1   Home range and dispersal of the field vole *Microtus agrestis* in an organic agro-ecosystem

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8

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11

12   **Abstract**

13   During 2008-2011 field voles *Microtus agrestis* were studied in a Danish agro-ecosystem in connection with

14   a programme elucidating the role of organic farming as refuge for biodiversity, due to the observed losses

15   of biodiversity in conventional farmland. The aim of the study was to quantify home ranges and dispersal of

16   voles in order to test a hypothesis that vole populations living in organic farms could colonize unoccupied

17   areas in conventional farms. Voles were radio-collared and tracked until death or disappearance. Results

18   showed that vole home ranges were larger during the onset of the breeding season than during the height

19   of the breeding season and the non-breeding period. Males had larger home ranges than females. Voles

20   occupying isolated small biotopes had restricted home range and only few individuals crossed fields from

21   one small biotope to another. Although crossings do occur, the magnitude of dispersal seems restricted in

22   fragmented agro-ecosystems.

23

24

25   *Keywords: Microtus agrestis,* home range*, dispersal, telemetry, organic farming*

Introduction

In North European lowlands such as Denmark, southern Sweden, northern Germany, northern Poland, the Netherlands, Belgium and northern France, most of the non-urban areas are used for agriculture, leaving few and often highly fragmented small biotopes in between. Conventional farming is often intensive with a minimal crop rotation, an abundant use of pesticides and artificial fertilisers, and large mono-cultural fields surrounding small fragmented biotope patches. In contrast, organic farming avoids pesticides and artificial fertilisers, and uses more mechanical weed control and organic manure. Organic farms are normally less intensively managed, and the number and the size of small biotopes are higher.

Generally, biodiversity in agro-ecosystems is associated with the surrounding small biotopes rather than the fields in rotation and the crops. On a farm level, small mammal biodiversity is low, although on a larger geographical scale several species can be found (Jensen and Hansen, 2003). Field vole *Microtus agrestis*, is one of the most common mammalian species in open grassy habitats and comprises one of the most important prey items for a number of specialist predators, e.g. weasel *Mustela nivalis* and stoat *Mustela erminea*, as well as generalist predators, e.g. fox *Vulpes vulpes*, badger *Meles meles*, buzzard *Buteo buteo*, kestrel *Falco tinnunculus* and a number of owl species. The voles are most often found in grassy habitats like banks, hedge rows, buffer zones, pond surroundings, moist meadows and set-aside fields (Jensen and Hansen, 2001). These agro-ecosystem components are often scattered and fragmented and can thus be considered as small habitat islands, where populations of voles are subjected to extinction and may rely on re-colonisation.

The population dynamics and dispersal of *M. agrestis* has been well described at northern latitudes in connection with the cyclicity of the species (Hansson, 1971; Myllymäki, 1977; Stenseth et al., 1977; Lambin et al., 2000) and more to the south in contrasting non-cyclic populations (Erlinge et al., 1990; Sandell et al., 1991). Also damage by the species to forest saplings has led to several studies (e.g. Larsson, 1975). In contrast, studies of the species in agro-ecosystems are few (Jensen and Hansen, 2003; Huitu et al., 2008; Yletyinen and Norrdahl, 2008).

51 In this study we employed radio telemetry to obtain information on home range and short

52 time dispersal of *M. agrestis* within and between small agro-ecosystem biotopes. The home range data are

53 necessary prerequisites for further development of agent-based models, i.e. ALMaSS (Topping et al., 2001)

54 and genetic models (Marchi et al., submitted).

55

56 **Materials and methods**

57 Field work was conducted in 2008-2011 in Eastern Jutland, Denmark, with seven sites selected within the

58 property of the Kalø Estate (56 17 N, 10 29 E). This estate is managed by means of organic farming

59 principles, i.e. the crops are not treated with pesticides, and artificial fertilisers are not used. The estate is

60 surrounded by a number of smaller private farms managed in conventional practice. Originally the project

61 intended to study differences between conventional and organic farming systems; however, due to a very

62 low number of voles in the conventional farms, all telemetry studies were performed within organic farms.

63 Crop rotations within the estate are dominated by spring barley, spring wheat, triticale, and

64 a leguminous crop and intercropping (or mixed cropping) with undersowing of clover and ryegrass.

65 Generally the size of the fields is large and the soil is mostly clay. As organic farming practices are

66 employed, several wildlife friendly small biotopes are created, e.g. set-aside strips along field margins,

67 beetle banks within larger fields, and smaller set-aside fields. The matrix surrounding the cultivated fields

68 consists of small habitat patches of different biotopes, e.g. hedgerows, grassy banks, ponds and their

69 immediate surroundings, and wildlife plantings. Two larger forests, Hestehave Forest and Ringelmose

70 Forest, are located at the western and eastern border of the estate, respectively.

71 The seven study sites (table 1) included: 1) a 17-year-old set-aside field surrounded by mixed

72 forest on one side, a hedge row on the opposite side and fields in rotation along the two remaining sides; 2)

73 a 17-year-old grassy bank along an old hedgerow and running between fields in rotation and connected to

74 site 1 in its southern end; 3) a 16-year-old grassy bank surrounding a rainwater reservoir, 4) a cattle grazed

75 field surrounded by mixed forest, hedge rows and a field in rotation; 5) a 5-year-old wildlife friendly set-

aside stripe with beetle bank running parallel with a grassy bank within a field in rotation; 6) a 6-year-old rectangular shaped set-aside field encircling a dry depression and surrounded by fields in rotation; and 7) a 15-year-old set-aside field surrounded by hedge row and coniferous forests.

INSERT TABLE 1

Live trapping for field voles was performed with Ugglan lemming and Ugglan special traps, Grahnab AB, Sweden. Voles were tagged with a Passive Integrated Transponder tag (BSA International AG, Sweden) and applied with a 0.9 g cable-tie radio tag from Biotrack (TW-4 and PIP3 transmitter types). Radio-collared voles were tracked by means of a Stabo radiotracking receiver carrying a Flexi Yagi antenna. Consecutive fixes were spaced by at least 45-minute intervals to avoid auto-correlations (de Solla et al., 1999).

The positions of the tracked voles were marked in the field and subsequently GPS positioned and transferred to MapInfo (Insight, 2011) to visualise activity area in relation to updated Ortophotos. All individuals were either adults or sub-adults weighing more than 20 g, i.e. transmitter weight was less than 5% of the vole weight.

The tracking of voles continued until the signal disappeared, or until the position remained fixed for several tracking sessions. In the latter case the transmitter was subsequently located and, if possible, the final status of the vole determined. If a vole was predated or it lost its collar before sufficient fixes were obtained, the tag was applied to a new animal and tracking sessions commenced. Three days before the tags were timed out due to the internal battery capacity the voles were recaptured and freed from their collar.

Home range data was analysed in Ranges 8 (Kenward et al., 2008) and included 99-5% convex polygon cores, incremental plots, and kernel contour core analysis. All statistical test were performed using the SAS Enterprise Guide 4.3 (SAS, 2006) and statistical significance was recognized at $P <$

101   0.05 and prior to pooling any predictor variables for more than one season or site, differences between

102   years and sites were tested, even though all such results are not presented in the paper. Differences among

103   sample means were examined using one way analyses of variance (ANOVA) when comparing more than

104   one sample, and reported as the distance between individual distributions (F) with degrees of freedom and

105   sample size in subscript and probability (P).

106

107   **Results**

108   In all periods loss of transmitters was high, and new individuals had to be caught in order to maintain a

109   recordable population. Losses could mainly be ascribed to probable predation (33%), when remains of the

110   animal was found attached to a collar. In further 31% the signal was lost as we were unable to locate the

111   animal, probably because the collar was moved too far away by a predator, and finally 17% of the collars

112   were found again without trace of the animal, partly because of a too loose collar or partly due to

113   predation (table 2). Main predators suspected were weasel *Mustela nivalis*, when transmitters were found

114   in the runways with parts of the animal remaining, and common buzzard *Buteo buteo* and kestrel *Falco*

115   *tinnunculus*, when transmitters were found in or below trees. Total disappearance of transmitter signal was

116   ascribed to long distance removal of the whole carcass by e.g. birds of prey or foxes *Vulpes vulpes*.

117

118   **INSERT TABLE 2**

119

120   **INSERT FIGURE 1**

121

122   In 2008 the studies were performed during late autumn, e.g. at a time of year when breeding

123   in general had stopped and the tagged individuals were either post-reproductive adults or sub-adults who

124   had not bred during the present breeding season. Only one set-aside field was used in contrast to the

125   consecutive seasons and except for one individual all tagged animals were males. Mean 95% polygon core

126   home range estimate was 262 m^2, range 11-900 m^2 (table 3). There was no significant difference in home

127   range estimates between 95% polygon core, the 95% kernel contour and the minimum convex polygon

128   analysis methods ($F_{2,30} = 0.43; P = 0.6535$; fig. 1).

129   In 2009 studies were performed during autumn at six different sites (table 1). The results

130   showed a mean 95% polygon core home range estimate for males of 421 m^2, range 10-1290 m^2, and for

131   females of 176 m^2, range 72-443 m^2 (table 3). Again, there was no significant difference in home range

132   estimates between the three different analysis methods ($F_{2,54} = 0.80; P = 0.4565$; fig. 1).

133   In July 2010, at the height of the breeding season, the mean 95% polygon core home range

134   estimate tended to be larger than in autumn 2008 and 2009 (fig. 1). The mean 95% polygon core home

135   range estimate was found to be 511 m^2 for males and 443 m^2 for females though considerable variation

136   was present with a male range of 12-1312 m^2 and female range of 7-1704 m^2 (table 3). The mean 95%

137   kernel contour home range estimate was somewhat larger than 95% polygon core and minimum convex

138   polygon ranges, however, not significantly so ($F_{2,66} = 1.85; P = 0.1657$; fig. 1).

139   In April-June 2011, at the onset of the breeding season and when field crops started growing,

140   home range estimates generally increased, especially so for sexually active vole males. The overall mean

141   95% polygon core home range estimate was 603 m^2 with a range of 12-2482 m^2, whereas mean male

142   estimates was 746 m^2 with a range of 12-2482 m^2 and for females 423 m^2 with a range of 37-666 m^2 (table

143   3). There was no significant difference between the three calculation methods ($F_{2,54} = 1.76; P = 0.1828$; fig.

144   1).

145

146   **INSERT TABLE 3**

147

148   **INSERT FIGURE 2**

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6

151   Generally, voles did not move much between consecutive telemetry tracking as indicated by

152   the overall mean inter-location line-of-sight dispersal distance being only 6 meters (fig. 2). However,

153   maximum distance was 122 meters (SD = 27) with a mean of 31 meters (table 4). The largest inter-location

154   distances found belonged to a few reproductive males at the onset of the breeding season; however, also a

155   few reproductive females had large inter-location distances. The mean inter-location dispersal distance did

156   not differ between voles in large versus small habitats (female: $F_{1,32} = 0.02; P = 0.8960$; male: $F_{1,36} = 0.04; P$

157    $= 0.8492$ and both sexes: $F_{1,68} = 0.67; P = 0.4158$).

158

159   **INSERT TABLE 4**

160

161   **INSERT FIGURE 3**

162

163   The overall relation between the inter-location dispersal distance and the size of the 100%

164   MCP area estimate was found to be positive and highly significant ($F_{1,68} = 38.74; P < 0.0001$; fig. 3a).

165   However, when data was separated between sex and habitat size only three of the four combinations were

166   significant (females in large habitats: $F_{1,22} = 34.28; P < 0.0001$; females in small habitats: $F_{1,10} = 3.36; P =$

167   0.1040; males in large habitats: $F_{1,13} = 10.16; P = 0.0087$; and males in small habitats: $F_{1,23} = 18.81; P =$

168   0.0003). Alternatively, there was no overall positive relation between mean inter-location measure and the

169   number of fixes obtained ($F_{1,68} = 1.46; P = 0.2309$; fig. 3b).

170   The incremental plots in figure 4 illustrate the relationship between number of telemetry

171   fixes and the estimated home range area for each individual and show at which point the final home range

172   area estimate only increases little in size when adding new fixes. The 100% minimum convex polygon area

173   estimate was generally reached within a relative short time, e.g. 20-30 fixes, indicating stable home ranges.

174   However, even though there was a gradual increase in 100% MCP over the entire tracking period for some

175   voles several individuals showed sudden abrupt increases indicating either a shift in core area or an

176   increase in home range size. In small habitats (fig. 4a) there was a higher tendency for voles to make

177   sudden increase in home range compared to the large habitat where home ranges increased more

178   gradually (fig. 4b) without sudden jumps. This was most commonly seen in the April-June sessions (fig. 4f).

179

180   **INSERT FIGURE 4**

181

182   In the linear habitats male voles stayed within the habitat and did not disperse beyond

183   habitat boundaries into the surrounding fields and, accordingly, they had very small home ranges with a

184   mean 95% polygon core estimate of 296 m^2, range 12-845 m^2. In linear habitats along hedge rows home

185   ranges were restricted to the habitat strip itself and in the wildlife friendly strip habitat (site 5) in particular

186   the 95% polygon core home range estimates were severely restricted in size with a range of only 12-288

187   m^2. The individual voles all stayed within the linear habitat completely without crossing the boundary into

188   the surrounding cultivated field. Voles in non-linear habitats such as all the large habitat sites and a few

189   small habitat sites stayed also mainly within the set-aside habitat, however, their home ranges were much

190   larger on average with a mean 95% polygon core estimate of 484 m^2, range 10-2482 m^2. The female vole

191   home range estimates were smaller than that of males, and were higher in spring than in autumn, with a

192   mean 95% polygon core of 436 m^2, range 64-1704 m^2.

193

194   **Discussion**

195   Predation rates were high overall. If we consider all disappeared voles as predated, the overall rate was

196   around 81% in total (2009: 89%, 2010: 77%, and 2011: 78%).This figure is high, however, when voles in

197   agro-ecosystems are concentrated in few and rather small biotope units, predators can concentrate in the

198   same areas and hence impact must be expected to be high. However, Korpimäki et al. (1996) raised the

199   question whether predation rates in telemetry studies are overestimated due to e.g. an inhibitory effect on

200   vole dispersal and a decreased ability to escape the predators when carrying a radio collar. In contrast,

201 Webster and Brooks (1980) found no effect of radio-transmitters on the survival of the meadow vole

202 *Microtus pennsylvanicus*.

203   Home range estimates of *M. agrestis* have mainly been obtained by means of live-trapping,

204 thus restricting the potential home range area to that determined by the trap design. Furthermore, in most

205 calculations the minimum convex polygon method has been applied, whereby the outermost points of

206 trappings have been connected and the area inside calculated, generally leading to an inclusion of areas

207 where the voles have not been recorded (Nilsen et al., 2008). We consider that the minimum convex

208 polygon method generally overestimates the actual home range, as it includes large areas with no

209 occurrence of voles. In contrast, especially the 50% kernel cores only include areas strictly around the main

210 number of actual records, excluding areas with known records, thus leading to obvious underestimates of

211 home ranges.

212   More recently, telemetry is employed, giving more precise data on vole locations. Loughran

213 (2006, 2007) found by the use of telemetry no significant variation in male home range size during the

214 breeding season or between years. However, there was significant variation in core area between years but

215 not during the breeding season. In contrast, the present results indicate larger mean home ranges during

216 the breeding season. This could be due to differences in population density, as in low density populations,

217 individuals may disperse larger distances and occupy larger territories without competition (Sandell et al.,

218 1991).

219   Christensen (1999) found by using telemetry on voles in a small set-aside field that mean

220 home ranges and core areas of female voles were considerably larger in April-May than in other seasons,

221 consistent with our findings. This applied both for minimum polygon core calculations and 95% cluster

222 analysis. The incremental plot analysis used in this study highlights that individual vole home range size is a

223 highly flexible entity, which is most difficult to assess. The large spring home ranges are most likely due to

224 an increased sexual and feeding activity at the onset of the breeding season. In contrast to feeding and

225 mate availability, presence of predators is an important factor which might suppress the size of the home

226 range (Carlsen et al., 2000) by altering microhabitat preferences.

227   We found that voles living in narrow linear habitats generally stayed within the habitat and

228 only rarely dispersed moved beyond habitat boundaries into the surrounding cultivated fields, and

229 especially voles in the wildlife friendly strip habitat (site 5) all stayed within the linear habitat completely

230 without crossing the habitat boundary. Presumably, they were more or less stranded on a habitat island in

231 a sea of hostile environment, i.e. between ploughed soils. Accordingly, voles in linear habitats had very

232 small home ranges in comparison with vole in non-linear habitats.

233   In contrast, several voles from the non-linear study sites occasionally entered the

234 surrounding cultivated field matrix; however, they always returned to the core area in their starting habitat.

235 In one case, however, a female vole made a temporally change in home range and dispersed from a set-

236 aside field across a cultivated field and into a grassy glade within an old forest; though shortly after she

237 moved back into the old core area in the set-aside field. Most other voles changed core area within the

238 same overall habitat as they were caught and when they occasionally reached the field boundaries they

239 moved back into the field without crossing into the other habitat type. Thus we found little evidence of

240 voles moving from grassy areas across crop fields to other small, grassy biotopes. As field voles are

241 positively recorded in isolated habitat islands like small biotopes in fragmented open farmland such

242 crossings do occur (Jensen and Hansen, 2001, 2003). Christensen (1999) found that out of 19 small biotopes

243 investigated, voles were found in 70% during autumn and 40% during spring. She also found that frequent

244 extinction and re-colonization of voles in small biotopes was a general phenomenon.

245   The studies on *Microtus agrestis* clearly reveal that vole individuals follow linear biotopes

246 and stay within small biotopes when dispersing and normally avoid open fields, and that the area and

247 quality of these biotopes set the limit for vole population numbers. Organic farms might contain higher

248 densities of vole due to a higher density of small biotopes, which also entails the basis for an increase in

249 predator numbers. Given that a reasonably fine meshed network of small biotopes is found, numbers of

250   voles and their predators can be increased by increasing these habitats, thus contributing to a higher

251   biodiversity in the agro-ecosystems.

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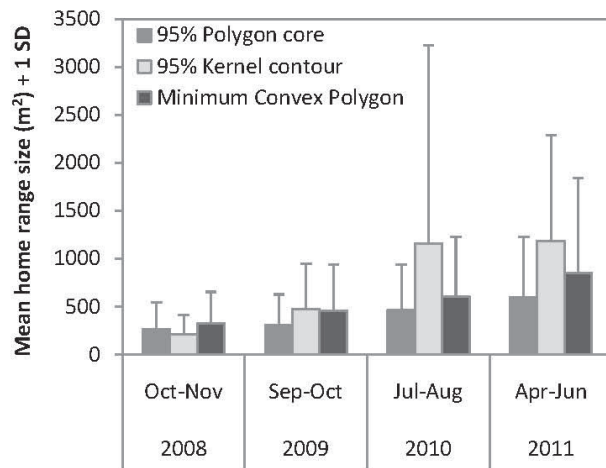345

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Figure

Figure 1: Mean home range estimates in square meters (m²) for all animals at all seven sites according to the three different analysis methods: 95% Polygon Core, 95% Kernel Contour and Minimum Convex Polygon (MCP). Number of sites: 2008 (n=1), 2009 (n=6), 2010 (n=4) and 2011 (n=5).
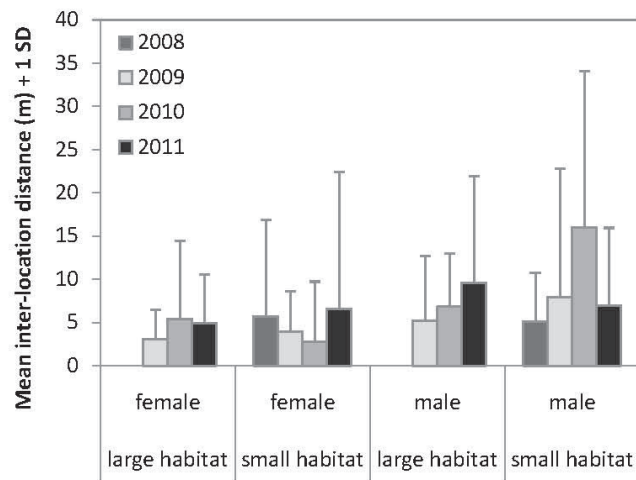
Figure

Figure 2: Mean line-of-sight dispersal distance between telemetry fixes divided into sex and habitat groups for each year.
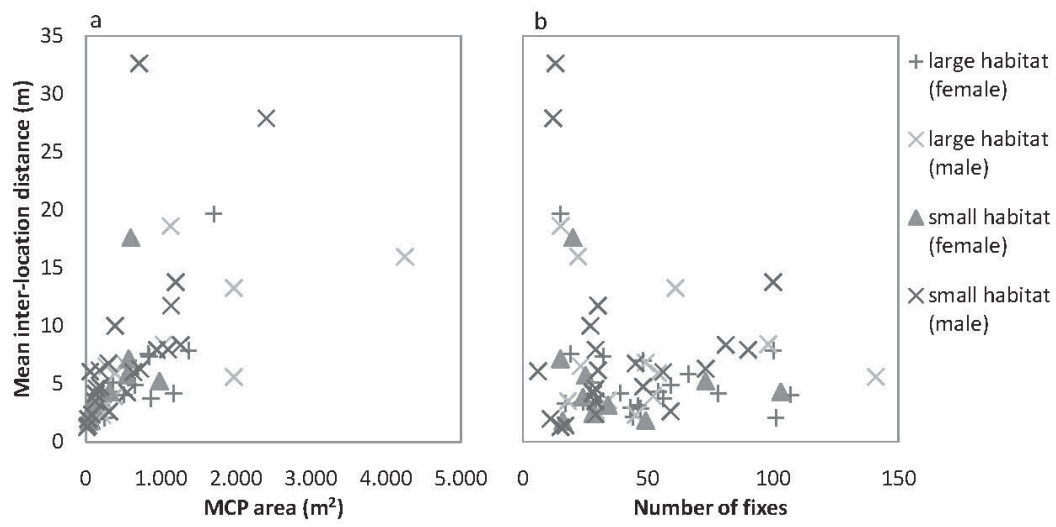
Figure

Figure 3: Mean inter-location line-of-sight dispersal distance as a function of minimum convex polygon (MCP) estimates for home ranges (a) and as a function of number of telemetry fixes (b). Illustrates differences between sex and habitat size.
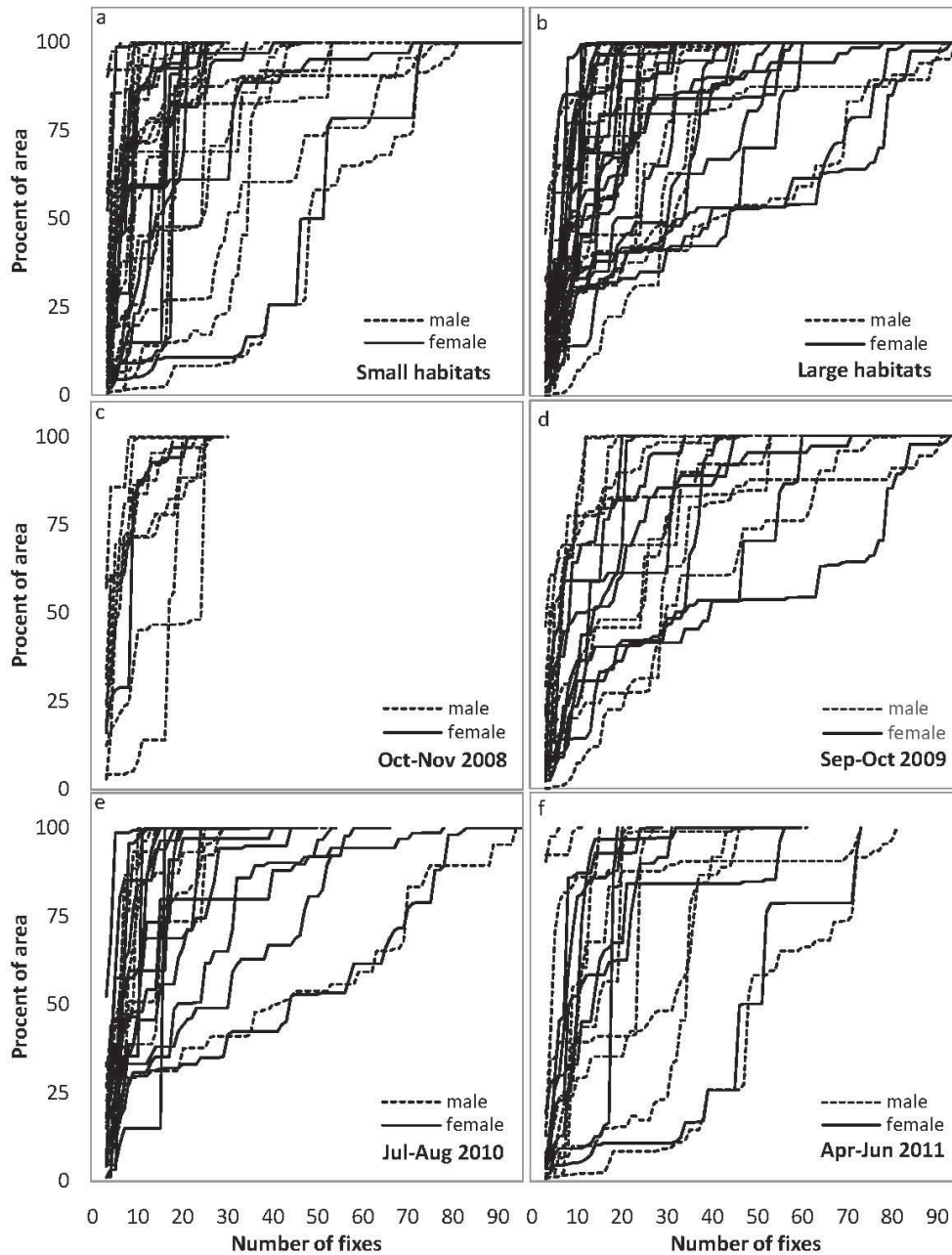
Figure 4. Incremental area plot based on minimum convex polygon (MCP) home range estimates with 100% of telemetry fixes. Illustrates differences between sex (all figures), habitat size (small (a) and large (b) habitats), and season (October-November (c), September-October (d), July-August (e) and April-June (f)).

Table

Site	Name	Habitat type	Habitat size	Area (m^2)	Perimeter (m)	Year of fieldwork
			Table 1: Characteristics of the sites used in the telemetry studies.			
1	Stegeloekke Field	Set-aside field	Large habitat	20,982	581	2009, 2010, 2011
2	Stegeloekke Stripe	Set-aside stripe	Small habitat	1,838	316	2009, 2010
3	Flintbjerg Parking	Habitat patch	Small habitat	3,389	547	2009, 2011
4	Flintbjerg Meadow	Grazed meadow	Large habitat	38,352	1,040	2011
5	Flintbjerg Stripe	Set-aside stripe	Small habitat	2,102	482	2009, 2011
6	Vikaer West Field	Set-aside field	Small habitat	3,208	249	2008, 2009, 2010, 2011
7	Vikaer East Field	Set-aside field	Large habitat	60,807	1,114	2009, 2010

Table

Table 2: Final status of tracked *Microtus agrestis*. *Alive*: Animals tracked until their radio transmitter was removed; *Predated*: Transmitter found together with the remnants of a predated animal or located underneath a tree; *Signal lost*: Signal lost, either due to defect transmitter or mostly likely due to predation; *Disappeared*: Transmitter relocated without the animal.

Year	Alive	Predated	Signal lost	Disappeared
2009	11 %	17 %	39 %	33 %
2010	23 %	50 %	18 %	9 %
2011	22 %	28 %	39 %	11 %
Total	19 %	33 %	31 %	17 %

Table

Table 3: Female and male *Microtus agrestis* home range estimates in square meters (m^2) according to the three different analysis methods: 95% Polygon Core, 95% Kernel Contour and Minimum Convex Polygon (MCP).

Sex	Analysis	n	2008 Oct-Nov Mean ± SD	n	2009 Sep-Oct Mean ± SD	n	2010 Jul-Aug Mean ± SD	n	2011 Apr-Jun Mean ± SD
All	95% Polygon Core	10	262 ± 282	18	312 ± 319	22	464 ± 476	18	603 ± 631
	95% Kernel Contour		212 ± 207		475 ± 477		1,157 ± 2,067		1,185 ± 1,104
	MCP		327 ± 330		463 ± 478		608 ± 625		854 ± 988
Female	95% Polygon Core	1	483	8	176 ± 116	15	443 ± 506	8	423 ± 268
	95% Kernel Contour		216		209 ± 122		995 ± 2,046		890 ± 880
	MCP		549		233 ± 132		500 ± 518		638 ± 358
Male	95% Polygon Core	9	237 ± 287	10	421 ± 390	7	511 ± 439	10	746 ± 802
	95% Kernel Contour		212 ± 220		688 ± 552		1,505 ± 2,230		1,421 ± 1,249
	MCP		303 ± 340		647 ± 577		839 ± 806		1,027 ± 1,293

Table

Table 4: Maximum inter-location line-of-sight dispersal distance in meters (m) divided into sex and habitat groups for each year.						
	Small habitats		Large habitats		All habitats	
	n	Distance	n	Distance	n	Distance
All	33	114	35	122	68	122
Female	10	114	22	122	32	122
2008	1	57	-	-	1	57
2009	3	36	5	16	8	36
2010	3	52	12	122	15	122
2011	3	114	5	28	8	114
Male	23	109	13	81	36	109
2008	9	51	-	-	9	51
2009	5	109	5	81	10	109
2010	4	79	3	35	7	79
2011	5	38	5	80	10	80