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12 **RH: Marsh rice rat home ranges and habitat**

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14 **Ranging behavior of marsh rice rats in a southern Illinois wetland complex**

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29 The marsh rice rat (*Oryzomys palustris*) inhabits wetlands that are often fragmented and isolated
30 by upland cover types. Persistence of marsh rice rat populations and metapopulations likely
31 depends on their ability to enter and traverse the upland matrix, yet basic information, such as
32 home-range size and landcover use patterns, is lacking. Our goal was to quantify home-range size
33 and habitat selection by marsh rice rats in southern Illinois. Between March and November 2011,
34 we radio-collared 21 male rice rats (8 subadults and 13 adults) that were each located 7 to 24
35 times each via triangulation and homing. We estimated home-range size, compared landcover
36 composition within kernel home ranges to what was available in the surrounding landscape, and
37 quantified daily movement distances. Mean (\pm SE) home ranges were 3.53 ± 0.66 ha based on
38 95% kernel isopleths and 1.85 ± 0.49 ha based on minimum convex polygons. Home ranges were
39 largest for individuals followed in early summer, but home-range sizes were similar for adults and
40 subadults. Rice rats' use of emergent wetland vegetation was greater than availability, indicating
41 they preferred emergent wetlands habitat at the home-range level. However, upland cover types
42 made up >40% of each home range, on average. Daily movements averaged 46.6 ± 3.4 m
43 (maximum: 396 m), and rice rats were located up to 464 m from the nearest wetland. Based on by
44 far the largest sample size (in individuals and locations per individual) available for space use of
45 the marsh rice rat, our findings support the characterization of male rice rats as highly vagile, and
46 suggest that rice rats move through upland cover more frequently than previously described.

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48 Key Words: activity, home range, Illinois, landcover, marsh rice rat, movement, *Oryzomys*
49 *palustris*, telemetry, wetland

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52 Home range is a spatial measure that represents the area in which individuals regularly
53 move in search of resources and mates (Burt 1934, Mohr 1947). Often, home ranges are used to
54 illustrate landscape-level habitat selection (Johnson 1980), and the extent of an animal's
55 movement through the landscape (Bowman et al. 2002, Schooley and Branch 2006). A home
56 range must contain all necessary resources for an individual's daily living, so comparing
57 landcover composition of home ranges with the broader landscape (i.e., second-order selection;
58 Johnson 1980) can provide information about which resources are most important or limiting.
59 Also, the size and distribution of movements that make up an individual's home range can
60 characterize the vagility of the species and predict the potential for long-distance dispersal
61 (Bowman et al. 2002, Revilla et al. 2004). Identifying the landcover use and movement potential
62 of a habitat specialist can help predict the persistence of a species in a highly-fragmented
63 landscape (Fahrig and Merriam 1994).

64 Home ranges can shift in size and position over time due to fluctuations in resources and
65 risk (Cameron and Spencer 1985, Byrne and Chamberlain 2011). Many small mammals expand
66 their home range in the summer, coinciding with mating, resource foraging, and population
67 recruitment (Gaines and McClenaghan 1980). In hispid cotton rats (*Sigmodon hispidus*), home
68 range was largest during the breeding season (May-August) as male and female territories began
69 to overlap (Cameron and Spencer 1985). Conversely, Cranford (1976) found that home ranges of
70 dusky-footed wood rats (*Neotoma fuscipes*) expanded between November and December as
71 animals foraged further for rare resources.

72 Home-range size and composition can change with age, especially if animals exhibit
73 territorial behavior or natal dispersal (Burt 1934, Gaines and McClenaghan 1980). For many
74 small mammals, younger individuals are pressured to seek out new territory through aggression

75 by older, more dominant animals (Gaines and McClenaghan 1980, Eiris and Barreto 2009).
76 Subadults tend to have smaller home ranges in territorial species, as established adults leave few
77 suitable areas unoccupied (Cranford 1976). In round-tailed muskrats (*Neofiber alleni*), home
78 range was larger in reproductive than non-reproductive males and increased with body mass
79 (Schooley and Branch 2006). Additionally, Spencer et al. (1990) found hispid cotton rats
80 exhibited similar daily home ranges across all age classes, but linear movements and elongated
81 home ranges were more common in adults. Identifying the age class that exhibits the highest
82 movement potential can help predict the life stage at which dispersal is most likely to occur
83 (Hanski 1994, Gaines and McClenaghan 1980).

84 The marsh rice rat (*Oryzomys palustris*, hereafter rice rat) is a medium-sized rodent for
85 which published information on home range is limited. As it is a specialist to emergent wetlands
86 (Wolfe 1982), most research on the rice rat has taken place in the Gulf Coast and Florida
87 Everglades. However, rice rats are found as far north as southern Illinois in the Midwest and New
88 Jersey on the Atlantic coast (Wolfe 1982). Using capture locations within trapping grids in
89 Brenton Island, Louisiana, Negus et al. (1961) estimated home-range size for rice rats at 0.33 ha
90 for males and 0.21 ha for females. Birkenholz (1963) reported similar home-range sizes for rice
91 rats (0.23 ha for males and 0.29 ha for females), again using simple grid trapping. McIntyre et al.
92 (2009) presented much smaller home-range estimates (averaging about 0.06 ha) based on grid
93 trapping in Brazoria County, Texas, but including animals with as few as 2 recaptures may have
94 skewed the results. The only known study to use radio telemetry to characterize home ranges of
95 rice rats was conducted at a reclaimed surface mine west of Harrisburg, Illinois (Hofmann and
96 Gardner 1992). These workers estimated an average home range of 0.73 ha using the convex

97 polygon method (Mohr 1947), but the study suffered from short duration (two nights of tracking),
98 frequent collar detachment, and few relocations.

99 Rice rats are believed to be highly vagile for their size (Wolfe 1982, Wolfe 1985, Forsyth
100 and Dueser 1993). In a controlled swimming-chamber experiment, Esher et al. (1978) found rice
101 rats moving > 200 m in a single night, 10 times farther than hispid cotton rats exposed to the same
102 conditions. Rice rats also have been reported moving into adjacent upland cover in response to
103 flooding (Wolfe 1982, Krucke 2004), wetland draw-downs (Smith and Vrieze 1979), and peaks
104 in population density (Wolfe 1985). Different age classes may move differently through the
105 landscape, and Krucke (2004) captured subadults in uplands at a higher rate than their adult
106 counterparts.

107 No study has quantified habitat selection by rice rats at the home-range level, although
108 several larger-scale habitat assessments of the species have been published. Rice rats are
109 associated with tidal marshes, estuaries, coastal wetlands, palustrine emergent wetlands,
110 palustrine scrub-shrub wetlands, palustrine aquatic beds, and riverine aquatic beds (Cowardin and
111 Golet 1995, Wolfe 1982, Hofmann et al. 1990). Additionally, rice rats have been captured in
112 matrix types such as sawgrass (*Cladium spp.*) prairies (Smith and Vrieze 1979), cordgrass
113 (*Spartina spp.*) uplands (Krucke 2004), pine plantations (Miller et al. 2004), and lowland brome-
114 dominated (*Bromus spp.*) meadows (McLaughlin and Robertson 1951). In southern Illinois,
115 Eubanks et al. (2011) found that wetlands surrounded by upland grasses were more likely to be
116 occupied by rice rats than those surrounded by upland forests and human development. Eubanks
117 (2009) also found that wetlands surrounded by bare ground or agriculture rarely were occupied by
118 rice rats and may be more isolated than wetlands surrounded by native plants. Visual obstruction
119 < 0.5 m and herbaceous cover were the best predictive variables for occupancy, indicating that

120 rice rats tend to persist in wetlands surrounded by dense ground cover. Rice rats have not
121 previously been reported in row crop agriculture fields or in upland deciduous woodlots (Goertz
122 and Long 1973; Wolfe 1985, Franz et al. 1998). Areas of open water (Forys and Dueser 1993)
123 and wet, vegetated ditches (Hofmann et al. 1990) may serve as dispersal corridors.

124 Rice rat conservation and recovery efforts would benefit from accurate estimates of home-
125 range size and composition to identify landscape-scale habitat selection and rank landcover
126 preference. The objectives of our study were to quantify home-range size and movement
127 distances, test whether movement and home-range size differed across age and season, and
128 characterize habitat selection by rice rats in a wetland complex in the northern portion of the
129 species' range. We expected that movement rates and home-range sizes would be greater for
130 subadults than adults and during periods of fluctuating water level.

131

132 MATERIALS AND METHODS

133 *Study area.*—Our study took place from 30 March to 7 November 2011 within the
134 Burning Star 5 Natural Wildlife Area, a 3400-ha reclaimed coal mine located 5 km east of
135 DeSoto, Illinois, USA (37° 50' 21" N, 89° 10' 56" W; Fig. 1). During this period, Burning Star 5
136 was owned by CONSOL Energy (Consolidation Coal Company, Elkhart, Illinois, USA) and
137 managed by the combined efforts of the Illinois Department of Natural Resources, the National
138 Wild Turkey Federation, and the Cooperative Wildlife Research Laboratory at Southern Illinois
139 University Carbondale. Located along the Little Muddy River, Burning Star 5 was composed of
140 approximately 1600 ha of cropland, 800 ha of timber, 400 ha of grassland, and 560 ha of lakes
141 and wetlands (Illinois Department of Natural Resources 2011). Landcover was diverse
142 throughout Burning Star 5, with mature oaks (*Quercus* spp.) and hickories (*Carya* spp.)

143 dominating bottomland forests; tall fescue (*Festuca* spp.), switchgrass (*Panicum virgatum*), and
144 big bluestem (*Andropogon gerardii*) within grasslands; and corn (*Zea mays*), soybeans (*Glycine*
145 *max*), sorghum (*Sorghum* spp.), and wheat (*Triticum* spp.) grown in croplands (Delahunt 2011).

146 *Collaring and relocation* – We placed radio transmitters on rice rats captured in 11
147 trapping grids in 4 wetlands during an ongoing study of matrix permeability (Cooney 2013),
148 collaring adult and subadult male rice rats in equal proportion. We only tracked one sex to
149 increase statistical power with a limited number of transmitters, and because we anticipated
150 higher capture success for males (Bloch and Rose 2005). Captured animals were handled in
151 accordance with an approved protocol (Southern Illinois University Carbondale, Institutional
152 Animal Care and Use Protocol 10-009), which included anesthetizing rice rats by inhalation of
153 isoflurane (Isothesia, Fisher Scientific, Pittsburgh, Pennsylvania, USA). We assigned age classes
154 based on body mass criteria modified from Negus et al. (1961), who grouped rice rats < 30 g as
155 juveniles, between 30-50 g as subadults, and > 55 g as adults (Wolfe 1985). We also placed
156 considered rice rats between 50 g and 55 g to be adults if they exhibited adult breeding conditions
157 (descended testes in males and perforated vaginas in females), otherwise they were considered
158 subadults (Wolfe 1985). While each rat was under anesthesia, we attached a radio transmitter
159 (Model SOM 2038; Wildlife Materials Inc., Murphysboro, Illinois, USA) around the neck using a
160 0.5-cm black cable tie. Transmitter mass (2.3-2.6 g) constituted 2.7-8.7% of body mass at
161 capture. After tightening the cable tie to a snug fit and removing the excess portion, we allowed
162 rats to recover from the anesthesia within a Sherman trap (H. B. Sherman Traps, Tallahassee,
163 Florida, USA). Once we confirmed the frequency of the radio transmitter with a digital receiver
164 (Communications Specialist Inc., Orange, California, USA), we released the animal at its point of

165 capture and recorded the location with a handheld global positioning system (GPS) device (Model
166 60 CSX, Garmin Inc., Olathe, Kansas, USA).

167 We relocated each collared rice rat up to 6 times per week for up to 6 weeks, alternating
168 between nighttime triangulation (2000-2359 hr Sunday, Tuesday, and Thursday) and daytime
169 homing (0800-1159 hr Monday, Wednesday, and Friday). We alternated relocations of collared
170 rice rats to include both nesting (diurnal) and activity (nocturnal) locations in home-range
171 estimates. For triangulation, we used a 6-element Yagi antenna and digital receiver to record 3-4
172 intersecting bearings for each transmitter from points about 50 m from the wetland boundary,
173 spaced >50 m apart, and taken within a 15-minute time frame. To minimize bearing error, we
174 discarded readings ≤ 10 degrees from the previously recorded azimuth and took a new bearing
175 from a different location. We later entered the Universal Transverse Mercator geographic
176 coordinates (UTMs) and compass bearings of each reading into Program LOAS (Ecological
177 Software Solutions LLC, Heymagas, Hungary) to estimate rice rat locations and calculate error
178 polygons. We discarded all values with an error polygon > 5000 m² as inaccurate relocations. We
179 located each collar by triangulation up to 18 times over the 6-week period.

180 For homing, we followed the signal on foot and recorded the location on hand-held GPS if
181 we found a nest or burrow occupied by the collared rat. If the collar was found detached from the
182 animal, we recorded date, location of the collar, and suspected fate of the animal (e.g., collar
183 removal or animal mortality). Up to 18 homing locations were recorded for each collar over the
184 6-week period, producing up to 36 combined relocations from telemetry and homing to generate
185 home ranges. If the transmitter signal could no longer be detected after 6 weeks of radio-tracking,
186 we attempted to recapture the animal to replace or remove the transmitter. To do so, we deployed
187 25 Sherman traps in a 50- x 50-m grid surrounding the last known location and continued

188 trapping until the rat was captured and the collar removed for up to 21 days or until we found the
189 collar detached from the animal.

190 *Data analysis* –Removing the initial and final locations from each data set, we entered
191 relocations into ArcGIS version 9.3 (ESRI 2009) and used the Animal Movements extension to
192 calculate a 100% minimum convex polygon (MCP; Mohr 1947) and kernel home range (fixed-
193 kernel 95% isopleth; Worton 1989) for each individual. For the fixed-kernel approach, we used
194 least-squares cross validation to calculate the smoothing parameter (Habbema et al. 1974). In
195 addition to home-range estimates, we used the Hawth's tools Extension in ArcGIS to calculate
196 step-length (m) between relocations made on different days. We divided each step-length by the
197 time between relocations to measure daily movement distance.

198 We used mixed-model two-way ANOVA (McCullough and Searle 2001) to test for the
199 fixed effects of the categorical variables age class, collaring interval (March-April, May-June,
200 July-August, September-October), and their interaction on the response variables of home-range
201 size, average daily movement distance, and percentage of home range located outside of emergent
202 wetland vegetation (i.e. the matrix). The trapping grid where each rice rat was captured was a
203 random variable. The analysis was carried out using PROC GLM (SAS Institute Inc. 2011).

204 We used compositional analysis to characterize habitat selection by rice rats at the home-
205 range level (Aebischer et al. 1993). Using ArcGIS, we calculated used habitat as the percentage
206 of each rice rat's kernel home range composed of emergent vegetation, agriculture, forest,
207 grassland, shoreline, open water, shrub cover, partially inundated ditches and gravel road. We
208 defined available habitat in 2 ways. First, we calculated the percentage of each landcover type
209 within 41.2-m buffers around the 4 study wetlands. This buffer represented the average distance
210 rice rats traveled from suitable habitat. Second, we combined all rice rat relocations collected at

211 each wetland and used them to generate a composite 95% isopleth, then calculated the percentage
212 of each landcover type within the composite isopleth. We replaced zero values with 0.00001,
213 calculated log-ratios, and used PROC BYCOMP (Ott and Hovey 2004) in SAS version 9.3 (SAS
214 Institute Inc. 2011) to perform multivariate analysis of variance (MANOVA) to test whether the
215 composition of rice rat home ranges differed from available (Aebischer et al. 1993). We then
216 used t-tests to detect pairwise differences in cover type selection at $\alpha < 0.05$ (McCullough and
217 Searle 2001) and ranked cover types from most to least preferred.

218

219

RESULTS

220 We collared 8 rice rats during March-April, 8 during May-June, 6 during July-August, and
221 3 during September-October (Table 1), as capture rate decreased over the course of the season
222 (Cooney 2013). One collar was recovered from a recaptured rice rat, 12 collars were discovered
223 detached from the rice rat, and 12 collars lost their signal and were never recovered (Table 1). Of
224 the 12 detached collars, 3 were confirmed predator kills (Table 1).

225 In total, we collected 319 locations that were usable for analysis with a median error
226 ellipse area of 518 m². We homed to rice rats 162 times in emergent wetland habitat, 3 times in
227 ditches, and 21 times in upland matrix cover, compared to 85 triangulated locations in wetland
228 habitat and 48 triangulated locations in the matrix. Of the 21 homed relocations in matrix cover
229 types, we found rice rats 11 times in grassland cover, 7 times in agriculture cover, 2 times in
230 forest cover, and 1 time in shrub cover. Rice rats were most often found in globular nests
231 constructed from sedge and grass leaves, though we did home to individuals in root masses,
232 underground burrows, and a pile of corn stalks.

233 We calculated home-range size and movement parameters using data from 21 rice rats (8

234 subadults and 13 adults) that were relocated ≥ 7 times (Table 1). We did not obtain any valid
235 relocations for 2 subadults whose collars failed or detached. Home-range sizes estimated from 2
236 additional subadult rice rats with < 7 relocations deviated visibly from the distribution of sizes for
237 rats with larger sample sizes, so we do not report those estimates. We tracked the 21 rice rats an
238 average of 32 days (range 13-54 days), collecting an average of 15 (range 7-24) relocations per
239 rat. Average (\pm SE) home-range size was 1.85 ± 0.49 ha for MCP and 3.53 ± 0.66 ha for 95%
240 kernel home range. Due to the small sample size ($n = 2$) of radiocollared rice rats in September–
241 November, we dropped telemetry interval 4 from all ANOVA analyses that included telemetry
242 interval. Kernel home-range size was similar ($P = 0.88$) for subadults (2.9 ± 0.9 ha; least squares
243 mean \pm SE) and adults (3.1 ± 0.7 ha), and the interactive effect of age class and telemetry interval
244 on home-range size was not significant ($F_{2,6} = 2.05$, $P = 0.21$). However, home-range size
245 differed among telemetry intervals ($F_{2,9} = 4.42$, $P < 0.05$), being largest for rice rats collared in
246 May-June (5.12 ± 0.90 ha), followed by July-August (3.66 ± 1.06 ha), and smallest during March-
247 April (1.49 ± 0.84 ha).

248 The distribution of daily movement distances was approximately exponential (Fig. 2) with
249 a median of 26.3 m, an average of 46.6 ± 3.4 m, and a maximum of 396 m. The average distance
250 rice rats were relocated from wetland habitat was 41.2 ± 6.2 m (maximum = 464 m). Average
251 daily movement distance did not vary significantly by age class ($F_{1,12} = 0.32$, $P = 0.58$), telemetry
252 interval ($F_{2,8} = 0.50$, $P = 0.62$), or their interaction ($F_{2,5} = 1.17$, $P = 0.38$). We also found no
253 evidence of interactive effects of age class and telemetry interval on the percentage of home
254 ranges overlapping the upland matrix ($F_{2,5} = 0.17$, $P = 0.85$). However, amount of rice rat home
255 ranges composed of matrix differed among telemetry intervals, being greatest for rice rats collared
256 during May-June, followed by July-August, and least in March-April. We found suggestive

257 evidence that home ranges of adults contained a higher percentage of upland matrix than did those
258 of subadults (Table 2). The interaction of age class and telemetry interval did not affect
259 percentage matrix overlap (Table 2).

260 Rice rats showed habitat selection at the home-range level, using availability assessed with
261 either 41.2-m buffers (Wilk's $\Lambda = 0.17$, $F_{8,15} = 9.19$, $P < 0.01$) and composite 95% isopleths
262 (Wilk's $\Lambda = 0.14$, $F_{8,15} = 11.4$, $P < 0.01$). Both measures of availability yielded similar
263 percentages of the various landcover types. Home ranges of rice rats contained more emergent
264 wetland and agriculture but less grassland, forest, and shrub cover than either measure of
265 availability (Table 3). Wetland (combining emergent wetland vegetation, shoreline, and open
266 water) composed an average of only 55.9% of rice rat home ranges (Table 3). In pairwise
267 comparisons, selection for emergent wetland vegetation was greater than for all other available
268 cover types except partially inundated ditches. Selection against shrub cover was stronger than
269 for all cover types except gravel roads, forest, and open water in the buffer analysis, whereas
270 selection against open water was stronger than for all other cover except grassland and agriculture
271 in the isopleth analysis. Selection ranking was consistently high for emergent wetland vegetation,
272 shoreline, and agriculture; and low for open water, gravel roads, and shrub cover (Table 3).

273

274 **DISCUSSION**

275 We provide the most extensive and intensive study of home range for this species, and the
276 average home-range size we estimated was substantially larger than any previous study (Negus et
277 al. 1961, Hofman and Gardner 1992, McIntyre et al. 2009). These previous studies likely
278 underestimated home-range size as a result of grid trapping and few relocations. Nevertheless,
279 Hofmann and Gardner (1992) believed that rice rats in Illinois move farther to forage for

280 resources than their southern counterparts. Most previous studies of rice rat home range took
281 place in coastal wetlands and estuaries in the southern United States where suitable habitat is
282 often contiguous (Negus et al. 1961, Wolfe 1982). Our study took place near the northern limit of
283 rice rat distribution (Wolfe 1982), in an area where emergent wetlands are highly fragmented by
284 upland grasses, forests, and agriculture (Illinois Department of Natural Resources 2011). Future
285 work should monitor rice rats occupying contiguous wetlands within the Mississippi and Cache
286 River watersheds. Also, studying female movements could provide insight into variation by sex
287 in home-range size.

288 Movement distances seen in our study reflected the high vagility of rice rats seen
289 elsewhere in their range. Negus et al. (1961) captured rice rats > 600 m from their original home
290 range in Louisiana, and Forsy and Dueser (1993) found that rice rats were capable of crossing >
291 300 m of open water between Virginia Barrier Islands. Esher et al. (1978) reported that rice rats
292 moved an average of 232.8 m per night in a laboratory swimming chamber. One collared adult in
293 our study traveled > 300 m in one night, only to return to its home range the following day.
294 Relative to sympatric species, rice rats were seen making inter-patch movements more frequently
295 than cotton rats in the Florida Everglades (Smith and Vrieze 1979), and moved up to 10 times
296 further than cotton rats in an enclosed swimming chamber (Esher et al. 1978). Rice rats may have
297 adapted to taking large daily movements in highly fragmented landscapes as a way to combat
298 habitat isolation. The ability to frequently make long-distance movements could contribute to the
299 persistence of rice rat metapopulations in fragmented habitats via gene flow, patch colonization,
300 and the rescue effect (Hanski 1994, Fahrig and Merriam 1994).

301 The male rice rats we studied selected emergent wetland vegetation over all other
302 available cover types. The vast majority of nesting occurred in emergent vegetation, as rice rats

303 occupied woven grass nests (as described in Hofmann and Gardner 1992), underground burrows,
304 and abandoned muskrat (*Ondantra zibethicus*) mounds. Partially-inundated ditches were also
305 selected slightly more than other cover types, which supports the assertion of Hofmann et al.
306 (1990) that irrigation ditches and roadside right-of-ways can be used as dispersal corridors. Rice
307 rats may find vegetated ditches to be suitable secondary habitat due their similarity to emergent
308 wetlands in vegetation structure and hydrology (Hofmann et al. 1990, Kruchek 2004).
309 Additionally, open shorelines may be used by rice rats to move between patches of wetland
310 vegetation alongside permanent, deep-water lakes.

311 Although the predominant use of emergent wetland habitat by rice rats in our study was
312 expected, we also found that > 40% of home-range area extended beyond wetlands into the
313 purportedly unsuitable upland matrix, including crop fields that made up > 20% of rice rat home
314 ranges. Additionally, we homed to rice rats nesting in upland grasses, crop fields, and other
315 upland land cover. The high amount of home range overlapping the matrix parallels the findings
316 of our study of matrix permeability (Cooney 2013), which showed that upland areas (particularly
317 soybean fields) were frequently entered and used by rice rats, presumably for foraging and
318 dispersal, especially when vegetation cover was available in those fields and rice rats were
319 abundant. Smith and Vreize (1979) found that rice rats occupied mesic sawgrass prairies in the
320 Everglades, but only when hammock habitat was dry. Additionally, Kruchek (2004) captured
321 subadult rice rats in upland grasses when adult densities in nearby wetlands were high. Eubanks
322 (2009) found that wetlands adjacent to agriculture were less likely occupied by rice rats, but our
323 findings suggest that mature crop fields facilitate matrix movement in the rice rat. It should be
324 noted that we specifically selected wetland study sites that were isolated within the landscape to
325 study permeability, so habitat fragmentation may have encouraged rice rats to occupy upland

326 areas. Future research comparing habitat selection by rice rats in fragmented and unfragmented
327 habitats would improve our understanding of the importance of upland to the species.

328 Wolfe (1982) and Kruchek (2004) noted that grassland may be more suitable to rice rats
329 than other matrix cover types due to its structural similarity to emergent vegetation. Grassland
330 buffers around wetlands could improve the suitability of wetland habitat for rice rats and increase
331 the probability of rice rat occupancy (Kruchek 2004, Eubanks et al. 2011). We found male rice
332 rats occupying nests and burrows under mounds of switchgrass (*Panicum virgatum*) and big
333 bluestem (*Andropogon gerardii*) in upland cover. Although we did not capture rice rats in
334 grasslands > 15 m from the wetland edge in the permeability study (Cooney 2013), we frequently
335 radio-tracked rice rats occupying upland grasses and moving > 250 m into grassland patches.
336 Unlike telemetry research, inferences about landcover use based on trapping rely heavily on
337 animal trappability, which can differ between seasons and cover types (Balph 1968, Hammond
338 and Anthony 2006). Radio-telemetry appears to be a more sensitive tool than trapping transects
339 for assessing matrix use by rice rats.

340 During our study of male rice rats, home ranges were largest and overlapped matrix the
341 most from late May to early July, corresponding with peaks in rice rat abundance and water depth
342 in wetlands (Cooney 2013). Small mammals tend to expand their movements when population
343 density peaks and individuals are forced out of the habitat to avoid intraspecific competition
344 (Gaines and McClenaghan 1980). Hispid cotton rats in Texas had larger movement distances in
345 summer than spring or fall (Spencer et al. 1990). Larger home ranges may also signal breeding
346 activity, which is believed to occur from May–October in rice rats (Negus et al. 1961, Eubanks
347 2009). For instance, male Key Largo woodrats (*Neotoma floridana smalli*) had larger minimum
348 convex polygon home ranges during June–August than in March–May and September–

349 November, likely as they sought females for mating (McCleery et al. 2006), which may explain
350 expanded home ranges of males at this time.

351 Home ranges of adult males overlapped more matrix cover than did subadult males.
352 Kruchek (2004) found adult rice rats entering grassy uplands during extended periods of flooding,
353 but we did not find that rice rats at Burning Star 5 entered the matrix at a higher rate during site
354 inundation (Cooney 2013). Our concurrent trapping study (Cooney 2013) also showed that adults
355 were captured in wetland habitat at a higher proportion than their subadult counterparts, which
356 contrasts with the high amount of matrix overlap in adult home ranges determined by
357 radiotelemetry. As Hofmann and Gardner (1992) point out, adult rice rats have a tendency to
358 shift home ranges and are likely to adopt multiple home-range centers over the course of a season.
359 Establishing multiple nesting sites is also a common feature of this species, as Smith and Vrieze
360 (1979) found 89% of rice rats were captured at multiple tree hammocks within the Florida
361 Everglades. We observed that 2 adult males dispersed from the wetland where they were
362 captured and established new home ranges > 100 m away. Dispersal in rice rats may not be age-
363 biased, as adults, subadults, and juveniles were found dispersing in equal proportion from Crescent
364 Island, Virginia (Forys and Dueser 1993). The willingness of adults to move through upland
365 cover and disperse can stabilize rice rat metapopulations if individuals successfully breed in novel
366 patches (Hanski 1994, Fahrig and Merriam 1994).

367 The relatively high dispersal potential of the rice rat should be considered when
368 developing or conserving habitat that is accessible to this species for colonization. Using
369 telemetry, we determined that rice rats can move at least 396 m in a day and may nest 464 m from
370 wetland habitat. Partially inundated, vegetated ditches can also provide dispersal corridors by
371 which rice rats could travel between permanent wetlands where breeding generally occurs (Wolfe

372 1985). Eubanks (2009) noted that improving connectivity between wetland complexes would
373 facilitate the expansion of rice rats to suitable wetlands in Illinois that currently remain
374 unoccupied. Although not a substitute for contiguous habitat, vegetated irrigation ditches can
375 provide temporary cover for transient rice rats during dispersal (Hofmann et al. 1990).

376 The marsh rice rat persists in the southern portion of Illinois, where agricultural practices
377 and urban development have historically contributed to wetland reduction (Suloway and Hubbell
378 1994). Continued wetland mitigation laws – where up to 5.5 ha of wetland must be replaced for
379 every 1 ha developed – should ensure the availability of suitable habitat for the marsh rice rat in
380 the near future (Illinois Administrative Code Title 17, Chapter 1, Subchapter C, Part 1090.10-100,
381 6 May 1996). Kruchek (2004) proposed that federal wetland protection should extend to adjacent
382 upland habitat to account for the important role uplands play in providing sink habitat or refuges
383 for rice rats and other wetland species. Additionally, mine reclamation in southern Illinois has
384 contributed to the development of novel wetland habitat where none might have existed in the
385 past (Nawrot and Klimstra 1989). Provided that wetlands are accessible to potential immigrants,
386 reclamation sites have the potential to increase the range and stability of the rice rat in Illinois and
387 similar areas (Nawrot and Klimstra 1989, Eubanks 2009).

388

389 **ACKNOWLEDGMENTS**

390 Funding for this project was provided by the Illinois Department of Natural Resources
391 (Federal Aid Project W-135-R) and the Graduate School at Southern Illinois University
392 Carbondale. We thank the National Wild Turkey Federation and CONSOL Energy for
393 cooperation and study site access. We thank Robert Schooley for advisory input and comments
394 on the Master's thesis (Cooney 2012) upon which this manuscript was based.

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LITERATURE CITED

397 Aebischer, N. J., P. A. Robertson, and R. E. Kenward. 1993. Compositional analysis of habitat
398 use from animal radio-tracking data. *Ecology* 75:1313-1325.

399 Balph, D. F. 1968. Behavioral responses of unconfined *Uinta* ground squirrels to trapping.
400 *Journal of Wildlife Management* 32:778-794.

401 Birkenholz, D. E. 1963. Movement and displacement in the rice rat. *Quarterly Journal of the*
402 *Florida Academy of Sciences*. 26:269-275.

403 Bloch, C. P., and R. K. Rose. 2005. Population dynamics of *Oryzomys palustris* and *Microtus*
404 *pennsylvanicus* in Virginia tidal marshes. *Northeastern Naturalist* 12:295-306.

405 Bowman, J., J. A. G. Jaeger, and L. Fahrig. 2002. Dispersal distance of mammals is proportional
406 to home range size. *Ecology Notes*. 83:2049-2055.

407 Burt, H. B. 1934. Territoriality and home range concepts as applied to mammals. *Journal of*
408 *Mammalogy* 24:346-352.

409 Byrne, M. E., and M. J. Chamberlain. 2011. Seasonal space use and habitat selection of adult
410 raccoons (*Procyon lotor*) in a Louisiana bottomland hardwood forest. *American Midland*
411 *Naturalist* 166:426-434.

412 Cameron, G. N., and S. R. Spencer. 1985. Assessment of space-use patterns in the hispid cotton
413 rat (*Sigmodon hispidus*). *Oecologia* 68:133-139.

414 Cooney, S. A. 2013. Landscape permeability and home range composition of the marsh rice rat
415 (*Oryzomys palustris*) in southern Illinois. Thesis, Southern Illinois University,
416 Carbondale.

417 Cowardin, L. M., and F. C. Golet. 1995. US Fish and Wildlife Service 1979 wetland
418 classification: A review. *Vegetation* 118:139-152.

419 Cranford, J. A. 1976. Home range and habitat utilization by *Neotoma fuscipes* as determined by
420 radiotelemetry. *Journal of Mammalogy* 58:165-172.

421 Delahunt, K. S. 2011. Nesting ecology, survival, and home range of wild turkey in an agricultural
422 landscape. Thesis, Southern Illinois University, Carbondale.

423 Eiris, G. C., and G. R. Barreto. 2009. Home range of marsh rats *Holochilus ciureus*, a rodent pest
424 in rice fields of Venezuela. *Intersciencia* 34:400-405.

425 ESRI. 2009. ArcGIS Desktop version 9.3. Environmental Systems Research Institute, Redlands,
426 California.

427 Esher, R. J., J. L. Wolfe, and J. N. Layne. 1978. Swimming behavior of rice rats (*Oryzomys*
428 *palustris*) and cotton rats (*Sigmodon hispidus*). *Journal of Mammalogy* 59:551-558.

429 Eubanks, B. W. 2009. Status and distribution of the state-threatened marsh rice rat (*Oryzomys*
430 *palustris*) in Illinois. Thesis, Southern Illinois University, Carbondale.

431 Eubanks, B. W., E. C. Hellgren, J. R. Nawrot, and R. D. Bluett. 2011. Habitat associations of the
432 marsh rice rat (*Oryzomys palustris*) in freshwater wetlands of southern Illinois. *Journal of*
433 *Mammalogy* 92: 552-560.

434 Fahrig, L., and G. Merriam. 1994. Conservation of fragmented populations. *Conservation Biology*
435 8:50-59.

- 436 Forys, E. A., and R. D. Dueser. 1993. Inter-island movements of rice rats (*Oryzomys palustris*).
437 The American Midland Naturalist 130:408-412.
- 438 Franz, R., D. Maehr, A. Kinlaw, C. O'Brien, and R. D. Owen. 1998. Distribution and abundance
439 of sensitive wildlife species at Avon Park Air Force Range. Final Report to the
440 Department of Defense, RWO-169.
- 441 Gaines, M. S., and L. R. McClenaghan Jr. 1980. Dispersal in small mammals. Annual Review of
442 Ecological Systems 11:163-196.
- 443 Goertz, J. W., and R. C. Long. 1973. Habitat of five species of rat in Louisiana. The American
444 Midland Naturalist 90:460-465.
- 445 Habbema, J. D. F., J. Hermans, and K. van der Broek. 1974. A stepwise discriminant analysis
446 program using density estimations. In: COMPSTAT 1974, Proceedings in Computational
447 Statistics, Vienna. G. Bruckman (editor). Physica-Verlag HD., Heidelberg, Germany. 110
448 pp.
- 449 Hammond, E. L. and R. G. Anthony. 2006. Mark-recapture estimates of population parameters
450 for selected species of small mammals. Journal of Mammalogy 87:618-627.
- 451 Hanski, I. 1994. A practical model of metapopulation dynamics. Journal of Animal Ecology
452 63:151-162.
- 453 Hofmann, J. E., and J. E. Gardner. 1992. A radiotelemetric study of home range size and dispersal
454 of the marsh rice rat (*Oryzomys palustris*) in southern Illinois: Progress Report. Illinois
455 Natural History Service CB1.

456 Hofmann, J. E., J. E. Gardner, and M. J. Morris. 1990. Distribution, abundance, and habitat of the
457 marsh rice rat (*Oryzomys palustris*) in southern Illinois. Transactions of the Illinois State
458 Academy of Science 83:162-180.

459 Illinois Department of Natural Resources. 2011. Burning Star 5 Wildlife Management Area.
460 Hunter Fact Sheet 2011-2012. <[http://dnr.state.il.us/lands/landmgt/hunter_fact_](http://dnr.state.il.us/lands/landmgt/hunter_fact_sheet/r5hfs/brs5.htm)
461 [sheet/r5hfs/brs5.htm](http://dnr.state.il.us/lands/landmgt/hunter_fact_sheet/r5hfs/brs5.htm)> Accessed February 2, 2011.

462 Johnson, D. H. 1980. The comparison of usage and availability measurements for evaluating
463 resource preference. Ecology 61:65-71.

464 Kruczek, B. L. 2004. Use of tidal marsh and upland habitats by the marsh rice rat (*Oryzomys*
465 *palustris*). Journal of Mammalogy 85:569-575.

466 McCleery, R. A., R. R. Lopez, and N. J. Silvy. 2006. Movements and habitat use of the Key
467 Largo woodrat. Southeastern Naturalist 5:725-736.

468 McCullough, C. E., and S. R. Searle. 2001. Generalized, Linear, and Mixed Models. John Wiley
469 & Sons, Inc., New York, New York, USA.

470 McIntyre, N. E., R. A. Nisbett, A. Abuzeineh, T. Holsomback, Y.-K. Chu, J. A. Carmichael, N.
471 de la Sancha, C. W. Dick, C. B. Jonsson, and R. D. Owen. 2009. Mastozoología
472 Neotropical 16(1) <<http://www.redalyc.org/pdf/457/45712055008.pdf>> Accessed 7
473 February 2014.

474 McLaughlin, C. A., and W. B. Robertson. 1951. A new record of the rice rat, *Oryzomys palustris*
475 *palustris*, from southern Illinois. Chicago Academy of Science Natural History.
476 Miscellaneous Note: 80.

477 Miller, D. A., R. E. Thill, M. A. Melchior, T. B. Wigley, and P. A. Tappe. 2004. Small mammal
478 communities of streamside zones in intensively managed pine forests of Arkansas. *Forest*
479 *Ecology and Management* 203:381-393.

480 Mohr, C.O. 1947. Table of equivalent populations of North American small mammals. *American*
481 *Midland Naturalist* 37:223-249.

482 Nawrot, J. R., and W. D. Klimstra. 1989. Wetland habitat development on mined lands. Pages
483 269-285 in J. D. Majer, editor. *Animals in primary succession*. Cambridge University
484 Press. New York, New York, USA.

485 Negus, N. C., E. Gould, and R. K. Chipman. 1961. Ecology of the rice rat, *Oryzomys palustris*
486 (Harlan), on Brenton Island, Gulf of Mexico, with a critique of the social stress theory.
487 *Tulane Studies in Zoology* 8:94-123.

488 Ott, P., and F. Hovey. 2002. BYCOMP.SAS. Department of Fisheries and Wildlife Sciences,
489 Virginia Tech, Blacksburg, Virginia, USA.

490 Revilla, E., W. Thorsten, F. Palomares, P. Ferreras, and M. Delibes. 2004. Effects of matrix
491 heterogeneity on animal dispersal: from individual behavior to metapopulation-level
492 parameters. *The American Naturalist* 164:E130-153.

493 SAS Institute Inc. 2011. SAS version 9.3. SAS Institute Inc., Cary, North Carolina.

494 Schooley, R. L., and L. C. Branch. 2006. Space use by round-tailed muskrats in isolated wetlands.
495 *Journal of Mammalogy* 87:495-500.

496 Smith, A. T., and J. M. Vrieze. 1979. Population structure of Everglades rodents: responses to a
497 patchy environment. *Journal of Mammalogy* 60:778-794.

498 Spencer, S. R., G. N. Cameron, and R. K. Swihart. 1990. Operationally defining home range:
499 temporal dependence exhibited by hispid cotton rats. *Ecology* 71:1817-1822.

- 500 Wolfe, J. L. 1982. Mammalian species: *Oryzomys palustris*. The American Society of
501 Mammalogists 176:1-5.
- 502 Wolfe, J. L. 1985. Population ecology of the rice rat (*Oryzomys palustris*) in a coastal marsh.
503 Journal of Zoology: Proceedings of the Zoological Society of London 205: 235-244.
- 504 Worton, B. J. 1989. Kernel methods for estimating the utilization distribution in home- range
505 studies. Ecology 70:164-168.

506 Table 1. Summary information and home-range and movement characteristics for the 25 radio-collared marsh rice rats (*Oryzomys*
 507 *palustris*) tracked during 30 March–7 November 2011 at Burning Star 5 Natural Wildlife Area (DeSoto, Illinois).

508

Collaring Interval	Collar Frequency	Age Class	Days Tracked	Relocations	MCP ^a (ha)	95% Isopleth (ha)	Average Daily Movement Distance (m)	Matrix in 95% Isopleth (%)	Collar Fate
March-April	149.125	Subadult	21	10	0.91	9.27	46.4	50.4	Detached
March-April	149.185	Adult	34	10	0.97	1.24	42.5	30.0	Detached
March-April	149.144	Subadult	40	20	1.11	2.04	60.4	20.9	Recapture
March-April	149.225	Subadult	39	16	0.28	0.45	19.5	5.5	Detached
March-April	149.104	Subadult	38	9	0.21	0.16	21.1	0.0	Signal Lost
March-April	149.304	Adult	25	8	0.81	2.49	22.7	58.3	Detached
March-April	149.425	Adult	16	8	0.47	2.13	28.7	43.9	Signal Lost
March-April	149.084	Adult	16	10	0.05	0.13	19.3	37.4	Signal Lost
May-June	149.245	Adult	16	7	0.83	0.82	76.7	68.8	Detached
May-June	149.405	Adult	40	24	1.32	3.62	27.6	48.4	Detached
May-June	149.044	Adult	24	14	6.41	6.52	158.0	83.7	Signal Lost
May-June	149.204	Adult	38	22	1.31	2.31	30.8	47.2	Signal Lost
May-June	149.445	Subadult	34	17	2.72	6.84	39.5	67.3	Detached ^b

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511 Table 1 Continued.

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Collaring Interval	Collar Frequency	Age Class	Days Tracked	Relocations	MCP ^a (ha)	95% Isopleth (ha)	Average Daily Movement Distance (m)	Matrix in 95% Isopleth (%)	Collar Fate
May-June	149.064	Subadult	36	15	9.26	7.29	84.2	72.1	Detached
May-June	149.024	Subadult	20	8	2.10	8.40	53.8	51.4	Detached ^b
May-June	149.024 ^c	Subadult	4	0	DID NOT CALCULATE				Signal Lost
July-Aug.	149.385	Adult	42	22	1.86	2.92	38.5	58.8	Signal Lost
July-Aug.	149.003	Subadult	35	21	2.02	3.92	67.9	58.6	Signal Lost
July-Aug.	149.285	Subadult	14	4	DID NOT CALCULATE				Signal Lost
July-Aug.	149.345	Subadult	4	0	DID NOT CALCULATE				Detached ^b
July-Aug.	149.264	Adult	45	23	0.97	1.81	39.4	38.3	Signal Lost
July-Aug.	149.325	Adult	44	24	4.36	8.73	64.7	48.6	Signal Lost
Sept.-Oct.	149.766	Adult	13	7	0.65	2.50	21.1	81.0	Detached
Sept.-Oct.	149.825	Adult	54	17	0.26	0.50	21.9	56.2	Signal Lost
Sept.-Oct.	149.604	Subadult	13	3	DID NOT CALCULATE				Detached

513

514 ^aMinimum convex polygon

515 ^bRat killed by predator

516 ^cCollar found detached, was reused

517 Table 2. Mixed model ANOVA for the response variable of percentage home range composed of
 518 upland matrix. Age class (Subadult and Adult) and collaring interval were categorical fixed-
 519 effect variables, while sub-location and wetland site were random effects.

Model Type	Effects	F-value	P-value	Parameters	Estimate (SE)
Main effects	AGE CLASS	4.44	0.06	Subadult	0.38 (0.07)
				Adult	0.55 (0.05)
	INTERVAL	4.94	<0.05	1 ^a	0.36 (0.07)
				2 ^b	0.63 (0.07)
				3 ^c	0.44 (0.08)
	Interactive	AGE CLASS	1.87	0.23	Subadult
Adult					0.52 (0.06)
INTERVAL		4.34	0.08	1	0.34 (0.07)
				2	0.62 (0.08)
				3	0.42 (0.08)
AGE CLASS× INTERVAL		0.17	0.85	Subadult 1	0.27 (0.10)
				Subadult 2	0.60 (0.12)
				Subadult 3	0.35 (0.13)
				Adult 1	0.42 (0.09)
				Adult 2	0.64 (0.08)
	Adult3	0.49 (0.10)			

520 ^a March-May

521 ^b May-July

522 ^c July-September

523 Table 3. Compositional analysis of used (within marsh rice rat [*Oryzomys palustris*] home ranges) and available landcover at Burning
 524 Star 5 Natural Wildlife Area (DeSoto, Illinois), March 30 – November 7, 2011. Used data were compared with 2 measures of available
 525 habitat: landcover within 41.2-m buffer surrounding wetland patches and within composite 95% isopleth ranges. Compositional
 526 analysis PROC BYCOMP in program SAS ranked landcover types in order of decreasing preference (8-0).

Landcover type	Used	Available within wetland buffers		Available within composite ranges	
	Average (\pm SE) %	Average (\pm SE) %	Selection rank	Average (\pm SE) %	Selection rank
Emergent wetland vegetation ^a	45.9 (4.3)	30.0 (3.6)	8	28.4 (4.2)	8
Shoreline	1.3 (0.9)	1.1 (1.1)	5	1.5 (1.5)	7
Agriculture	21.8 (4.2)	18.3 (11.5)	6	16.5 (7.7)	6
Partially inundated ditch	0.7 (0.4)	0.5 (0.5)	7	0.7 (0.4)	2
Grassland	11.0 (2.1)	17.8 (5.3)	4	16.6 (5.7)	5
Forest	8.3 (2.4)	16.2 (7.4)	3	14.3 (6.0)	4
Open water	8.7 (2.4)	10.3 (6.1)	2	13.8 (6.8)	0
Gravel road	2.5 (0.6)	4.3 (1.6)	1	3.2 (0.6)	3
Shrub cover	1.2 (0.4)	4.4 (3.0)	0	2.4 (1.1)	1

527 ^aCover type was used significantly more than would have been expected based on availability

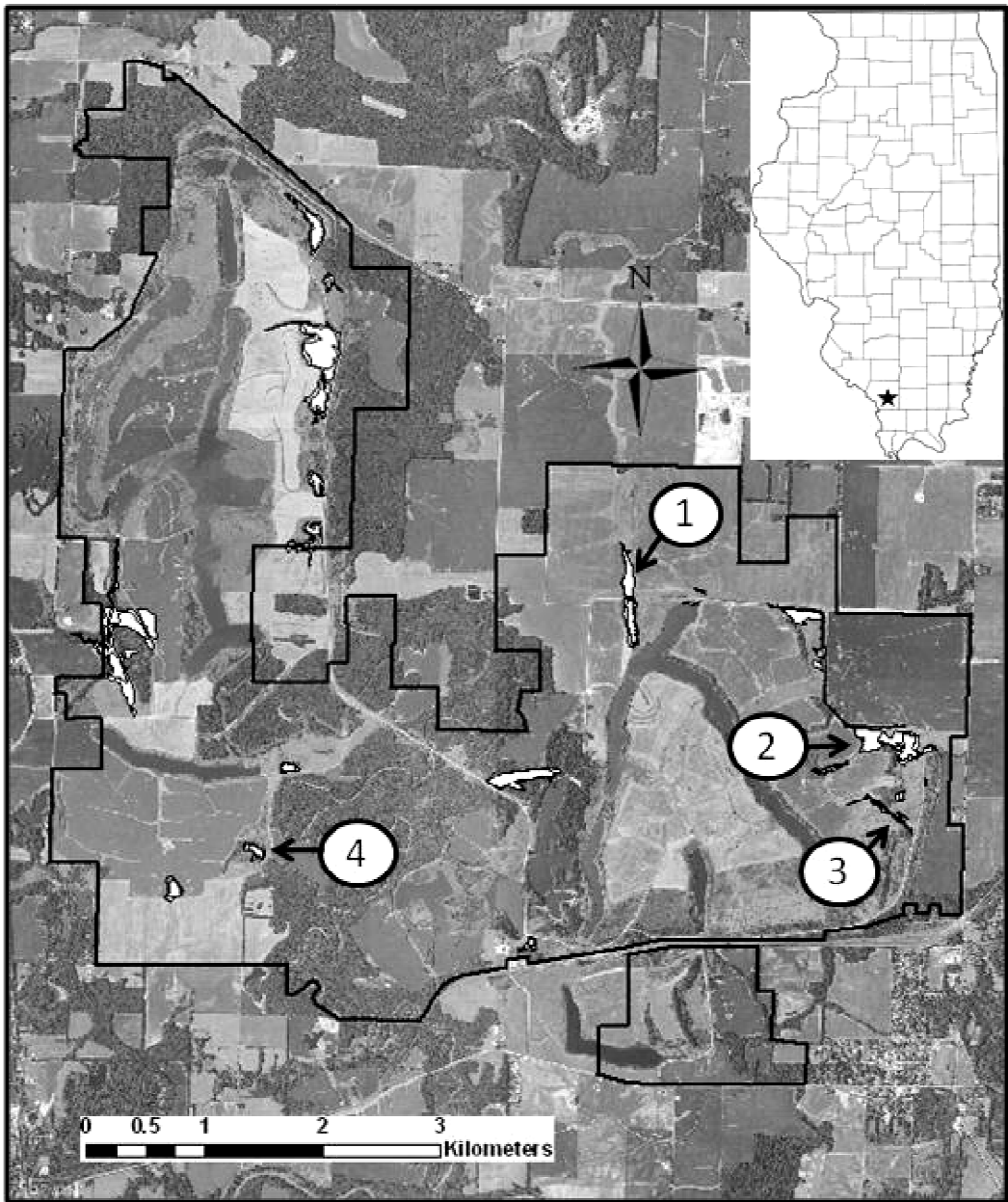
528 **FIGURE LEGENDS**

529 Fig. 1. Burning Star 5 Natural Wildlife Area in northwest Jackson County, near DeSoto, Illinois,
530 USA (inset), showing property boundary and 4 wetlands where marsh rice rats (*Oryzomys*
531 *palustris*) were livetrapped and radio-collared March–October 2011.

532

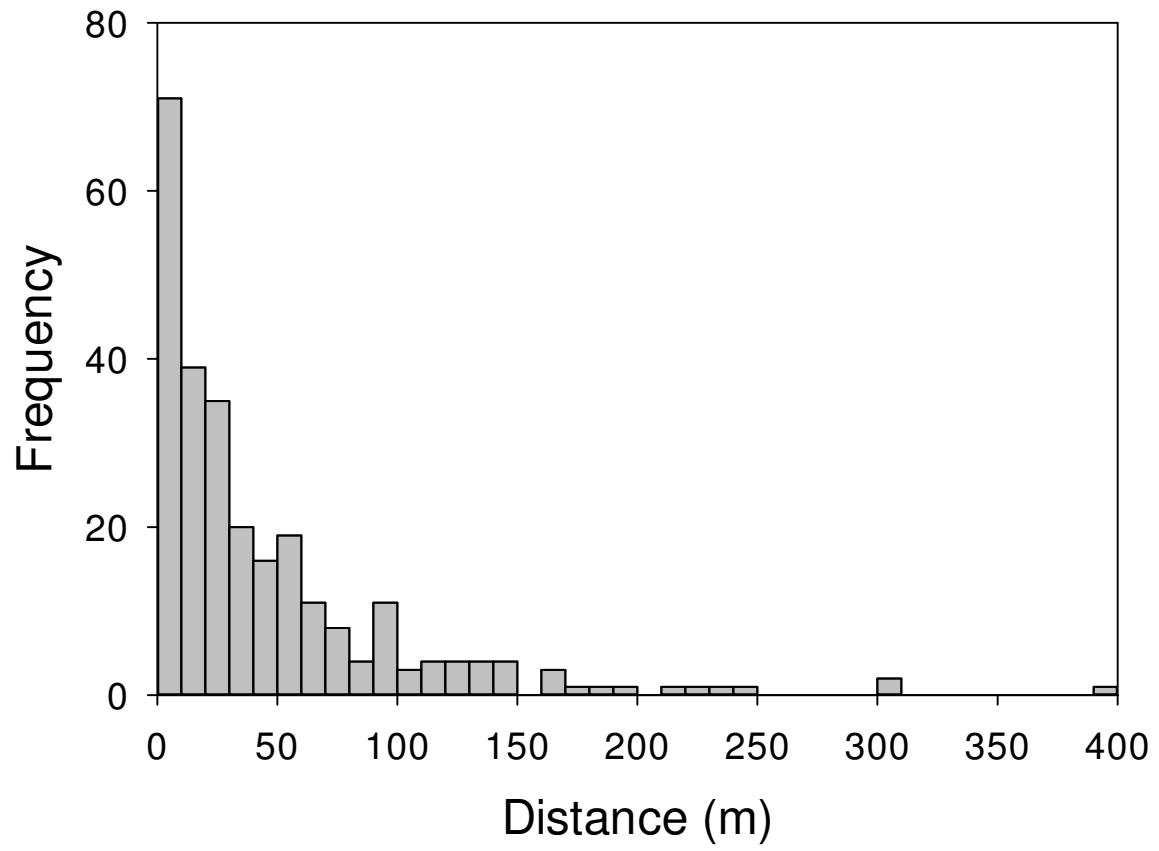
533 Fig. 2. Frequency distribution of daily movement distances made by radio-collared marsh rice
534 rats (*Oryzomys palustris*) at Burning Star 5 Natural Wildlife Area, (DeSoto, Illinois) between
535 March 30 and November 7, 2011.

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