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Baptiste Wijas, Robyn Stewart & Dominic McCafferty

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Baptiste Wijas[1,2], Robyn A. Stewart[1] and Dominic J. McCafferty[1]*

ABSTRACT

Water voles (*Arvicola amphibius*) occur in urban areas in mainland Britain but relatively little is known about their ecology in these environments. In Scotland's largest city Glasgow, fossorial water voles occupy areas of grassland, some of which may be faced with urban development. The aim of this study was to estimate the area of habitat required by water voles in these urban grasslands by determining their home range size and spatial overlap. Radio-tracking was undertaken at two grassland sites over 29 days during September to October 2018. The mean ± SD home range size of males was 881.4 ± 636.21 m^2 (n=5, range 197.8 -1836.2) and 996.5 ± 643.45 m^2 (n=5, range=435.1 - 2044.6) for females. There was no difference in home range size between sexes or sites and no correlation with body mass. Where home ranges overlapped, the percentage area overlap was 37.4 ± 26.81%. These initial findings provide valuable information on spatial use of urban grasslands by water voles that will inform the management of habitats for this species.

INTRODUCTION

Water voles (*Arvicola amphibius*) occupy both riparian and dry grassland habitats throughout their full geographical range. Many of their habitats are highly fragmented and metapopulations exist in isolated patches that rely on movements of animals between colonies (Lawton & Woodroffe 1991; Telfer *et al.* 2001). In mainland Britain, water vole populations have decreased due to predation by American mink (*Neovison vison*) but recent research has highlighted water vole occurrence within several cities (Leivesley *et al*. 2021), suggesting that urban areas may possibly act as refuges for this species (Brzeziński *et al*. 2017).

In riparian habitats water voles have a polygamous mating system, with males typically overlapping the home range of many females and other males (Strachan *et al*. 2011). Home range size varies by sex with males having larger home ranges than females (Stoddart 1970; Leuze 1976; Moorhouse & Macdonald 2005; Strachan *et al*. 2011). In riparian habitats female water voles are territorial during the breeding season with small, non-overlapping home ranges (Strachan *et al*. 2011). Typically home ranges are regarded as linear with daily movements within 1-2 m from the water course and territory lengths of approximately 60-300 m for males and 30-150 m for females (Stoddart 1970; Strachan *et al*. 2011). Home range size is also strongly influenced by population density (Moorhouse & Macdonald 2008) and habitat quality (Lawton & Woodroffe 1991; Strachan *et al*. 2011). In dry grassland (terrestrial) habitats, water voles are fossorial and excavate extensive burrow systems with branching tunnels, bolt holes, food stores and nesting chambers reaching up to 100 m in length (Meylan 1977; Giraudoux *et al*. 1995; Frafjord 2016; Stewart *et al*. 2017). As seen in riparian habitats, home range sizes of water voles also vary according to sex averaging 1700 - 2700 m^2 in males and 650 - 850 m^2 in females (Frafjord 2016; Jeppsson 1986). Home ranges of fossorial voles show considerable overlap both in males and females suggesting social organisation broadly similar to riparian voles but lacking exclusive female territoriality for breeding (Frafjord 2016).

In comparison to research on riparian water voles, less is known about the spatial ecology of animals in grassland distant from water, and there are also few studies in urban areas in mainland Britain. However, in Scotland's largest city Glasgow, fossorial water voles occupy areas of grassland, some of which may be faced with redevelopment for housing (Stewart *et al*. 2017). To understand more about fossorial water voles in these urban grasslands, the aim of this study was to estimate the area of habitat required by determining their home range size and spatial overlap. This research will be used to inform the conservation of this species in urban grasslands, especially in areas faced with redevelopment and habitat loss.

[1] School of Biodiversity, One Health & Veterinary Medicine, Scottish Centre for Ecology and the Natural Environment, University of Glasgow, Rowardennan G63 0AW, Scotland, UK
[2] School of Biological, Earth and Environmental Sciences, UNSW Sydney, 2052, Australia
*corresponding author: dominic.mccafferty@glasgow.ac.uk

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METHODS

Study sites

Two sites were chosen that were representative of urban grasslands in the north-east of Glasgow; one was a park and the other vacant and derelict land. Site 1: Cranhill Park (NS644655), holds the largest colony of grassland water voles recorded in Glasgow since 2011 (Glasgow Museums Biological Records Centre, unpublished data). Mark-recapture studies carried out in 2014 showed that the site supported high densities of fossorial water voles (Stewart *et al*. 2017, Stewart *et al*. 2018). Site 2: Baldragon Road (NS680662), a former housing site left vacant for more than five years, was colonised more recently in 2016 with patchy occupation at low density across the site. In March 2018 this site was used as a receptor site for 58 (unmarked) individuals being relocated because of land development.

Trapping

Twenty live traps were deployed at both sites (Sherman XLF15; 10.2 x 11.4 x 38.1 cm) and trapping was undertaken over the period 22 August to 21 September 2018. Traps were baited but not set for 24 hours and then provisioned with hay, apple and carrot, set at dawn and checked 6 hours later each day. No overnight trapping took place to reduce the risk to captured animals from human interference. Trap position was recorded using GPS (Garmin eTrex 10; Garmin Ltd). All individuals were sexed and body mass ± 0.1g recorded (Pesola MS500). A total of 24 water voles (12 sub adults, 11 adults + 1 retrap adult) were captured, 10 adults were large enough (>120 g) to be fitted with radio-collars (see below), consisting of two males and three females at Site 1 and three males and two females at Site 2 (Table 1). All collared individuals survived for the duration of the study period and remained within the site where they were originally trapped. Trapping was undertaken for seven days at the end of the study but no collared animals were re-captured.

Radio-tracking

The 10 selected water voles were fitted with radio-collars (PiP cable-tie collar Ag393; mass 2.9g; Biotrack Ltd; <2.5% of body mass). Collared individuals were marked with a subcutaneous PIT tag injected into the scruff (AVID Friendchip single-use sterile microchip). Animals were allowed to recover for 10 minutes before being released at the point of capture. After 24 hours post release, water voles were tracked by two observers using Sika receivers with Yagi antennae (Biotrack Ltd.) between the hours of 0700 and 1800. Fixes were taken every 2 minutes for a 30-minute block for triangulation. One 30-minute block was carried out per individual per hour time slot giving a total of 11 hours of radio-tracking data per individual. Radio-tracking was conducted over 29 days from 03 September to 17 October 2018. The location error from triangulation was within positioning accuracy of the GPS (±5 m).

Vegetation surveys

Phase 1 and 2 Habitat Surveys were carried out on 22 November 2018. Both sites were classified in Phase 1 Habitat Survey as species poor neutral grassland, with Site 1 being poor semi-improved grassland (B6) and Site 2 marsh/marshy grassland (B5). A total of 11 plant species were recorded at Site 1 compared to 20 species at Site 2. Site 1 was dominated by grasses (89.4% abundance), with *Holcus lanatus* accounting for almost half of all grass abundance. The sward at Site 2 was also dominated by grass species (45.8%), together with rush (27.6%) and sedge (7.8%).

Data analysis

Analyses were performed using R Studio with R version 3.5.1 using packages adehabitatHR for calculating home ranges and the Pianka function in EcoSimR for home range overlap. Home ranges were calculated using 95% minimum convex polygons (MCP) following the methods used for home range estimates for water voles and a range of other species (Nilsen *et al*. 2008; Frafjord 2016). Due to small sample size non parametric tests were used. Comparison of home range size with site and sex were determined with separate Mann Whitney Wilcoxon signed-rank tests (wilcox.test) and the correlation between home range size and body mass was examined with the Spearman's rank test (cor.test).

RESULTS

Home range size

The mean ± SD home range size of males was 881.4 ± 636.21 m^2 (n = 5, range 197.8 -1836.2) and 996.5 ± 643.45 m^2 (n = 5, range 435.1 - 2044.6) for females (Table 1). Mean home range size was 638.7 ± 251.08 m^2 (n = 5, range 424.0 – 929.6) at Site 1 and 1239.1 ± 733.97 m^2 (n = 5, range 197.8 – 2044.6) at Site 2 (Figure 1). There was no difference in home range size between sites (W = 20, P = 0.15) or sex (W = 16, P = 0.55) and there was no correlation with body mass (r = -0.03, P=0.94).

Home-range overlap

Where home ranges overlapped (i.e. excluding zero overlaps), the percentage area overlap averaged 37.4 ± 26.81%. Mean overlap was 46.3 ± 17.80 % and 25.4 ± 27.99 % in Site 1 and Site 2, respectively but there was no difference between sites (W=9 P=0.055) (Table 2, Figure 1). At Site 1, the male with the largest home range M370 overlapped another male M248 by 47.4%. Both males overlapped the female F317 home range by 46.4.5% and 52.5% for M370 and M248, respectively. The female F317 however was found almost entirely within the home range of both these males with overlaps of 43.5 - 80.7%. There was no overlap of females F723 and F740 with the other three individuals at Site 1 because they were located in a different grassland patch (Figure 1) but both females overlapped by 20 - 42.6%. At Site 2 the greatest overlap corresponded to the smallest male home range size, where M337 was found entirely (100% overlap) within the home range of female F231. The other males M295 and M705 had home range overlaps of 13.9 - 24.1% while both females F239 and F231 had overlaps of 16.9 - 32.7%.

Figure 1. Individual home ranges of male and female water voles (n=10) at Site 1: Cranhill (top) and Site 2: Baldragon (bottom) using 95% minimum convex polygons (95% MCP). Trap coordinates were recorded in Site 2: Baldragon (numbered circles) and correspond to captures in Table 1.

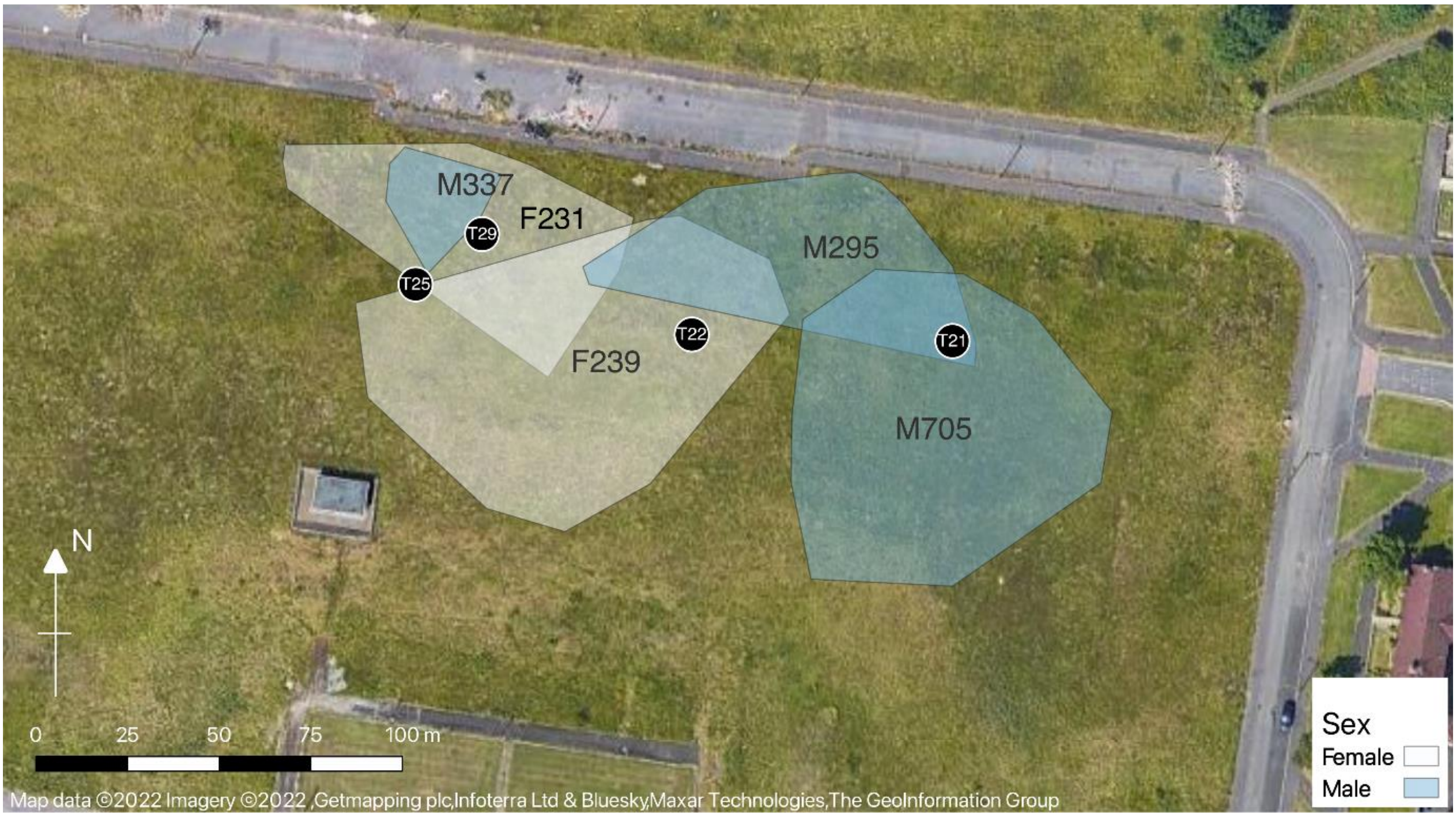

Table 1 Location, trap number, tag ID, sex, body mass (g) and home range (m²) based on 95% minimum convex polygon (MCP) of water voles in Site 1 and Site 2.

Location/Trap	Tag ID	Sex	Body mass (g)	Home range 95% MCP (m²)
Site 1: Cranhill				
T14	F740	F	119.4	435.1
T14	F723	F	163.6	929.6
T18	F317	F	163.8	512.9
T13	M370	M	130.4	892.0
T18	M248	M	183.2	424.0
	Mean ± SD		**152.1 ± 26.35**	**638.7 ± 251.08**
Site 2: Baldragon				
T22	F239	F	133.2	2044.6
T22	F231	F	133.6	1060.3
T25	M295	M	128.9	1056.8
T29	M337	M	143.9	197.8
T21	M705	M	205.6	1836.2
	Mean ± SD		**149.0 ± 32.10**	**1239.1 ± 733.97**
Both sites	**Mean ± SD**	F	**142.7 ± 19.99**	**996.5 ± 643.45**
Both sites	**Mean ± SD**	M	**158.4 ± 34.31**	**881.4 ± 636.21**

Table 2 Percentage area overlap of home ranges (95% minimum convex polygon) between different individuals (ID) in Site 1 and Site 2. At Site 1, F317, M248 and M370 were tracked in one habitat patch, and F723 and F740 in a second habitat patch (see Figure 1).

Home Range Overlap (%)					
Site 1: Cranhill					
ID	**F317**	**M248**	**M370**	**F723**	**F740**
F317	**-**	**43.5**	**80.7**		
M248	**52.5**	**-**	**99.6**		
M370	**46.4**	**47.4**	**-**		
F723				**-**	**20**
F740				**42.6**	**-**
Site 2:Baldragon					
ID	**F231**	**F239**	**M295**	**M337**	**M705**
F231	**-**	**32.7**	**2.4**	**18.7**	**0**
F239	**16.9**	**-**	**14.7**	**0**	**0**
M295	**2.4**	**28.6**	**-**	**0**	**24.1**
M337	**100**	**0**	**0**	**-**	**0**
M705	**0**	**0**	**13.9**	**0**	**-**

DISCUSSION

This study provides some of the first estimates of home range size of fossorial water voles within urban grasslands in mainland Britain. The mean home range size of male water voles was 881 m² (range 198 - 1836) and 996 m² (range= 435 – 2045) for females. For comparison, Frafjord (2016) recorded mean terrestrial (fossorial) home ranges of 2774, 848 and 401 m² for males, females and juveniles, respectively, while Jeppsson (1986) recorded 1772 m² for males and 621 m² for females. We found no difference in home range size between sexes and did not find any correlation of home range size with body mass, although the sample size was small. All individuals were recorded as adults in our study but mean body size (females = 143 g and males = 158 g) was in the lower size distribution of previously tracked water voles (130 – 270 g: adults > 180 g by Frafjord 2016). Water vole home range sizes vary and linear ranges of riparian water voles have been found to be considerably shorter in high quality habitat and at higher vole density (Moorhouse & Macdonald 2008; Strachan et al., 2011). We did not find significant differences in home range size or overlap between sites, even though the trend in overlap at Site 1 was greater than Site 2, which had a more recent history of water vole occupation. Vegetation surveys found a greater proportion of grasses at Site 1 and relatively high densities of water voles have previously been recorded there (Stewart *et al*. 2019), which could possibly explain the high home range overlap at this site.

Data on home range size are valuable for conservation planning as they provide useful guidelines for area of habitat required. Studies on fossorial voles are needed to characterise male and female home ranges in both early spring prior to breeding and when breeding, and across a range of habitats and seasons to fully understand spatial use. Furthermore, urban open space is often redeveloped for housing and relocation of water voles to donor sites is used to mitigate impacts on local populations (Dean *et al*. 2016; Baker *et al*. 2018). Future research should therefore consider tracking water voles in response to development in other urban areas where water voles occur.

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