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8 **Drivers of wood mouse body condition in Mediterranean agroforestry landscapes**

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20

21 Abstract

22 Agriculture and pastureland for cattle grazing are common land uses in Mediterranean  
23 landscapes. These activities significantly alter the habitat conditions, affecting the body  
24 conditions of wild communities, especially those with low vagility, as small mammals.  
25 We aimed to evaluate how cattle grazing and the habitat composition affected the body  
26 condition of the wood mouse *Apodemus sylvaticus* in a Southern Mediterranean  
27 agroforestry system using the Scale Mass Index (SMI) as an indicator of individuals  
28 condition. To assess variation in body condition, wood mice were live-trapped in a  
29 gradient of grazed sites with different stocking intensities, as well in sites excluded to  
30 grazing at different time periods (1998, 2004 and 2008). Wood mice body conditions  
31 were influenced by both microhabitat and macrohabitat drivers, with sex-biased  
32 patterns. While for the females only the shrub species had an influence (a microhabitat  
33 variable), for the males, both the shrub species and the undercover density (and  
34 specifically their interaction) were the important drivers (microhabitat and macrohabitat  
35 variables). Unexpectedly, the physical condition variation detected between periods was  
36 not directly proportional with the exclusion period, but rather a certain degree of  
37 similarity was found between the different sites (sites excluded since 2004 paired with  
38 grazed sites). These results suggest that the presence of food and shelter are  
39 determinants to the wood mouse physical condition: for females securing food sources  
40 enhance the body condition while for males the degree of cover, and consequently  
41 refuge against predators, seem to be determinant. These results reinforce the need for a  
42 sustainable landscape management, to assure the maintenance of habitat heterogeneity.  
43  
44 Keywords: *Apodemus sylvaticus*; cattle grazing; *montado* ecosystem; Scaled Mass  
45 Index; Micro and Macrohabitat drivers

46 Introduction

47           The physical condition of an animal can be defined as the energy capital  
48 accumulated in the body as the result of feeding, after accounting for the energetic costs  
49 associated with body maintenance and normal activities associated with territorial  
50 maintenance, food capture, mate's location, reproduction, etc. (Peig and Green 2009). It  
51 is assumed to be an indicator of the animal's health (Peig and Green 2009), since it  
52 influences its reproductive performance (Cameron et al. 1993; Guinet et al. 1998;  
53 Robbins et al. 2012), resistance to disease and pathogens (Møller et al. 1998),  
54 vulnerability to predation (Murray 2002) and ability to endure long periods when food  
55 is scarce (Millar and Hickling 1990; Verrier et al. 2011). Indices based on an  
56 individual's body condition are very important since it allow comparisons between  
57 populations of the same species, inhabiting different regions and being therefore subject  
58 to distinct environmental constrains, as well as to analyze if the habitat characteristics  
59 and disturbances influence the individual's fitness (Maceda-Veiga et al. 2014). So, by  
60 studying the physical condition of the individuals in a population we are obtaining a  
61 wider picture and a more functional perspective of its relationship with the habitat and  
62 its surroundings, something that the occurrence or even relative abundance does not  
63 show.

64           Nowadays, wildlife researchers are increasingly trying to understand the  
65 influence of environmental factors on animal's health (Bourbonnais 2014). These  
66 research efforts include not only the understanding of the effect of anthropogenic  
67 disturbances and habitat characteristics but also how these vary in space and time to  
68 provide crucial information to effectively manage or conserve wild populations (e.g.  
69 Bandeira et al. 2019; Santos et al. 2018). Furthermore, some body condition indexes are  
70 considered also good predictors of the individual's fitness, since animals that evidence a

71 higher condition can assign resources to enhance their fitness (Milenkaya et al. 2015).  
72 Several studies have showed that distinct taxa have their body condition dependent on  
73 similar types of drivers, associated mainly with anthropogenic activities and habitat  
74 characteristics (Auman 2008; Bourbonnais 2014; Liker 2008). Variations in this index  
75 are often linked to changes in the food that is available (Auman 2008), with the  
76 structure of the local vegetation (Bourbonnais 2014; Teixeira 2015), or with landscape  
77 changes associated with urbanization and human presence, at distinct scales  
78 (Bourbonnais 2014; Liker 2008).

79         Although the agricultural intensification of the European landscape has led to a  
80 large decrease in habitat diversity (Alain 2006), by creating large and homogeneous  
81 crop areas, the creation of agricultural landscapes does not only bring negative  
82 consequences. It can also provide a steady and reliable source of food, especially for  
83 granivorous species (Bonecker 2009), and particularly for those less sensitive to  
84 anthropogenic disturbance. This is especially true for Mediterranean landscapes, where  
85 the extensive agriculture regime mitigates the negative effects of more industrialized  
86 and intensive practices, by inducing lower disturbance regimes. The trade-off between  
87 the loss of native vegetation and habitat and the possible increase of food availability  
88 can influence the physical conditions either positively or negatively. Cattle grazing,  
89 however, at some extent, can have a more deleterious effect. In intensely grazed sites,  
90 the vegetation cover is scarcer, and the soil is often degraded (Ascensão 2012), making  
91 these places poor habitats, with reduced refuge and food resources (Fernandes et al.  
92 2019), which is proven to have a negative influence on the physical condition  
93 (Bourbonnais 2014). However, some species can take advantage of cattle presence,  
94 especially those that are more ecologically plastic and that benefit from a competition  
95 reduction in grazed areas due to the absence of competitors (e.g. deer mice, *Peromyscus*

96 *maniculatus*; Bueno et al. 2012). In some region, other vertebrates seem to benefit also  
97 from moderate grazing, since in such situations cattle facilitates the maintenance of  
98 temporary wetlands, which are used by amphibians communities (Hartel and von  
99 Wehrden 2013). Furthermore, in less intense cattle grazing areas, dung can enhance soil  
100 productivity (and earthworms' abundance, potential prey for some small mammals;  
101 Holter 1983), attracting coprophagous insects (Verdú et al. 2007) that can be used as  
102 food resource by some rodents (Zubaid and Gorman 1991).

103         Among those vertebrates that managed to cope with human-induced change in  
104 Mediterranean Europe, small mammals (Mammalia: orders Rodentia and Eulipotyphla)  
105 are crucial functional components of the southern European's biodiversity. They are  
106 important elements of food webs, because they are the main prey of higher trophic  
107 levels species, like birds of prey and carnivores (Tew 2000; Rosalino 2011a). They are  
108 also highly susceptible to environmental changes, with a very fast response to  
109 disturbances (Pocock and Jennings 2008), allowing the rapid assessment of the impacts  
110 of these changes. Such characteristics makes them a good model for studies aiming to  
111 understand the effects of land use change, especially when targeting the bottom-up  
112 effects on communities (Wei-chun 1989). Although somewhat resilient to anthropic  
113 disturbances (Teixeira et al. 2017), this functional group's physical condition can be  
114 negatively affected by the grazing effect on the landscape structure. Several studies  
115 have showed that body condition is mostly affected by lower shrub cover, which results  
116 in reduced availability of shelters, increased predation risk (Torre et al. 2007; Ascensão  
117 2012), and lower food abundance (Eccard et al. 2000).

118 Although some studies suggest that the distribution and abundance of small mammals  
119 are mainly determined by the microhabitat structure (e.g., flora species, local abundance  
120 of shrubs, trees, etc.; Bellows et al. 2001; Jorgensen 2004; Traba et al. 2009; Tarjuelo et

121 al. 2011), more specifically by the vegetation cover and food availability (Traba et al.  
122 2009; Tarjuelo et al. 2011), and also by the macrohabitat characteristics (e.g., landscape  
123 patch composition; Morris 1984, 1987; Orrock et al. 2000; Corbalán 2006), few studies  
124 have assessed the effect of such factors on the body condition of small mammals (e.g.  
125 Teixeira et al. 2019). Among small mammals, the wood mice, *Apodemus sylvaticus*, is  
126 an adequate species for addressing this issue, as it is a relatively abundant species (being  
127 the most abundant rodent in some areas; Todd et al. 2000; Tattersall et al. 2001;  
128 Teixeira et al. 2017), is the main prey of most Mediterranean predators (Tew 2000;  
129 Rosalino 2011a) and its body dimension allows for an rapid detection of significant  
130 variations among populations (Alcántara 1991; Rosário and Mathias 2004).

131 We aimed to assess the effect of cattle grazing and habitat composition and structure, at  
132 two different scales (i.e. micro and macrohabitat; see methods) on the physical  
133 condition of a wood mouse population inhabiting an agro-silvo-pastoral Mediterranean  
134 landscape, in Portugal. To fulfill this aim we formulated four hypothesis to explain  
135 variations in rodent's physical condition: H1 - microhabitat conditions, which includes  
136 the vegetation structure (e.g. shrub cover, presence of fruit trees), determine wood mice  
137 body condition; H2 - macrohabitat characteristics, including the landscape context (e.g.  
138 habitat heterogeneity, topography) and the years of exclusion from grazing, are the main  
139 drivers of *A. sylvaticus* body condition; H3 - wildlife community relationships, i.e.  
140 intraspecific and interspecific (with other small mammals) competition, and predation  
141 risk are the most influential determinants of body condition variation; and H4 – body  
142 condition drivers are multifactorial encompassing micro and macrohabitat  
143 characteristics, as well as the effect of intra and interspecific relationships.

144

145 Methods

146 Study area

147 This study was conducted between September 2017 and May 2018 in Charneca do  
148 Infantado, which is part of Companhia das Lezírias S.A., a public limited company  
149 wholly owned by public funds that holds the largest agro-silvo-pastoral farmstead in  
150 Portugal. The study area was included in the LTsER Montado program network, a  
151 platform dedicated to the long-term socio-ecological investigation of the *montado*  
152 system (an agro-silvo-pastoral system, where forestry - e.g. cork and wood extraction,  
153 livestock raising – cattle, goats, sheep and/or black pig - and agriculture (cereal field)  
154 co-occur within a single space (Blondel 2006). The weather is typically Mediterranean,  
155 with hot, dry summers and cold and humid winters, with a mean annual temperature of  
156 16.3° C and an annual rainfall average of 700 mm (Gonçalves et al. 2011).

157 The “Charneca” occupies around 10.000 ha and is characterized by poor, sandy soils,  
158 with deficient drainage. The area is mostly forested by cork oak *montado*, although  
159 there are also some pine and eucalyptus plantations, as well as agricultural crops  
160 (Gonçalves et al. 2011). One characteristic of the study area is the seasonal presence of  
161 cattle - around 3000 animals - that graze on fenced *montado* patches, but that are absent  
162 in summer. In these grazed sites, shrub density is kept at a very low level, either due to  
163 grazing itself or shrub clearance for pasture cultivation. Still in “Charneca”, about 700  
164 ha are excluded from grazing, where different patches are not grazed for a different  
165 period of years, thereby protecting the habitat and the natural ecological succession and  
166 generating patches in different stages of succession (Gonçalves et al. 2011).

167

168 Sampling scheme

169 In order to compare between grazed and non-grazed locations, we have selected 15  
170 sampling sites in the study area: six with cattle presence (and therefore grazing), acting



171 as control sites, and nine excluded to cattle in different time periods: three since 1998,  
172 three since 2004 and three since 2008. These threshold dates correspond to years  
173 selected by the farm management to start the cattle exclusion for several patches (i.e. we  
174 could be sure that from that year forward no cattle entered those patches). Both grazed  
175 and non-grazed sites were sampled simultaneously, to avoid seasonal effects.

176 In each site we placed 25 Sherman traps (Folding Traps with Aluminum Treadle and  
177 Doors Galvanized; H.B. Sherman Traps, Inc.) with a dimension of 8x9x23 cm,  
178 displaced in a cross design and spaced  $\pm 10$  m between each other. Each trap was baited  
179 with a mixture of canned sardines and oat flakes, and included a piece of hydrophobic  
180 cotton for nesting. The traps were checked every morning (Gurnell and Flowerdew  
181 2006), and each site was sampled until at least 10 individuals were captured (i.e. traps  
182 were left active for periods of four nights - Monday-Friday - until 10 different animals  
183 in each specific site were captured). This sample size per site was defined *a priori*,  
184 based on the suggestions by Wilson et al. (2007) that stated that when testing difference  
185 between different groups (e.g. t-test, ANOVA) a minimum number of seven participants  
186 per groups should be considered. Furthermore, as we had a limited number of traps  
187 (100) we only manage to monitor four sites simultaneously (one of each type). Thus, to  
188 assure that we had samples from all the 15 sites, we need to move to another site as  
189 soon as 10 individuals were captured. The captured animals were individually marked  
190 (at the first capture) with a combination of fur cuts and the gender, age, as well as the  
191 metrics used for the estimating the body condition index - length (total and body  
192 length), and weight - were recorded.

193 The habitat was characterized in each of the 15 areas at two spatial scales: three meters  
194 around each trap for the microhabitat variables (Tew 2000) - percentage of vegetation  
195 cover and understory height (grasses and shrubs); and 50 meters around each of the trap

196 site for the macrohabitat variables - topography, habitat heterogeneity, understory  
197 density, and number of trees. In each trapping site, predation risk was also assessed,  
198 using the frequency of signs of presence of mammalian carnivores as a surrogate:  
199 footprints, and scats/latrines (carnivore species richness: level I – traces of one or two  
200 species; level II – traces of three species; level III – traces of more than three species).  
201 Signs (scats and footprints) were surveyed using line pedestrian transects (25cm each),  
202 implemented in the trapping sites, and monitored once a week during trapping sections  
203 The footprints and scats/latrines of the carnivores that may occur in the study sites (e.g.  
204 red fox, *Vulpes Vulpes*, European badgers, *Meles meles*, stone marten, *Martes foina*,  
205 polecat, *Mustela putorius*, weasel, *Mustela nivalis*, common genet, *Genetta genetta*, and  
206 Egyptian mongoose, *Herpestes ichneumon*; Gonçalves et al. 2011), were identified  
207 based on their morphological and scent characteristics (Sanz 1997).

208

209 Data analyses

210 The individual's physical condition of *Apodemus sylvaticus* was estimated using the  
211 Scaled Mass Index, SMI (Peig and Green 2009). For the index estimation both juveniles  
212 and lactating females were excluded, to avoid bias associated with weight variations due  
213 to physiological dependencies (growth and pregnancy). SMI standardizes body mass  
214 based on a linear body measurement estimated from the scaling relationship between  
215 mass and length (see Peig and Green 2009 for details). It is considered an accurate  
216 indicator of the animal's physical condition, because it is more highly correlated with  
217 fat, lean dry mass, and protein body contents in several vertebrates, including rodents,  
218 than other body condition indexes (Peig and Green 2009). Furthermore, although it  
219 accounts for differences between genders of a species accurately (Peig and Green 2010),  
220 genders were tested separately, to assess how different ecological strategies affect SMI.

221 To test the effect of time of grazing exclusion on body variation, we used an ANOVA,  
222 with the years of grazing exclusion as the independent variable (*posteriori* tests were  
223 conducted to assess possible differences between sites).

224 The candidate variables that may influence the Scale Mass Index were aggregated in  
225 three different groups (Table 1), according to their correspondent hypothesis: H1)  
226 microhabitat, which included variables related to the habitat structure; H2)  
227 macrohabitat, composed of the landscape variables and the number of years of grazing  
228 exclusion; and H3) intra and interspecific relationships, aggregating the predation risk  
229 level, the number of other *Apodemus sylvaticus* captured in the same trap, and the  
230 number of individuals from other small mammal species captured in that trap (Table 1).

231 The continuous variables from the three groups were tested for multicollinearity, based  
232 on the Variation Inflation Factor (VIF)(Zar 2010) estimated using the “fmsb” package  
233 in R-studio. All variables with a  $VIF > 5$  were excluded (see Zurr et al. 2007).

234 To test the influence of the remaining variables (Table 1) on the Scale Mass Index, we  
235 produced several Generalized Linear Mixed Models (GLMMs; Zuur et al. 2009), with a  
236 Gaussian distribution and considering the capture month as a random factor. We  
237 produced a set of models using separately the variables from each of the three groups  
238 (corresponding to the working hypothesis) as independent variables and the mice Scale  
239 Mass Index as the dependent variable. For each set, models produced corresponded to  
240 all possible variable combinations of the variables included in that group. All models  
241 produced for each hypothesis were ranked according to their AICc value (Akaike  
242 Information Criteria with a correction for small sample sizes) (Burnham and Anderson  
243 2002; Bolker et al. 2009). For each set of models, those with  $\Delta AICc < 2$  – i.e. the  
244 difference between the AICc of a model and the lowest AICc of any model in the same  
245 set - were considered best models (Burnham and Anderson 2002). When more than one

246 model reached a  $\Delta AICc < 2$ , we applied a model averaging procedure. Finally, the  
247 influence of the variables according to these best models was determined by the 95%  
248 confidence intervals (95%CI) of its coefficient. It was assumed to be positive or  
249 negative if the 95%CI included only positive or negative values, respectively. However,  
250 if the 95%CI of any variable include the 0, we assumed that we could not be sure of the  
251 direction of the variable influence. To identify non-informative parameters, we also  
252 estimated the relative variable importance (i.e. sum of the Akaike weights of all the  
253 models that contained that variable) (Arnold 2010).

254 To test the fourth hypothesis (i.e. SMI variation is influenced by factors associated with  
255 different types of drivers - microhabitat, macrohabitat and intra and interspecific  
256 relationships - and not only a single type of drivers), we applied the same approach as  
257 described before, but used as candidate variables those identified as influential variables  
258 for the previous three hypotheses. We also tested models including only the interaction  
259 between the variables that were identified as influential variables. Using this approach,  
260 the best supported hypothesis was that whose best models showed the lowest overall  
261 AICc value. Finally, we assessed the goodness-of-fit of fixed effects models using the  
262 “variance explained” ( $R^2$ ), using the approach suggested by Nakagawa and Schielzeth  
263 (2013), which includes two components: the marginal  $R^2$ , a surrogate of the variance  
264 explained by fixed factors, and the conditional  $R^2$  that represents the variance explained  
265 by fixed and random factors. To capture possible differences in the body condition  
266 driver’s effects between genders, we analyzed male and female data separately. All  
267 models were produced in R (R Core Team 2015), by applying the packages “lme4”  
268 (Bates et al. 2015) and “MuMIn” (Barton 2016).

269

270 Results

271 Overall results

272 In the 15 sampled sites, a total of 185 small mammals were captured: 10 *Mus spretus*,  
273 24 *Crocidura russula* and 151 *Apodemus sylvaticus* (83 males and 68 females; 143  
274 adults and four juveniles) For the wood mouse, 59 were captured in the control sites and  
275 92 in the non-grazed ones (30, 38 and 24 individuals in the non-grazed sites since 2004,  
276 2008 and 1998, respectively). The Scale Mass Index variation according to the capture  
277 site showed two distinct groups: the first one composed by the sites that were not grazed  
278 since 1998 and 2008, which had higher, but similar averages (26.76 and 26.51) of SMI  
279 values, with no significant differences between them ( $p>0.05$ ); and the second group  
280 that included sites excluded from grazing since 2004 and the ones grazed, also with  
281 similar SMI averages (22.51 and 22.79) and no significant differences between them  
282 ( $p>0.05$ ).

283

284 Drivers of females SMI variation

285 For the females, the microhabitat hypothesis was the one generating models with the  
286 lowest AICc (Table 2). From the first three hypothesis only two variables fulfilled the  
287 criteria to be included in the combined hypothesis (included in the best models of the  
288 first three hypothesis and whose 95%CI did not include the zero; Supplementary  
289 material 1) – shrub species and year. Nevertheless, the microhabitat hypothesis was the  
290 one with more support in explaining variations in body condition's, or SMI's. Only one  
291 model showed a  $\Delta AICc < 2$  (Table 2). This model included also just one variable: the  
292 shrub species. Consequently, only shrub species showed an influence over female's  
293 body conditions, with the *Cistus ladanifer*, *Cistus monspeliensis*, *Phillyrea angustifolia*  
294 and *Myrtus communis* having a negative influence on the SMI and the *Calluna vulgaris*  
295 having a positive influence on the SMI, when compared to *Ulex* sp. This best model

296 marginal and conditional  $R^2$  reached 10% and 48% of the SMI explained variance,  
297 respectively.

298

299 Drivers of males SMI variation

300 For males, the combined hypothesis was the one with the lowest AICc (Table 3), and  
301 therefore that showing a higher support in explaining SMI variation for this gender. To  
302 build this hypothesis we used the variables shrub species, understory density,  
303 percentage cover of fruit trees and of shrubs, which were those included in the best  
304 models of H1-H3 and whose 95%CI excluded the zero, as well as the interaction  
305 between them (Supplementary material 2). Similar to what was observed for females,  
306 only 1 model had the  $\Delta AICc < 2$  (table 3). This model was composed of only one  
307 variable: the interaction between the density of shrubs and the shrub species. (Table 4 &  
308 5). This interaction's variable highlights that dense and spaced shrubs have a positive  
309 influence on males on SMI, when compared to aggregated understory sites, especially if  
310 composed by particular shrub species: *Ulex* sp., *Cistus* spp. and *Myrtus communis*.  
311 (Table 5). The variance of the fixed factor explained by the best model reached 27.5%  
312 and accounted for 32,7 % of the fixed and random factor's variance of SMI variation.

313

314 Discussion

315 Some studies have highlighted that cattle grazing has a negative influence on wild  
316 populations and individuals, since it lowered the habitat conditions, especially the  
317 availability of food resources (Ascensão 2012; Fernandes et al. 2019). However,  
318 unexpectedly our results did not reveal a linear increase in the SMI with the years of  
319 grazing exclusion. This is most possibly because the increase in habitat complexity does  
320 not only depend on the cattle exclusion effect. However, the group sites were paired two

321 by two, with the sites isolated since 2008 and 1998 having similar average SMI and the  
322 same happening for the sites isolated from 2004 and the control ones. This pattern may  
323 suggest that the body conditions may have a cyclic variation (i.e. inter-year variation),  
324 possibly not depending on the exclusion period, as expected, but on, for example,  
325 climatic variations (e.g. inter-annual variation in rainfall). This is in line with other  
326 studies that proven that small mammals are affected by climatic variations, not only in  
327 their population dynamics and access to resources (Bergallo 1999; Lima 2002; Previtali  
328 2009), but also in their metabolic rates (Lovegrove 2003) and body size (Yom-Tov  
329 2006). Thus, implementing a medium-long term monitoring of this population's body  
330 condition would allow to gather data to test this hypothesis. Furthermore, other  
331 variables, like the pre 1998 habitat conditions and geological or soil variables can also  
332 be responsible for this result, but this cannot be confirmed since we do not have this  
333 data.

334 Focusing on resource availability effects, several previous studies showed that small  
335 mammals habitat selection depends mostly on food and shelter availability (Boitani  
336 1985; Khidas et al. 2002; Torre et al. 2002; Michel 2007; Traba et al. 2009; Tarjuelo et  
337 al. 2011). With this study we can now explain how these variables not only influence  
338 the individuals SMI, but also show different ecological strategies according to the  
339 gender.

340 Male *A. sylvaticus* typically exhibit territorial behavior, in which their habitat selection  
341 is based on female presence (Rosalino et al. 2011b). As such, males usually travel large  
342 distances daily, either for territorial marking or to search for female (Wolton 1985;  
343 Rosalino 2011b). Associated with the movements is a larger predation risk (Longland  
344 and Jenkins 1987), as the individuals are more easily detected while moving, especially  
345 if they are exposed (Longland and Price 1991; Jedrzejewska and Jedrzejewski 1990).

346 Thus, the male's habitat should be understood as a multi-level area (both macro and  
347 microhabitat). Our results seem to corroborate this view, as suggested by the relevance  
348 of our combined hypothesis, which is the best in explaining the male's SMI variation.  
349 Higher vegetation or shrub density can provide more/better shelter for males while  
350 moving around their territory, possibly leading to lower predatory stress levels and  
351 vigilance behaviors (Longland and Price 1991, Rodrigo et al. 2002). The saved energy  
352 might be allocated to enhancing the animal's body condition which may result in the  
353 detected patterns, since our results showed a positive influence of vegetation density  
354 and a negative influence of the absence of shrubs on the SMI. The fact that sites with  
355 sparse undercover also had a positive influence on the SMI can be explained by the fact  
356 that these sites have an understory more or less uniformly distributed but reaching lower  
357 densities. This situation seems to be a better situation for maintaining wood mouse body  
358 condition that sites where understory is aggregated in patches, with the remaining area  
359 without any cover. In such situations animals that need to cross between aggregated  
360 patches are more exposed to predation than those moving around within sparse, but  
361 uniform, understory. The resulted increased predatory pressure or stress from inferred  
362 risk of predation may negatively impact animals living in such sites, resulting in a  
363 decline in body condition. The associated positive effect of *Ulex* sp., *Cistus* spp. and  
364 *Myrtus communis* on the males SMI, is probably associated with these shrubs structure. *Ulex*  
365 sp. are spine species (Clements et al. 2001) that form dense patches which make  
366 difficult for carnivores to cross (and therefore search and prey wood mice), reducing the  
367 predation pressure and, consequently enhancing SMI. Simultaneously, *Cistus* spp. and  
368 *Myrtus communis* form dense patches (Malo and Suarez 1998) that also seem to  
369 increase the protective cover that reduce rodents detectability by predators, and thus  
370 may lead to higher SMI..



371 For the females, the macrohabitat does not seem to be as important as for the males,  
372 since they tend to have smaller home-ranges (Rosalino et al. 2011a) and a higher nest  
373 fidelity (Rosalino et al. 2011a). Due to this spatial pattern, to their annual energetic  
374 budget, which varied between non-breeding and breeding phases (where lactating  
375 females may increase energy intake by 45%; Degen et al. 2002), and to the fact that  
376 food intake scale determines their reproductive activities and success (Bergallo and  
377 Magnusson 1999), the food availability closer to the burrows becomes extremely  
378 important, not only for their own nutrition, but also to sustain the cubs nursing  
379 (Gittleman 1998). Therefore, the shrub species located near the burrow becomes  
380 relevant, since some species can provide good food resources, like seeds and fruits.  
381 Nevertheless, some of these species can also be a food source for mesocarnivores with  
382 more omnivorous diets, like the genet, *Genetta genetta*, the red fox *Vulpes vulpes* and  
383 Egyptian mongoose *Herpestes ichneumon* (Rosalino and Santos-Reis 2009, Rosalino et  
384 al. 2010). If so, the presence of these shrubs can influence negatively *A. sylvaticus* SMI,  
385 since it increases the predatory risk by luring more predators near the female's burrows  
386 which can explain our results, that showed a negative influence of the fruit producing  
387 species (*Cistus ladanifer*, *Cistus monspeliensis*, *Myrtus communis* and *Phillyrea*  
388 *angustifolia*) on the females SMI when compared to a non-fruit producer shrub species,  
389 *Ulex* sp.. The positive influence of *Calluna vulgaris*, that was proven to be a food  
390 resource for *A. sylvaticus* (Butet 1985), can be explained by the fact that this shrub is  
391 too dense for carnivores to enter and successfully capture prey, since denser shrubs  
392 provide high quality shelters and difficult prey detection and capturing (Torre and Díaz  
393 2004), therefore providing a good site for the female's burrows. In conclusion, this  
394 study highlights that shelter and food availability are important drivers of *Apodemus*  
395 *sylvaticus* SMI, although with different relevance depending of the individual's gender,

396 a pattern probably linked to differences in ecological strategies of both groups. Grazed  
397 sites often show low shelter and food availability (Torre et al. 2007), and therefore cattle  
398 grazing can have an indirect negative influence on rodent's body condition, even if we  
399 were unable to detect an influential direct effect of this driver. Therefore, implementing  
400 landscape management that allows the coexistence of habitats with distinct structures,  
401 subject to different land uses, but providing varied types of resources (e.g. food, refuge).  
402 is crucial to maintain a healthy wildlife community. This is especially true for the  
403 *montado* system, characterized by a fragile balance between nature and human  
404 activities, in which external/stochastic pressures may lead to the decline of certain  
405 species of flora or fauna, or even, in an extreme situation, the local extinction of less  
406 resilient ones.

407

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417

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654

655 Table 1 – Candidate variables used in the modeling procedures to assess the factors  
 656 influencing the Scale Mass Index variation in *Apodemus sylvaticus*. Variables are  
 657 grouped *per* hypothesis.

Hypothesis	Code	Variable description	Type
<i>Microhabitat</i>	Shrub_c	Percentage cover of shrubs (3 m radius)	Continuous
	Fruit_c	Percentage cover of fruit trees (3 m radius)	Continuous
	Oak_c	Percentage cover of cork oak trees (3 m radius)	Continuous
	Grass_c	Percentage cover of grasses (3 m radius)	Continuous
	LitterLayer_c	Percentage cover of the litter layer (3 m radius)	Continuous
	Shrub	Most frequent shrub specie (3 m radius): <i>Myrtus communis</i> , <i>Ulex</i> sp., <i>Cistus monspeliensis</i> , <i>Cistus ladanifer</i> , <i>Phillyrea angustifolia</i> , <i>Calluna vulgaris</i> , <i>Lavandula pedunculata</i> , <i>Cirsium vulgare</i> or no shrub	Factor (9 classes)
	Shrub_h	Average height of the most frequent shrub specie	Continuous
	Grass_h	Average height of grasses	Continuous
	<i>Macrohabitat</i>	Und_den	Understory density (50 m radius) (dense understory, sparse understory, aggregate understory)
Heterogeneity		Degree of landscape heterogeneity (50 m radius) (from homogeneous to heterogeneous)	Factor (3 classes)
Topography		Topography of the landscape (plain, hill, valley, slope)	Factor (4 classes)

<i>Relations</i>	Oak_n	Number of cork oak trees (50m radius)	Continuous
	Pine_n	Number of pine trees (50 m radius)	Continuous
	Years	Number of exclusion years (0, 10, 14, 20)	Factor (4 classes)
	Other_sps	Number of individuals from other species captured on the trap	Continuous
	Pred_risk	Predation risk of the site (I – traces of 1 or 2 species; II – traces of 3 species; III – traces of more than 3 species)	Factor (3 classes)
	Other_ind	Number of other <i>Apodemus sylvaticus</i> captured on the trap	Continuous

658

659

660 Table 2 - Generalized linear mixed models produced to test which hypothesis had more  
661 support in explaining the variation in the Scale Mass Index among females. "DF" -  
662 degrees of freedom, "LogLik" - logarithm likelihood of the model, "AICc" - Akaike  
663 Information Criteria for small samples, " $\Delta$ AICc" - difference between the model's AICc  
664 and the lowest AICc for the hypothesis, "W" - model's weight, "Global  $\Delta$ AICc" -  
665 difference between the model's AICc and the lowest from all hypothesis. "1" - this  
666 model has the same AICc as the best model as well as the same variables, therefore we  
667 considered it a replica of the microhabitat one. \*Model including only the interaction  
668 between variables identified as influential in previous hypothesis (i.e. CI95% does not  
669 include the zero).

Females	DF	LogLik	AICc	$\Delta$ AICc	W	Global $\Delta$ AICc
<u>H1 - Microhabitat</u>						
<i>Shrub</i>	9	-167.785	356.8	0.00	0.636	0
<i>Shrub + Fruit_c</i>	10	-167.460	359.0	2.15	0.217	2.2
<i>Shrub + Shrub_c</i>	10	-169.702	363.5	6.63	0.023	6.7
<i>Shrub + Oak_c</i>	10	-169.746	363.6	6.72	0.022	6.8
<i>Shrub + Grass_c</i>	10	-169.951	364.0	7.13	0.018	7.3
<u>H2 - Macrohabitat</u>						
<i>Und_den + Heterogeneity + Topography</i>	9	-169.705	360.7	0.00	0.271	5.3
<i>Heterogeneity + Topography</i>	7	-172.370	360.7	0.02	0.269	5.3
<i>Und_den + Heterogeneity + Topography + Years</i>	10	-168.590	361.3	0.57	0.204	5.9
<i>Und_den + Topography</i>	7	-174.111	364.2	3.50	0.047	8.8
<i>Und_den + Topography + Years</i>	8	-172.867	364.3	3.62	0.044	8.9
<u>H3 - Intra and interspecific relations</u>						
<i>Other_sps + Pred_risk</i>	6	-177.945	369.3	0.00	0.283	13.9
<i>Other_sps</i>	4	-180.572	369.8	0.47	0.223	14.4
<i>Other_sps + Pred_risk + Other_ind</i>	7	-177.141	370.2	0.91	0.180	14.8
<i>Other_sps + Other_ind</i>	5	-179.838	370.7	1.35	0.144	15.3
<i>Pred_risk</i>	5	-180.737	372.5	3.15	0.058	17.1
<u>H4 - Combined hypothesis</u>						
<i>Shrub</i>	9	-167.785	356.8	0.00	0.895	0 <sup>1</sup>
<i>Shrub + Years</i>	10	-168.020	360.1	3.27	0.103	3.3
<i>Null model</i>	3	-183.364	373.1	16.28	0.000	16.3



<i>Years</i>	4	-184.640	377.9	21.10	0.000	21.1
<i>Shrub:Years*</i>	10	-184.527	393.1	36.33	0.000	36.3

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672 Table 3 – Variables present in best model for the females SMI variation. “Coefficient” –  
 673 Variable, “SE” – standard error of the coefficient, “t-value” - Wald statistic to test the  
 674 hypothesis of the coefficient being 0 , Pr(>|t|) – p-value, “CI” – confidence intervals; In  
 675 grey variables whose CI (95%) does not includes the zero.

<i>Variable</i>	<i>Coefficient</i>	<i>SE</i>	<i>t-value</i>	<i>Pr(&gt; t )</i>	<i>CI (95%)</i>	<i>Relative importance</i>
<i>Calluna vulgaris</i>	7.029	3.879	1.812	0.076	6.868 10.270	0.997
<i>Cistus ladanifer</i>	-3.848	4.092	-0.940	0.351	-3.909 -1.469	0.997
<i>Cistus monspeliensis</i>	-1.379	2.242	-0.615	0.541	-1.702 -0.614	0.997
<i>Lavandula pedunculata</i>	2.141	3.816	0.561	0.577	-5.234 9.303	0.997
<i>Myrtus communis</i>	-1.960	1.281	-1.530	0.132	-2.132 -1.516	0.997
<i>Phillyrea angustifolia</i>	-2.323	1.568	-1.481	0.145	-2.535 -1.752	0.997

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678 Table 4 - Generalized linear mixed models produced to test which hypothesis had more  
679 support in explaining the variation in the Scale Mass Index among males. "DF" -  
680 degrees of freedom, "LogLik" - logarithm likelihood of the model, "AICc" - Akaike  
681 Information Criteria for small samples, " $\Delta$ AICc" - difference between the model's AICc  
682 and the lowest AICc for the hypothesis, "W" - model's weight, "Global  $\Delta$ AICc" -  
683 difference between the model's AICc and the lowest from all hypothesis. \*Model  
684 including only the interaction between variables identified as influential in previous  
685 hypothesis (i.e. CI95% does not include the zero).

males	DF	LogLik	AICc	$\Delta$ AICc	W	Global $\Delta$ AICc
<u>H1 - Microhabitat</u>						
<i>Shrub + Shrub_c + Fruit_c</i>	11	-227.560	480.9	0.00	0.481	21.1
<i>Shrub + Shrub_c</i>	10	-230.074	483.2	2.36	0.148	23.5
<i>Shrub</i>	9	-231.462	483.4	2.53	0.136	23.7
<i>Shrub + Fruit_c</i>	10	-230.937	485.0	4.08	0.063	25.3
<i>Shrub + LitterLayer_c</i>	10	-232.073	487.2	6.35	0.020	25.5
<u>H2 - Macrohabitat</u>						
<i>Und_den + Heterogeneity + Topography</i>	10	-228.206	479.5	0.00	0.698	18.8
<i>Und_den + Topography</i>	8	-232.810	483.6	4.08	0.091	23.9
<i>Und_den + Heterogeneity + Topography + Years</i>	11	-229.347	484.5	4.95	0.059	24.8
<i>Und_den + Heterogeneity + Topography + Oak_n</i>	11	-229.729	485.2	5.72	0.040	25.5
<i>Und_den + Heterogeneity + Topography + Pine_n</i>	11	-230.187	486.1	6.64	0.025	26.4
<u>H3 - Intra and interspecific relations</u>						
<i>Other_sps + Pred_risk</i>	6	-241.547	496.2	0.00	0.384	36.5
<i>Other_sps + Pred_risk + Other_ind</i>	7	-240.803	497.1	0.91	0.244	37.4
<i>Pred_risk</i>	5	-243.692	498.2	1.96	0.144	38.5
<i>Pred_risk + Other_ind</i>	6	-242.893	498.9	2.69	0.100	39.2
<i>Other_sps</i>	4	-245.712	499.9	3.73	0.059	40.2
<u>H4 - Combined hypothesis</u>						
<i>Shrub : Und_den *</i>	15	-211.207	459.7	0.00	0.955	0.0
<i>Shrub : Heterogeneity *</i>	13	-217.407	466.2	6,52	0.037	6.5
<i>Shrub + Und_den + Heterogeneity</i>	13	-219.452	470.3	10,62	0.005	10.6
<i>Shrub + Und_den + Heterogeneity + Fruit_c</i>	14	-218.707	471.7	12.02	0.002	12.0
<i>Shrub + Und_den + Heterogeneity + Fruit_c + Shrub_c</i>	15	-218.644	474.6	14.92	0.001	14.9

<i>Shrub + Und_den</i>	11	-224.536	474.8	15,12	0.000	15.1
<i>Heterogeneity : Und_den</i>	8	-233.245	484.5	24.82	0.000	24.8
<i>Shrub + Und_den + Heterogeneity + Shrub_c</i>	14	-220.882	486.0	26.32	0.000	26.3
<i>Fruit_c : Heterogeneity *</i>	5	-245.368	501.5	41.82	0.000	41.8
<i>Fruit_c : Und_den *</i>	4	-247.666	503.9	44.22	0.000	44.2
<i>Fruit_c : Shrub *</i>	6	-247.337	507.8	48,12	0.000	48.1
<i>Shrub_c : Fruit_c *</i>	4	-251.123	510.8	51.12	0.000	51.1
<i>Shrub_c : Und_den *</i>	6	-249.068	511.3	51.62	0.000	51.6
<i>Shrub_c : Heterogeneity *</i>	6	-249.192	511.5	51.82	0.000	51.8
<i>Shrub_c : Shrub *</i>	10	-251.440	526.0	66.32	0.000	66.3

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687 Table 5 - Variables present in best model for the males SMI variation. “Coefficient” –  
688 Variable, “SE” – standard error of the coefficient, “t-value” - Wald statistic to test the  
689 hypothesis of the coefficient being 0 , Pr(>|t|) – p-value, “CI” – confidence intervals. ;  
690 In grey variables whose CI (95%) does not includes the zero.

Variable	Coefficient	SE	t-value	Pr(> t )	CI (95 %)		Relative importance
Intercept	19.016	2.691	7.067	<0.001	13.358	23.879	0.955
Shrub ( <i>Ulex</i> sp.) : Und_den (aggregate)	2.873	3.153	0.911	0.365	-2.881	9.792	0.955
Shrub ( <i>Phillyrea angustifolia</i> ) : Und_den (aggregate)	1.127	5.176	0.218	0.828	-8.492	10.579	0.955
Shrub ( <i>Ulex</i> sp.) : Und_den (dense)	8.203	2.871	2.857	0.006	3.004	14.394	0.955
Shrub ( <i>Cistus monspeliensis</i> ) : Und_den (dense)	15.180	5.336	2.845	0.006	5.652	25.344	0.955
Shrub ( <i>Phillyrea angustifolia</i> ) : Und_den (dense)	13.704	4.194	3.268	0.002	6.219	22.151	0.955
Shrub ( <i>Myrtus communis</i> ) : Und_den (dense)	6.716	3.013	2.229	0.029	1.225	13.346	0.955
Shrub ( <i>Cistus ladanifer</i> ) : Und_den (dense)	7.986	3.167	2.522	0.140	2.326	14.473	0.955
Shrub ( <i>Ulex</i> sp.) : Und_den (spaced)	7.409	2.817	2.631	0.011	2.384	12.995	0.955
Shrub ( <i>Cirsium vulgare</i> ) : Und_den (spaced)	9.510	5.336	1.782	0.079	-0.018	19.674	0.955
Shrub ( <i>Cistus monspeliensis</i> ) : Und_den (spaced)	12.243	3.895	3.143	0.003	5.286	19.663	0.955
Shrub ( <i>Phillyrea angustifolia</i> ) : Und_den (spaced)	0.505	5.304	0.095	0.924	-9.048	11.743	0.955
Shrub ( <i>Myrtus communis</i> ) : Und_den (spaced)	8.975	3.340	2.687	0.009	2.964	16.138	0.955

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