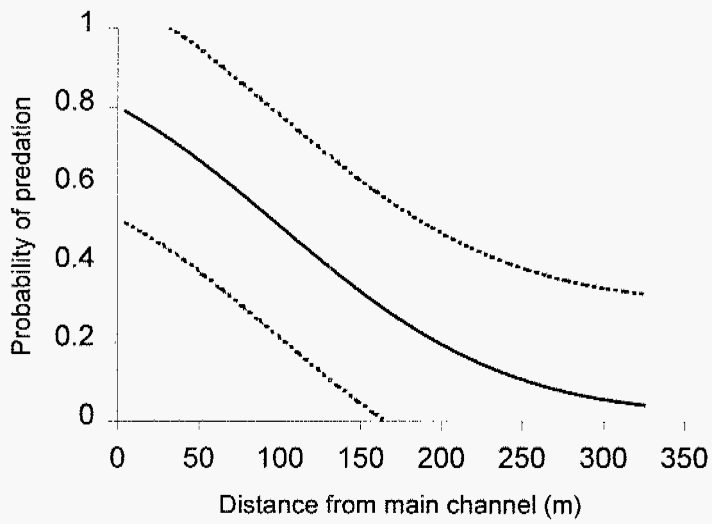

Figure 4. *Risk of predation in relation to distance of nest sites from main water channels for water voles at Stodmarsh. Solid line represents the fitted relationship from a generalised linear model (Table 3), broken lines show 95% confidence limits*

Mink activity and predation

Mink activity was much higher at Stodmarsh than the other two sites ($p<0.001$). Known mink predation on water voles correlated very closely with mink activity at each site (Fig. 5).

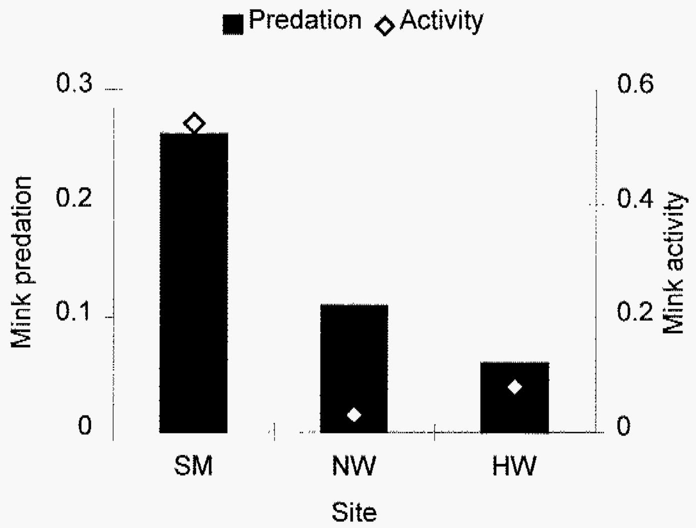

Figure 5. Proportion of radio tagged water voles known unequivocally to have been predated by mink and mink activity (indexed by counts of scats and tracks) during winter at three reedbeds sites. Mink activity was higher at Stodmarsh (SM) than the other sites (generalised linear model: response variable was the number of mink signs offset by the duration [days] of a site visit; Poisson errors, square root link; $p<0.001$).

Potential national key sites

Of the 15 sites short-listed as known to meet the selection criteria, half had not been surveyed for water voles and only two included water voles specifically in their management plans (Table 4; Fig. 6). Of ten selected sites where earthmoving operations were conducted as part of management, only two cleared vegetation before beginning work. The latter encourages water voles to move away from areas that are to be subject to earthmoving. As we found at North Warren, earthmoving without taking this precaution entombs and crushes water voles.

Water voles were known from our own fieldwork, or thought by our correspondents, to be abundant at most of the short-listed sites (71%), even though mink were present at 64% of them. Proactive mink control was only practised at three sites (Table 4). We have identified 12 further sites (and this list is by no means exhaustive) which might be considered as National Key Sites in the near future (Table 5). Some of these sites have not been included in the short list because the status of water voles at them is not certain, or precise sites that contain extensive areas of habitat have not been identified.

***Figure 6**. Distribution of sites short-listed as potential National Key Sites for water voles.*

Table 4. *Preliminary short list of potential National Key Sites for water voles. Water vole status was assess from our surveys (*), or otherwise by site managers.*

Site name, status, county	Managers	Area (ha)	WV status	WV surveys	Mink status & control	WV in m. plan	Water level change	Islands in reedbed	Banks cleared before earthmoving
Hickling Broad NNR, Norfolk	NNT	487	Abundant	No	Absent	Not specifically	0.2m	Yes	No
Bure Marshes NNR, Norfolk	NNT	451	Frequent*	Yes	Present	Yes	0.3m	Yes	No
Titchwell Marsh, Norfolk	RSPB	100	Frequent	No	Absent	Not specifically	0.5m	Yes	Yes
Minsmere, Suffolk	RSPB	930	Abundant*	Yes	Present, controlled	Not specifically	0.3m	Yes	Sometimes
North Warren, Suffolk	RSPB	23	Abundant*	Yes	Present	Not specifically	0.3m	Yes	No
Walberswick Marshes NNR, Suffolk	EN	582	Abundant*	No	Present, controlled	Not specifically	0.4m	Yes	No
Redgrave & Lopham Fen NNR, Suffolk	SWT	125	Frequent	No	Present	Not specifically	0.3m	Yes	No
Rainham Marshes SSSI, Essex	Various	200	Abundant*	Yes	Absent	Not specifically	0.5m	NA	NA
Blackwater Estury – Old Hall Marshes NNR, Essex	RSPB	1031	Abundant	No	Absent	Pending	0.4m	Yes	NA
Shapwick Heath NNR, Somerset	RSPB	390	Abundant*	No	Present, controlled	Not specifically	0.5m+	Yes	No
Ham Wall NNR, Somerset	RSPB	77	Abundant*	Yes	Present	Not specifically	0.5m+	Yes	No

Table 4 continued

Site name, status, county	Managers	Area (ha)	WV status	WV surveys	Mink status & control	WV in m. plan	Water level change	Islands in reedbed	Banks cleared before earthmoving
Stodmarsh NNR, Kent	EN	163	Abundant*	Yes	Present	Not specifically	0.3m	Yes	No
North Kent Meadows SSSI	Various	c.500	Abundant	Yes	Absent	Not specifically	NA	NA	NA
Brownsea Island	NT	20	Abundant*	No	Absent	Not specifically	NA	No	NA
Fenn's, Whixall & Bettisfield Mosses NNR, Cheshire	EN	104	Frequent	No	Present	Not specifically	0.3m	Yes	NA

Table 5. Preliminary list of sites that might in future be National Key Sites for water voles.

Site name, status, county	Area (ha)	WV status	WV surveys	Mink status & control	WV in m. plan	Water level change	Islands in reedbed	Banks cleared before earthmoving
Woodwalton Fen NNR, Cambridgeshire	208	Occasional	No	Present	Not specifically	1m+	No	No
Ouse Washes, Cambridge		Frequent	No	Present	Not specifically	>2m	Yes	No
Blue House Farm, Essex		Abundant	Yes	Absent	Yes	0.4m	NA	NA
Pevensey Levels NNR, Sussex	184	Occasional	No	Present, controlled	Not specifically	NA	NA	No
Dingle Marshes, Suffolk		Frequent	No	Present	Pending	0.6m+	Yes	No
Pagham Harbour, Hampshire		Abundant	Yes	Present, controlled	Yes	NA	Yes	No
Lower Test, Hampshire		Abundant, patchy	Yes, in part	Present, controlled			NA	
River Itchen, Hampshire		Abundant, patchy	Yes, in part	Present, controlled			NA	
Erwash Meadows, Derbyshire	21	Frequent	Yes	Absent	Yes	NA	NA	NA
Aqualte Mere NNR, Staffordshire	210	Occasional	Yes	Present, controlled	Yes	0.3m	NA	No
Marazion Marsh, Cornwall		Occasional	Yes	Present	No	0.3m	Yes	NA
Isle of Wight		Frequent	Yes	Absent				

Discussion

We have shown that over-winter mortality in water voles living in reedbeds is due almost entirely to predation. Mustelids were the main predators, mink probably being chief among them. Crucially, however, we showed that predation rate at Stodmarsh declined strongly with the distance a water vole lived from a main channel. Thus reedbeds within which water voles can spend the winter offer a refuge from predation. This is a very important finding for conservation and explains, at least in part, how water voles and mink have been able to coexist for so long at sites like Stodmarsh.

It remains, however, to be determined whether the rates of predation we found will allow water vole populations to survive. It may be that mink are inducing a chronic long-term decline, even in reedbeds. Our data suggest that this may not be the case. It is important to remember that our work was conducted over winter when mortality is known to be highest. The overall winter mortality rate we recorded (based on the most pessimistic calculation) was slightly less than previous estimates of about 70%, for water voles in the absence of mink (*e.g.* Macdonald and Strachan 1999; G. Woodroffe, pers. com.). Though this rate is high, it will not necessarily lead to water vole decline, since their fecundity is also high. Assuming that water voles have on average 3.4 litters of six young a year (Corbet and Harris 1991), their gross *per capita* rate of population increase, *i.e.* ignoring summer mortality, is likely to be about 10.2. To merely replace the average losses we recorded over winter (63%), the rate of increase over summer would need to be 2.70. Summer mortality among young-of-the-year may be 70%, none breed in their year of birth and very few adults (here we assume zero) survive to breed in a third year. On this basis water voles have a net summer rate of increase of 2.76, enough to replace the winter losses we recorded.

However, voles wintering within reedbeds (away from main channels) suffered much lower predation. How does this influence their population dynamics? If we assume that all voles winter 150m from a main channel and so experience only 30% predation (Fig. 4), then the rate of increase needed to merely replace winter loses would be only 1.43. Assuming the summer increase described above, such water vole populations would grow by 33% a year. This would provide a rich source of dispersers to colonise areas surrounding reedbeds.

Though a simplification of complex reality, these calculations have a strong empirical message of over-arching importance for conservation. The refuge effect offered by reedbeds may not only allow local water vole populations to sustain themselves in the face of intense predation pressure. Reedbeds may also support source populations vital to the viability of water vole metapopulations in surrounding landscapes. Thus reedbeds (and similar refuges) may not only offer a redoubt for water voles, but demonstrable hope for future recolonisation once degraded habitats are restored.

It is essential to recognise that the influence of predators on water voles that we recorded is likely to be strongly dependent on the density of non water vole prey. In particular, reedbeds are likely to provide abundant fish, avian and amphibian prey for mink. The abundance (numerical response) of mink will likely follow the density of such abundant prey. Mink, and other predators, may thus more often predate water voles where non-water vole prey are most abundant. The abundance of non water vole prey at our study sites was undoubtedly high: all were rich wetlands teeming with wildlife. The impact of mink, and other predators, on water voles in our study sites would thus be expected to be at the high end of that experienced by water voles.

Mink were resident at Stodmash during the study, but infrequent visitors at Ham Wall and North Warren, though there were resident mink in nearby wetlands. Clearly mink were very patchily distributed and this may partly be due to the distribution of suitable den sites (Halliwell and Macdonald, 1996). We suspect that sites for dens were lacking near our study sites. Furthermore, at least one mink was present at Ham Wall for an extended period in summer 1999, but left as water levels rose. The dispersion of voles throughout reedbeds in summer may be crucial in allowing them to evade mink.

Our experiments concerning water vole behaviour at feeding stations were revealing. At stations 1m from reed cover, a large proportion of food was eaten. The amount consumed at stations just 4m further from cover showed a very marked reduction. Clearly water voles were less inclined to feed away from cover, exactly as foraging theory predicts. This suggests that they do perceive greater risk from predators further away from cover. However, there was no difference in giving-up-density between main channels and in the reedbed, despite the fact that predation risk was higher near the former (Fig. 4). This implies that water voles failed to perceive the greater risk of predation near main channels. We hypothesise that this is because water voles lack evolved behavioural mechanisms to combat predation by mink, which appeared to be more active along main channels.

Given that reedbeds can support large populations of water voles that elsewhere have become the subject of intense scrutiny, it is perhaps surprising that so few reedbed sites have been surveyed for water voles. It is also remarkable, given the high profile of water vole decline, how few sites have the water vole explicitly included in their management plans. Clearly these issues need addressing, and with some urgency.

Conservation management recommendations

Reedbed management

1. Wintering water voles are tied closely to burrow systems, unlike voles in reedbeds in the summer. For the refuge effect we discovered to operate, reedbeds need dykes (earth banks) or, better still, islands within them. These need to have steep banks, suitable for water vole burrows. They must remain un-flooded throughout winter. Many reedbeds have such places (Tables 4 & 5), but the creation of suitable islands where these are lacking would greatly enhance reedbeds as refuges for water voles. Ideally, these intra-reedbed islands need to be as far as possible from main channels and the edge of the reedbed, but just 50m in is enough to reduce predation rates. We suggest islands should be about 5m wide, so that there is room for extensive burrow systems. Based on the length of water vole winter ranges and the configuration of islands at Stodmarsh, we suggest 25-50m lengths of such island per hectare of reedbed.

2. In winter water voles feed largely on roots, rhizomes and bulbs from within their burrow systems. Dykes and islands within reedbeds should be planted with these preferred food sources.

3. It is vital that shrubs, trees or other structures that might provide dens or lying up sites for mink are kept off dykes and islands within reedbeds.

4. For reedbeds to function as refuges and to be useful habitats for water voles, it is obviously essential that they do not dry out. Water depths of at least 0.3m will be needed to dissuade terrestrial predators from entering reedbeds. Deeper water facilitates the water voles ability to escape from predators by diving and water depth is an important determinant of habitat quality for water voles (Woodall, 1993). We found that water voles were much less abundant in areas of reedbed prone to drying out in summer.

5. Conversely, it is vital that winter water levels in reedbeds do not rise so high as to flood water vole burrows. Flooding will force voles to move out of or away from reedbeds, abandoning the protection that they offer.

6. Current reedbed management practises (Hawke and José 1996), including the work designed to aid bittern recovery, will be greatly beneficial to water voles. So too will the creation of new reedbeds. The creation of ditches and pools within a reedbed promotes recolonisation by marginal vegetation, which diversifies the food and cover available for water voles.

7. Re-profiling of banks and other earthmoving operations in reedbed habitats will crush water voles in their burrows. This happened to one of our radio tagged voles at North Warren. A large proportion of a local water vole population could easily be wiped out in this way. Such deaths can at least partly be prevented by the simple expedient of removing vegetation from banks well before earthmoving starts. This encourages water voles to move elsewhere, but is likely to be less effective in winter when voles are less active on the surface. If earthmoving is to be done in winter, consideration should be given to clearing banks in the previous autumn.

National key sites: conservation strategy & monitoring

1. Reedbeds can support large, dense populations of water voles and provide a refuge from predation. The current fortunes of water voles in reedbeds are clearly much better than in most other sites. It should be readily possible to ensure that habitat management in reedbeds benefits water voles. Ensuring the same in the wider countryside, in many smaller dispersed sites, will not be so straightforward. Ultimately water voles may not survive at most sites unless mink are controlled. Our results suggest that in reedbeds water voles may be able to coexist with mink. We therefore recommend that reedbeds, and like sites where water vole populations appear resilient (see below), are made one focus of water vole conservation efforts. These will be National Key Sites. They will be a very important part of the conservation strategy for the water vole, ensuring it survives in at least some places. National Key Sites will be integrated into landscape scale management for the water vole. They should enhance, not detract from, key site and other conservation initiatives already underway in many linear riparian habitats.

2. We have provided a provisional list of potential National Key Sites. These are not set in stone and we expect the list to change and be extended in the light of further fieldwork. We have included some non-reedbed sites in the list. These are dense networks of ditches, for example on grazing marshes. Water voles are often still abundant in these places, probably not least because they are likely to be less suitable for mink. It must be stressed, however, that there is no evidence that such sites offer a refuge from mink which may, sooner or later, colonise. Further research is needed on this issue (see below). Our list of

potential sites also includes river catchments that are heavily gamekeepered. Specific series of sites within these catchments need to be identified to allow targeting of conservation management.

3. There is general agreement that a landscape scale conservation programme is needed for the water vole. We therefore recommend that the National Key Sites (NKS) strategy extends out of single refuge sites into surrounding areas. We envisage a work programme as follows:

(I) Visit NKS and advise managers about the habitat management needs of the water vole and ensure that these are incorporated into management plans. This needs to be done soon, so that necessary management can be conducted this coming winter.

(II) Instigate a programme of monitoring at NKS and at riparian sites within a 5km radius of each. This should consist of summer surveys to determine breeding distribution at most or all NKS and surrounding sites. Where the status of water voles is in doubt at potential NKS, baseline surveys will need to be conducted. At least three NKS post-breeding and pre-breeding population sizes and mortality should be monitored by trapping and marking water voles. This is essential because we must determine whether reedbeds provide a sustained refuge for water voles from mink.

(III) Use NKS to promote water vole recolonisation of surrounding areas. Ensure that surrounding habitats are managed to maximise suitability for water voles. Determine whether reedbeds provide sufficient dispersing water voles to sustain (meta) populations in areas surrounding reedbeds, even in the presence of mink. Conduct experimental reintroductions to areas around reedbeds.

(IV) Determine whether non-reedbed sites, *e.g.* dense networks of ditches on grazing marshes, can offer a sustained refuge from mink. If so, incorporate more of these sites and areas surrounding them into the NKS strategy.

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