

Urban grasslands support threatened water voles

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Abstract

Urbanisation is often linked with habitat loss and a reduction in species richness but some species may be able to adapt to urban environments. Water voles *Arvicola amphibius*, a rapidly declining species in the UK, have recently been recorded in isolated grassland habitats in Glasgow, Scotland's largest city (human population 1.2 million). The aim of this study was to determine the distribution and habitat characteristics of water vole populations occupying these dry grasslands. Field work was undertaken from March to October 2014 in a 34 km² study area located 3 km east of the city centre. Field sign transects recorded water vole presence in 21/65 (32%) and 19/62 (31%) surveyed sites in spring and autumn, respectively. Vole occupancy increased with distance from water and was greatest in parkland, followed by sites with rank vegetation and roadside habitats. Occupancy was lower where signs of predators were recorded but surprisingly occupancy was found to be greater in the most disturbed sites, perhaps linked to the fact that many of these sites were public parks containing suitable grassland. Sites occupied by water voles were classed as neutral grasslands with species composition dominated by two main species. The number of grassland sites occupied by water voles, especially within public areas suggests that careful management of these urban grassland habitats will benefit the conservation of this highly threatened species in the UK.

Key words: water vole, fossorial, grassland, urban biodiversity, habitats, city

Introduction

Urbanisation is often linked with habitat loss and a reduction in species richness but some species may be able to adapt and thrive in urban environments (Pickett et al. 2001; McKinney 2002; Lopucki et al. 2013). Numerous vertebrate species are reported to occupy cities (Adams and Lindsey 2011) and some species such as the brown rat *Rattus norvegicus* are considered to be commensal with humans (Feng and Himsworth, 2013). Water voles *Arvicola amphibius* are one of the fastest declining

mammals in the UK. Since 1990 there has been an overall decline of 88% in previously occupied sites and as a consequence water voles are a highly protected species (Strachan 2004). Historically, water voles have been declining since the early 1900s due to changes in land-use and habitat fragmentation. The move towards intensive agriculture and urbanisation has resulted in the loss and degradation of riparian habitats (Rushton et al. 2000; Jefferies 2003; Strachan and Moorhouse 2006). Rushton et al. (2000) estimated that a third of all semi-

natural vegetation once available to water voles on farmland has been lost in the UK since 1940. Introduction of the American mink *Neovison vison* from fur farms in the 1950s resulted in a rapid decline in water vole populations (Woodroffe et al. 1990; Barreto et al. 1998; Strachan 2004; Carter and Bright 2003). The rate of decline has shown signs of slowing in recent years, largely in part due to mink control programmes but also because of collective efforts between government agencies, statutory nature conservation bodies and wildlife charities to improve habitats and reintroduce water voles to previously occupied sites (Strachan et al. 2011).

Approximately 40% of the UK water vole population is thought to reside in Scotland (CWC 2005) with the majority of water vole colonies found as upland metapopulations (Stewart et al. 1998). Water vole numbers in the lowlands are considered marginal, being small and spatially scattered, primarily because of urbanisation and well-established mink populations (Telfer et al. 2001). Urbanisation is largely concentrated in the lowlands and in Scotland 80% of the human population inhabits just 6% of the total land area (Office of National Statistics 2011). This high human population density means that the majority of the landscape in urban areas has been modified for housing, recreation, infrastructure and industrial use.

In the UK, most accounts of water voles are from riparian habitats (Harris and Yalden, 2008). Riparian water voles have highly specialised habitat requirements and their distribution is limited by the availability of wetland vegetation along rivers and streams (Stoddart 1970; Lawton and Woodroffe 1991; Strachan et al. 2011). Non-linear wetland habitats like reed beds have also been found to support extensive water vole populations (Carter and Bright 2003). Riparian habitat may not normally be associated with cities but well managed urban areas can include artificially created parks with water courses or reed beds, remaining sections of canal and sustainable urban drainage systems (SUDS) which can all prove favourable to water voles (Strachan et al. 2011). Water voles have previously been recorded in cities (Dickman 1987), but the importance of urban habitats for water vole populations have generally been neglected. For example, riparian water voles have been recorded in the north west, south west and north east of Scotland's largest city, Glasgow (human population 1.2 million; Fig. 1). However, since 2008 water voles have been recorded in isolated grassland distant from riparian habitats in derelict areas of land, road verges and public parks. The occurrence of water voles in these habitats along with their characteristic fossorial behaviour is unusual in the UK. This ecotype has only been recorded in a small number of isolated islands, mainly in Scotland (Telfer et al. 2003). However, in continental Europe the fossorial ecotype is common, particularly in upland meadows (Meylan 1977; Berthier et al. 2014). Fossorial populations can become a serious pest in some areas due to the economic impact they can have on agricultural crops and orchards by damaging root systems, consuming plants and digging extensive burrow systems which can destabilize soil structure (Meylan 1977). These populations oscillate with a 4–8 years cyclicity and in peak years water vole numbers can reach 'outbreak' densities of a 1000 individuals per hectare (Giraudeau et al. 1995; Weber et al. 2002; Berthier et al. 2014).

Aim

Given the unfavourable conservation status of water voles in the UK and the recent finding of grassland populations within Scotland's largest city, the aim of this study was to investigate

their distribution and habitats within urban grasslands. This research was intended to inform the conservation of this species in city environments.

Methods

Distribution and habitat

Field work was undertaken from March to October 2014 in a 34 km² study area (55°53'0.515"N, 4°6'53.467"W) located 3 km east of Glasgow city centre, Scotland, UK (Fig. 2). A stratified sampling methodology based on Sibbald et al. (2006) was used for surveying water vole presence from field signs. The study area was subdivided into 34 primary sampling units (PSUs) using 1 km² grid squares. Each PSU was viewed using satellite images (www.google.co.uk/maps) to identify areas of continuous grassland habitat suitable for field sign surveys. The PSU was walked on foot to locate suitable sites and where possible a maximum of two sites (minimum 200 m apart) were identified for each 1 km² grid square. Site location was recorded using a GPS receiver (Garmin GPSmap76CSx). Water vole occurrence (1/0) was recorded in spring (March–April) and autumn (September–October) at each survey site by searching for field signs (faeces, latrines and burrows) at 10 m intervals (within 2.5 m either side of transect line) along a 100 m transect (Telfer et al. 2003). Predator occurrence was recorded by the presence of scats on each transect or visual observations of predators at the site during the survey. At 0, 50 and 100 m along the transect, all grass species were recorded and identified to at least the genus level (Averis 2013) and their percentage cover ranked using the DOMIN scale of the National Vegetation Classification system (Rodwell 2006). At each site, habitat type and neighbouring land use were recorded and the site was ranked on an ordinal scale of 1 (low), 2 (medium) and 3 (high) for trampling (human or livestock), traffic noise, human activity (e.g. grass cutting, use of public park) and evidence of dug out burrows. The mean rounded sum of these scores was then used as an estimated level of disturbance at each site. The minimum straight line distance (m) to a water body (stillwater, river/stream or marsh) was recorded from satellite maps for each site. All locations with water vole signs were submitted to the Biological Records Centre (www.brc.ac.uk).

Data analysis

Occupancy modelling

Habitat factors influencing the occurrence of water voles were examined, with the presence or absence of water voles from spring and autumn surveys (hereafter 'occupancy') as our response variable. We used single-season site occupancy models to simultaneously evaluate variables affecting site occupancy via an occupancy sub-model (MacKenzie et al. 2002) and detection probability via a detection sub-model in the package 'unmarked' (Fiske and Chandler, 2014). Variation in occupancy and detection probabilities were evaluated using backwards model selection based on Akaike's information criterion (AIC) weights to select the optimal model amongst a set of biologically relevant candidate models (Burnham and Anderson 2002). We tested the overall fit of our optimal model by a parametric bootstrap and χ^2 goodness-of-fit test, ensuring that our explanatory variables adequately described variability in the response variable (MacKenzie and Bailey 2004). Explanatory variables were habitat type ('park': managed public parks or gardens; 'rank vegetation': rough grassland with shrubs/derelict sites; and 'roadside': road verge habitats), neighbouring land use ('natural': natural/semi-natural

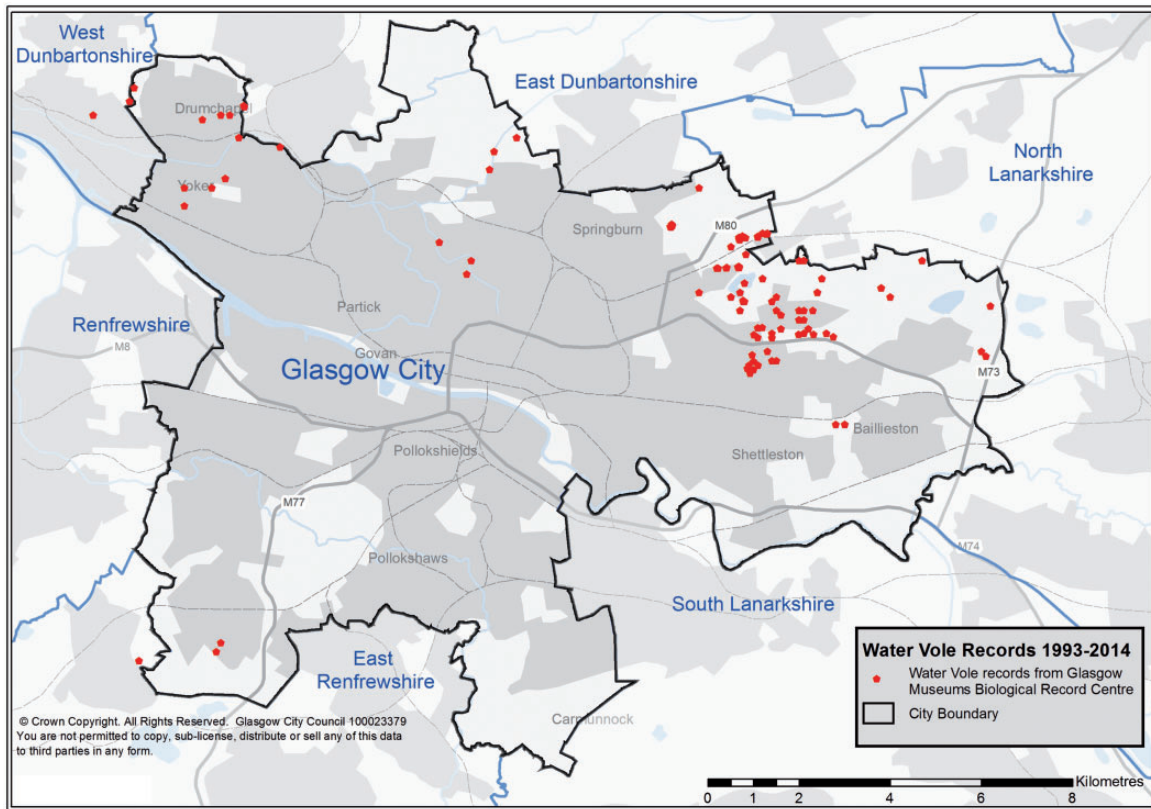


Figure 1: Records of water voles in the City of Glasgow prior to 2014 survey.

habitats; 'park': as above, 'road': adjacent to road(s)), distance to water (m), disturbance score (low, moderate and high) and predator signs (presence/absence). We then used a model-averaging approach to estimate the probability of water vole occupancy. We generated predictions of parameters under each model and computed a weighted average comprised of AIC weights. Weighted averages and unconditional standard errors were used to calculate 95% confidence intervals for predicted occupancy. Analysis was performed using the statistical programming environment R Version 3.3.3 (www.r-project.org).

Habitat composition

Principle component analysis (PCA) was used to determine grass species associated with water vole occurrence. This analysis was based on autumn survey data only, due to the difficulties of identifying old and dead grass in spring. Species occurrence (1/0) was $\log(x+1)$ transformed to eliminate the effect of multiple zeros within the data set. The occurrence of grass species was then examined using the Bray–Curtis measure of similarity in SIMPER analysis (Community Analysis Package Ver. 5, www.pisces-conservation.com). This estimated the similarity of grass species in relation to water vole occurrence giving their percentage contribution for occupied and unoccupied sites.

Results

Distribution and occupancy

Sixty-five out of the total 68 sites were surveyed for water vole presence in spring and 62 sites re-visited in autumn. The 65 sites surveyed were 23–1148 m from water, 36 sites were classed

as containing rank vegetation, 15 roadside and 14 park habitats. Water vole presence was recorded in 21 sites (32%) and 19 sites (31%) in spring and autumn, respectively. Signs of red fox *Vulpes vulpes* were the most common predator recorded on survey sites (24 sites on both survey occasions), followed by domestic cats *Felis catus* (7 sites in spring and 5 in autumn surveys) and the brown rat (one site in both surveys). Signs of American mink were not observed.

Nine candidate models were used to explain detection probability and site occupancy of water voles (Table 1). Occupancy (back transformed from logit scale) averaged across all models was 0.33 (95% C.I. 0.201–0.483) with a detection estimate of 0.82 (S.E. = 0.067). Season of survey did not increase the explanatory power of the model and therefore was not further included (Table 1). Based on AIC score the best model included disturbance, habitat category, distance to water and predator signs (Table 1). The χ^2 goodness-of-fit indicated that our optimal model fitted our data adequately ($\chi^2 = 1.7$, $P = 0.2$). This model predicted that water vole occupancy increased with increasing distance to water, although the relationship at distances greater than 500 m was based on a small sample size at these distances, hence wide confidence intervals (Table 2, Fig. 3). Occupancy was greatest in parkland followed by sites with rank vegetation and roadside habitats. Occupancy was also lower where predator signs were recorded but occupancy was predicted to be greater in the most disturbed sites.

Grass species composition

All surveyed sites were classed as B2 Neutral Grassland (Joint Nature Conservation Committee [JNCC], 2014). Occupied sites had an average of 27% similarity in dominant grass species and

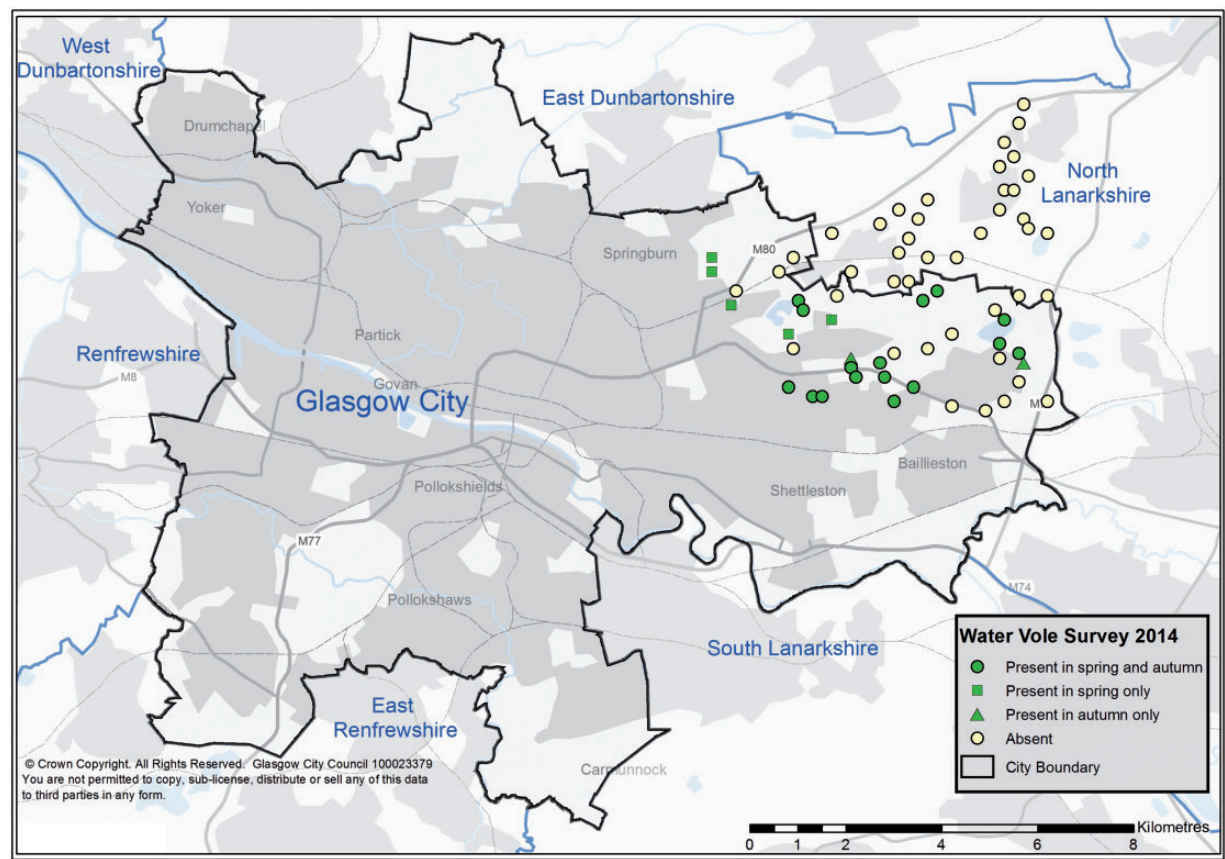


Figure 2: Presence and absence of water voles in 34 km² survey area in east end of Glasgow during spring and autumn 2014.

Table 1: Model selection results for nine candidate models for detection probability and occupancy of water voles in 2014

Model	K	AIC	Δ AIC	AIC weights
p(.) ψ (DI + HC + DW + PS)	6	114.000	0.000	0.475
p(.) ψ (DI + HC + DW + NL + PS)	7	116.000	2.000	0.175
p(.) ψ (DI + DW + NL + PS)	6	116.280	2.290	0.151
p(S) ψ (DI + HC + DW + NL + PS)	8	116.730	2.730	0.121
p(.) ψ (DI + HC + NL + PS)	6	118.350	4.350	0.054
p(.) ψ (DI + HC + DW + NL)	6	121.170	7.170	0.013
p(.) ψ (HC + DW + NL + PS)	6	122.050	8.050	0.008
p(.) ψ (.)	2	125.960	11.960	0.001
p(S) ψ (.)	3	126.830	12.830	0.001

K = # of parameters; AIC = Akaike's information criterion, Δ AIC and AICweights. p = probability of detection; ψ = probability of occupancy; S = season; DI = disturbance; HC = habitat category; DW = distance to water; NL = neighbouring land; PS = predator signs; '.' = null submodel.

unoccupied sites, an average similarity of 20% (Table 3). Velvet grasses *Holcus mollis* and *H. lanatus* were the dominant species on 43% of occupied sites. The average similarity between occupied sites by *Holcus* species (similarity = 11.54) was higher compared to unoccupied sites (similarity = 2.89). The rush *Juncus effusus* also showed a high average abundance on occupied sites compared to unoccupied sites. *Agrostis* species and tufted hair-grass, *Descampsia cespitosa*, were the dominant grass species in 52% of sites where water voles were absent. False oat-grass, *Arrhenatherum elatius* was found in unoccupied sites but was

Table 2: Model averaged parameter estimates (Estimate: logit scale, Standard error (SE), Z statistic and P value) for variables used to model occupancy of water voles in 2014 (AIC = 114.0). Detection estimate (logit scale) for the model was 1.51 (SE = 0.45)

Variable	Estimate	SE	z	P(> z)
(Intercept)	-1.3631	1.19274	-1.14	0.25310
DI	1.6097	0.58401	2.76	0.00585
HC	-0.7381	0.48224	-1.53	0.12586
DW	0.0029	0.00135	2.14	0.03249
PS	-1.9412	0.81546	-2.38	0.01729

DI = disturbance; HC = habitat category; DW = distance to water; NL = neighbouring land; PS = predator signs.

absent where water voles were present. Cocksfoot, *Dactylis glomerata*, was the only dominant grass species found in equal abundance on sites irrespective of water vole occurrence.

Discussion

Distribution and habitats

Water voles have not often been reported in cities and this species is generally recorded within close proximity to water bodies in the UK. This study however recorded water voles in a variety of highly modified grassland habitats including public parks, residential gardens, road verges and derelict land. Water voles occupied an extensive network of tunnels in these grasslands

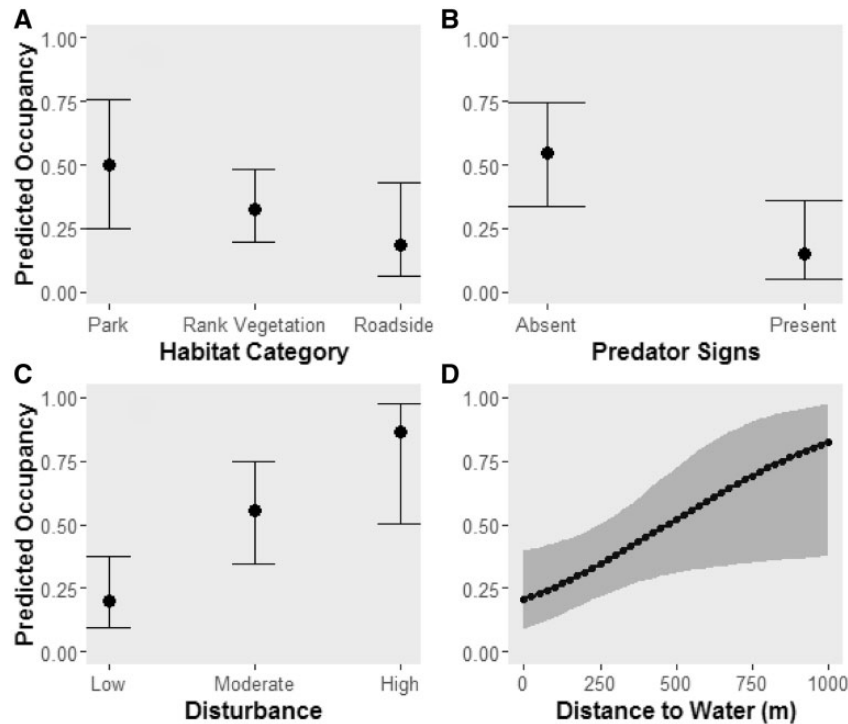


Figure 3: Predicted occupancy (Mean \pm 95% CI) of water voles according to (A) habitat category, (B) predator signs, (C) disturbance score and (D) distance to water (m).

Table 3: Mean similarity and percentage contribution (SIMPER analysis) of dominant grass species for sites that were occupied and unoccupied by water voles in autumn 2014

Species	Occupied sites		Unoccupied sites	
	Mean similarity	% Contribution	Mean similarity	% Contribution
<i>Holcus mollis/lanatus</i>	11.54	43	2.89	14
<i>Juncus effusus</i>	5.01	19	1.44	7
<i>Agrostis spp.</i>	3.25	12	5.82	29
<i>Descampsia glomerata</i>	2.98	11	2.31	11
<i>Descampsia cespitosa</i>	1.99	7	4.59	23
<i>Arrhenatherum elatius</i>	0	0	1.69	8

(Supplementary Material). This fossorial habit in dry grassland has only been recorded in a few UK locations and is more typical of water vole populations in continental Europe. Neutral grasslands dominated by *Holcus* grass species, along with rushes *J. effusus* were particularly common at sites where signs of water voles were observed. Water vole occupancy was greatest in parks/gardens compared to sites with rank vegetation and along roadsides. Relaxation of grass cutting regimes, creation of meadow habitats and vegetation succession particularly in parks, may be responsible for creation of suitable habitat in these areas.

Water voles occupying riparian habitats have been recorded in Glasgow but in the eastern side of the city where this study was undertaken, water vole occupancy was found to increase with increasing distance to water. It is possible that water voles in this area are a relic of populations once found along the Monkland Canal and have persisted in the area since the canal was filled in during the 1950s to create space for the M8 motorway (Scottish Canals 2015), displacing animals into surrounding

grassland habitats. Mink, the main predator of water voles are largely associated with riparian habitat in the UK (Harris and Yalden 2008) and therefore predation may be reduced in grassland areas. In this study, occupancy was found to be greater where signs of predators were absent. Although there was no evidence of mink at the sites surveyed, signs of red fox, domestic cat and brown rat were recorded. Elsewhere, water voles are found frequently in the diet of the red fox (Weber and Aubry 1993; Forman 2005) and predation of young by the brown rat has been suggested as a source of mortality (Barreto and MacDonald 1999). Water voles in urban and dry grassland habitats therefore have a range of predators. However, reduced occupancy closer to riparian habitats (<500 m) may suggest that mink continue to influence water vole populations in this area. Surprisingly, the occupancy model showed that occupancy of water voles increased with greater estimated levels of disturbance. This counter-intuitive result may be due to the fact that many of these parkland sites contain areas of less intensively managed grasslands, and suggests that if suitable habitat is available,

human disturbance is not necessarily a limiting factor for water voles in urban environments.

Management implications

Water voles occur in Scotland's largest city (fifth in the UK) in an area that is undergoing a redevelopment programme to improve housing and infrastructure. Land-use change is inevitable and is likely to be extensive. In the UK, habitat creation, water vole displacement, translocation and mitigation guidelines for development are currently based on the ecology of riparian populations (Strachan 2004; Strachan et al. 2011). A management strategy for water vole populations occupying terrestrial grassland habitats is therefore a high priority, so as to provide clear guidelines for developers, land owners and the wider public. Habitat management regimes, particularly in public parks are also required to ensure grassland continues to provide suitable species diversity for water voles. Although human disturbance does not appear to be a major factor influencing water vole populations in urban environments at present, the potential for human-animal conflict is considerable given the urban environment and the close proximity of water voles to people. In conclusion, urban grasslands have been found to support fragmented populations of threatened water voles and these habitats should therefore be considered an important refuge for water voles in the UK.

Supplementary material

Supplementary material are available at JUECOL online.

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