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1 Title: Potential importance of urban areas for water voles, *Arvicola amphibius*

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3 Jessica A. Leivesley^{1,2*}, Robyn A. Stewart¹, Victoria Paterson³, Dominic J. McCafferty^{1,4}

4 ¹Institute of Biodiversity, Animal Health and Comparative Medicine, College of Medical, Veterinary and Life
5 Sciences, University of Glasgow, Glasgow G12 8QQ, Scotland, UK

6 ²Department of Ecology and Evolutionary Biology, University of Toronto, Toronto M5S3B1, Canada.

7 ³School of Life Sciences, College of Medical and Veterinary and Life Sciences, University of Glasgow, G12 8QQ,
8 UK.

9 ⁴Scottish Centre for Ecology and the Natural Environment, Institute of Biodiversity, Animal Health and
10 Comparative Medicine, College of Medical and Veterinary and Life Sciences, Rowardennan, Glasgow G63 0AW,
11 Scotland, UK

12 * Corresponding author: email jessica.leivesley@mail.utoronto.ca

13 ORCID ID

14 Jessica Leivesley - 0000-0002-3620-975X

15 Dominic McCafferty - 0000-0002-3079-3326

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18 **Abstract**

19 Cities are not often considered priority areas for threatened mammals; however, recent research suggests that urban
20 areas may be important for water vole (*Arvicola amphibius*) conservation. To establish the potential importance of
21 cities in supporting water vole populations we used National Biodiversity Network (NBN) Atlas data to examine the
22 occurrence of water voles within the United Kingdom (UK). Water voles were recorded in 28 out of 64 official UK
23 cities in the last decade (2010-2018), and rivers and streams within parks, sports grounds, and urban reserves were the
24 most important habitat types. In total, we found 497 records of water vole sightings within official cities, representing

25 5.0% of all records for this species in the NBN Atlas. Our results show that water voles are indeed found within many
26 cities, suggesting that urban populations of water voles are more common in the UK than previously recognised. We
27 therefore recommend that the importance of these urban populations for conservation of this species should be further
28 established.

29 **Key words:** water vole, urban, city, refuges

30 **Declarations**

31 **Funding** The work was funded by the Seven Lochs Wetland Park (Heritage Lottery Fund), Scottish Natural
32 Heritage, Glasgow City Council and the Peoples' Trust for Endangered Species.

33 **Conflicts of interests** – The authors declare that they have no conflict of interest.

34 **Availability of data and material** – all data is freely downloadable from the National Biodiversity Network Atlas:
35 <https://species.nbnatlas.org/species/NHMSYS0020546253>.

36 **Code availability** – Not applicable

37 **Author contributions** – All authors contributed to the study conception and design. Material preparation, data
38 collection, and analysis were performed by Jessica A. Leivesley. The first draft of the manuscript was written by
39 Jessica A. Leivesley and all authors commented on drafts of the manuscript. All authors read and approved the final
40 version.

41

42 **Main Text**

43 Water voles (*Arvicola amphibius*) are considered one of Britain's fastest declining mammal species
44 (Strachan and Jefferies 1993; Strachan et al. 2011). Surveys show that between 1990 and 1998, water voles were lost
45 from 88% of occupied sites throughout the United Kingdom (UK), (Strachan, Strachan, & Jefferies, 2000; Strachan,
46 2004). More recently, surveys have found population estimates to have declined by 50% between 1999 and 2017
47 (Mathews et al. 2018). Habitat loss and fragmentation due to urbanisation and a shift to intensive agriculture have
48 been identified as main drivers behind these rapid declines (Rushton et al. 2000). Further to this, predation from
49 introduced American mink (*Neovison vison*) has increased pressure on already fragmented populations, increasing
50 their vulnerability to localised extinction (Carter and Bright 2003).

51 Water voles tend not to be regarded as a species living in urban environments and so the importance of
52 urban areas for water vole conservation has largely been neglected (Stewart et al. 2017). However, in 2008,
53 populations of water voles were discovered living in grasslands in the city of Glasgow, Scotland (Stewart et al.
54 2017); and recently, urban ponds in Poland have been identified as important habitats for water voles which act as a
55 refuge from American mink predation (Brzeziński et al. 2018). Despite this, we do not know how commonly water
56 voles are found within urban areas in the UK. Considering this, we carried out a preliminary investigation to
57 determine the occurrence of water voles in cities using records of water vole sightings contained in the National
58 Biodiversity Network (NBN) atlas. As this is a preliminary investigation, we searched for water vole records only
59 within the 64 official cities within mainland UK. These cities span mainland UK and are of different sizes, thus
60 comprising a representative sample of urban areas.

61 The NBN atlas is a public source of biodiversity data. Records of species sightings are uploaded to the atlas
62 by registered organisations (data partners; see online resource 1 data partners that contributed to the water vole
63 records used here). Data assembled by a range of citizen science recording and systematic surveys in the NBN
64 database is challenging to interpret because of potential biases – mainly because it difficult to detect and account for
65 differences in sampling effort across geographical areas and across years. However, this type of data has nonetheless
66 been previously useful in examining distribution patterns of UK species (Blight et al. 2009; Van Der Wal et al.
67 2015). Therefore, we extracted all water vole records from the NBN atlas (52,598). The dates of these records
68 ranged from the 1800s to 2018. We then filtered these so that only records with at least 1000m accuracy were

69 selected (11,132). We further filtered records based on NBN's verification status only keeping those records that
70 were accepted or were considered correct (9,966). Bounding box polygons were drawn around each of the 64
71 official cities in mainland UK using the online program boundingbox (Klokkan Technologies, Switzerland). This
72 identifies four coordinates that completely encapsulate each city. QGIS 3.10 (QGIS Development Team 2015) was
73 used to extract records which fell within a city bounding box. We then vetted each of the records within a bounding
74 box to ensure that they fell within the official city limits (defined by council districts). This bounding box technique
75 is particularly useful when shapefiles of cities or urban areas are unavailable or are not easily accessible. Of 9,966
76 water vole sightings, 497 fell within a city (5.0%; Table 1). We separated records by decade and location (city/rural)
77 and conducted a chi square test of independence to determine if the frequency of water vole records has changed
78 over time. This partially accounts for differences in sampling effort across decades as the relative changes in city to
79 rural records is being assessed under a null distribution.

80 Searching the NBN Atlas records has revealed water voles are indeed found within the boundaries of cities
81 (Fig. 1). Sightings were recorded in 15-28 of the 64 official cities in the UK from 1970 to 2018. In the last decade
82 (2010-2018), water voles were recorded in 28 of the 64 cities (Table 1), indicating that urban/suburban populations
83 of water voles may be more common than initially thought. Most sightings in the last decade took place in the South
84 of England, and it appears that water voles have reduced in number in Scotland and the North of England (Fig. 1).
85 This is similar to reports showing that water voles have largely been lost from areas such as Sutherland in North
86 East England (McGuire and Whitfield 2017; Mathews et al. 2018). There have also been concentrated water vole
87 conservation efforts in Hampshire and around London (McGuire and Whitfield 2017), which corresponds with our
88 results in 2010-2018. We found that the frequency of records in cities did indeed differ across decades ($\chi^2 = 86.5$, df
89 $= 5$, $p < 0.0001$). On inspecting the Pearson residuals, we found that there was a positive association between city
90 records and pre-1970, 1970-1979, and 1980-1989 ($r = 2.4, 2.6, 7.0$ respectively), and a negative association in 2000-
91 2009, $r = -4.1$. These results align well with national, extensive water vole surveys that found a widespread decline
92 in occupied habitat between 1990 and 1998 (Strachan et al. 2000; Strachan 2004), and a recent increase between
93 2011 and 2015 (McGuire and Whitfield 2017).

94 Of the 497 records, 116 had associated additional notes, allowing the habitat type where the sighting took
95 place to be identified. Rivers and streams were the most common habitat type (62.1% of records), followed by lakes

96 and ponds (20.7%). Sightings also took place in canals (15.5%), and rarely took place in fields (1.7%). We also
97 attempted to classify the space use type where sightings took place. This was possible for 228 records. Most
98 sightings were in green spaces within cities such as parks, sports grounds, and small reserves (33.5%), and in urban
99 built-up areas (i.e. on housing estates or close to street; 31.6% of records). The remaining sightings were in fields
100 and rural areas surrounding cities (23.7%) and small rural towns (11.5%). It is likely that both habitat type and space
101 use type were assigned with error in some cases, however, this descriptive work is intended to inform more rigorous
102 scientific exploration into suitable habitats and where to find them within urban areas.

103 Our results provide initial, promising data indicating that urban habitats may host water vole populations.
104 We show that within official cities of mainland UK, water vole populations do occur and that across decades,
105 observations within cities account for 3.4-10.8% of all observations. As we only use the 64 official cities in the UK
106 to subset data into urban and rural observations, this likely represents the lower limits on the number of observations
107 within urban areas as the UK has large urban towns which do not have official city status. The data we use (NBN
108 Atlas), is a collection of sighting records from biodiversity surveys, and citizen observations. There are limitations
109 associated with using this type of data, however, the temporal trends we find match with intensive survey efforts
110 (Strachan et al. 2000; Strachan 2004; McGuire and Whitfield 2017). We, therefore, are confident that useful
111 information can be extracted from such sources. However, we cannot perfectly account for differences in sampling
112 effort across years, and cannot account for sampling effort changes across geographical locations, thus, we cannot
113 state conclusively that the temporal trends in number of records found do not result from changes in effort within or
114 out with cities across the years. Therefore, our results should only be considered preliminary findings.

115 Our research suggests that water voles are sighted in nearly half of all UK cities and may indicate that
116 populations of water voles are likely to be established within these urban areas. From our purely descriptive analysis
117 of habitat types, it appears that rivers and streams are the most common urban water vole habitat, as they are in rural
118 areas. Further, it appears the most suitable habitat occurs within parks, sports areas (such as golf courses), and small
119 urban reserves. Previous work has suggested that these areas may be of importance to water voles as refuges from
120 American mink predation, as mink tend to avoid heavily populated areas (Lundy and Montgomery 2010; Brzeziński
121 et al. 2018). Data at a finer spatial resolution is necessary to determine if these identified habitats and areas in UK
122 cities also act as refuges, as NBN atlas data also show that mink have been recorded in 24 of 64 official UK cities

123 during 2010-2018 (Leivesley, unpublished data). Overall, this study indicates that water vole populations are present
124 in many UK cities, and therefore could be a potential focus for conservation efforts for this species in the UK.

125

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159

160 **Tables**

161 **Table 1. Counts of water vole records in the UK, and within official cities.** Records were obtained from the
 162 National Biodiversity Network Atlas. The first column of counts represents the total number of sightings found
 163 within the specified date range. The next column displays how many of these sightings were within city limits.
 164 These columns are used to calculate the percentage of sightings within cities for a given date range.

Date range	Total number of records	Number of records in cities	% of total records in cities	Number of cities with records
Pre-1970	599	43	7.2%	20
1970-1979	1216	81	6.7%	19
1980-1989	725	78	10.8%	19
1990-1999	1454	56	3.9%	15

2000-2009	3216	108	3.4%	23
2010-2018	2756	131	4.8%	28

165

166 **Figure Captions**

167 **Fig. 1** Total number of water vole records in each UK city (left), and the number of records for the most recent
168 period 2010 and 2018 (right). Dark-shaded points show cities with more sightings and lighter points show cities with
169 less sightings

170 Fig. 1 created by QGIS 3.10.

171

172 **Supplementary Material Captions**

173 Online Resource 1 – Names of data contributors to water vole records in the National Biodiversity Network Atlas
174 used. If available, this also contains the doi of each dataset and licensing.