

SMALL SCALE FACTORS AFFECT POPULATION SIZE OF THE WOOD MOUSE
(*APODEMUS SYLVATICUS*) IN A MEDITERRANEAN ISLAND (SARDINIA)Giovanni AMORI^{1*}, Luca LUISELLI², Giuliano MILANA¹ & Paolo CASULA³¹ CNR – Istituto per lo studio degli ecosistemi, Roma² Centre of Environmental Studies Demetra, Eni s.p.a. Environmental Department, Rome, Italy; and Niger Delta Ecology and Biodiversity Conservation Unit, Department of Applied and Environmental Biology, Rivers State University of Science and Technology, PMB 5080, Port Harcourt, Rivers State, Nigeria³ Ente Foreste Sardegna, Servizio Tecnico, Cagliari

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RÉSUMÉ.— *Les facteurs à petite échelle affectent la taille des populations du Mulot (Apodemus sylvaticus) dans une île méditerranéenne (Sardaigne).*— La variation de la taille des populations de Mulot (*Apodemus sylvaticus*) a été étudiée le long de 30 transects indépendants sur l'île de Sardaigne (Italie), avec un accent mis sur la relation entre la taille de la population et les variables environnementales (type de boisement, épaisseur de la litière, diversité et taille des arbres, nombre de souches, couverture du sol, couverture buissonnante, bois mort). Les études ont été conduites selon un protocole de capture-marquage-recapture à l'aide de pièges placés le long des transects et surveillés au printemps et en automne. Sept variables environnementales ont été confrontées aux estimations de taille de population sur chaque transect, estimations obtenues à partir de cinq modèles démographiques distincts pour populations fermées. Des différences inter-saisonnnières significatives ont été observées dans le nombre de spécimens capturés (pic au printemps) mais, en dépit de variations considérables selon les transects, la taille des populations de Mulot ne différait pas de manière significative entre les types d'habitats forestiers. La taille des populations de l'espèce est apparue positivement influencée par (i) la couverture au sol, (ii) le nombre de souches, et (iii) le % d'*Erica arborea*; à l'inverse elle est apparue négativement influencée par (a) la hauteur des buissons de *Rubus ulmifolius* et (b) par le % de *Rubus ulmifolius*. Les raisons de ces patterns sont envisagées et discutées.

SUMMARY.— The variation of population size of the Wood Mouse (*Apodemus sylvaticus*) was studied across 30 independent transects in Sardinia island (Italy), with emphasis on the relationships between population size and environmental variables (type of wood, litter depth, tree diversity, tree size, number of stumps, ground cover, shrub cover, dead wood). Studies were conducted through a capture-mark-recapture protocol with live traps placed along line transects, and surveyed in both spring and autumn. Seven environmental variables were contrasted to population size estimates in each transect, with estimates of population size being obtained from five distinct demography models for close populations. There were significant inter-seasonal differences in the number of captured specimens (peak in springtime), but the population size of the Wood Mouse, despite varying considerably by transect, did not differ significantly among types of forest habitats. Population size of this species was positively influenced by (i) ground cover, (ii) number of stumps, and (iii) % *Erica arborea*; conversely, it was negatively influenced by (a) height of *Rubus ulmifolius* bushes and (b) by % *Rubus ulmifolius*. The possible reasons behind these patterns were explored and discussed.

The ecological distribution and the relative abundance of small mammals are relevant factors in shaping ecosystem structure and functioning (Rosalino *et al.*, 2011). Despite the abundance of rodent populations is well known in several ecosystems of temperate regions (e.g., Capizzi & Santini, 1997; Amori *et al.*, 2008), there are relatively few studies on the relationships between population size and environmental variables of free-ranging rodent species (e.g., Hansson, 1978; Mazurkiewicz, 1994; Dickman, 1999; Carey & Harrington, 2001; Pearce & Venier, 2005), especially in Mediterranean habitats (e.g., Capizzi & Luiselli, 1996). Indeed, in Italy, all the studies concerning the Mediterranean rodent populations have been carried out in mainland Italy and in Sicily (e.g., Sarà & Casamento, 1993; Capizzi & Luiselli, 1996; Amori *et al.*, 2008), whereas no study has ever been performed in Sardinia. This is surprising because the large size of

this latter island may have provided many good environments where to analyse aspects of field ecology of the rodent species. Consequently, rodent diversity and relative abundance are poorly known in Sardinian forest ecosystems, and fundamentally no knowledge is available on habitat requirements of local rodent populations.

The Wood Mouse *Apodemus sylvaticus* is widespread across a range of Sardinian forest types (Amori *et al.*, 2008). However, nothing is known on the variation of its abundance in relation to the various types of island vegetation. To understand determinants of Wood Mouse local abundance, we thus analysed the variation of population size across a relatively large number of independent transects carried out in several areas of Sardinia, with emphasis on the relationships between population size and some environmental variables that were *a priori* considered of some importance for rodent ecology, such as type of wood, litter depth, tree diversity, tree size, number of stumps, ground cover, shrub cover, and dead wood (Hansson, 1978; Gurnell, 1985; Montgomery & Dowie, 1993; Fitzgibbon, 1997; Tattersall *et al.*, 2001).

More specifically, we test the following hypotheses:

(1) Considering that the various forest types can differ remarkably in terms of productivity (Scarascia-Mugnozza *et al.*, 2000), is the abundance of wood mice also remarkably variable across the various forests?

(2) Considering that rodents typically respond to micro-scale ecological conditions (Panteleyev, 1998), what are the small-scale habitat variables that affect the local abundance of the wood mice in Sardinia?

MATERIALS AND METHODS

STUDY AREA

The field study was carried out in 10 distinct areas of Sardinia (Fig. 1), during two survey sessions: one in May-June 2012 and one in October 2012. All selected study sites were located within regional government property forests, under public management by the Ente Foreste della Sardegna. They were also all within mountainous areas and with altitude ranging from 625 to 1182 m. Wood mice were known to occur across the whole altitudinal range of our study areas in Sardinia (Amori *et al.*, 2008). The various study areas covered a wide variety of forest habitat types available to small mammals in Sardinia: (i) pinewood (*Pinus* spp.; n = 8 transects); (ii) *Quercus ilex* forests (n = 13); (iii) *Quercus suber* forests (n = 5); and (iv) *Castanea sativa* forests (n = 4). Thirty distinct transects were surveyed in total (three for each study area; Fig. 1).

SMALL MAMMAL SAMPLING

The field study consisted of live trapping with traps aligned along line transects, using Sherman, Ugglan and Longworth traps (Gurnell & Flowerdew, 1990). We used three trap types to maximize probability success of capturing mice, because we were unsure on whether one of the trap types performed better in the island habitats. Each line transect consisted of an alignment of 10 trap stations, each one with two traps. Hence, each transect consisted of 20 live traps spaced 10 m apart. In each trapping station, there was a Sherman or Ugglan trap and a Longworth trap; hence, the number of used Longworth was double to that of the other two types of trap. All traps were baited with chocolate cream and corn cereals. In total, 600 traps were used for each of the two surveys in spring and autumn.

Once captured, the individuals were sexed and marked by a hear target (Le Boulengé-Nguyen & Le Boulengé, 1986), and then released. Each trapping session consisted of 5 night trappings in spring and 5 night trappings in autumn.

ENVIRONMENTAL VARIABLES

The population size of the study species was explored in relation to a suite of environmental variables that were *a priori* considered of some importance for rodent ecology, as described below. We were forced to use some environmental variables that were of general importance for rodents instead of using specific variables of interest for the Wood Mouse because of the lack of scientific data concerning the ecological requirements of the study species in Sardinia. All environmental variables refer to small scale site features and, apart from variable (a) that refers to the main wood type present over the transect, they were all measured in 5 squares of 5 x 5 m randomly placed within a rectangle of 120 x 20 m surrounding the line transects with live traps aligned.

The variables that were used for the analysis were the following:

a) *habitat type (= type of wood)*. This variable was chosen because it is well known that various types of Mediterranean forest communities generally support rather different species, some of which are even exclusive to a certain type of forest

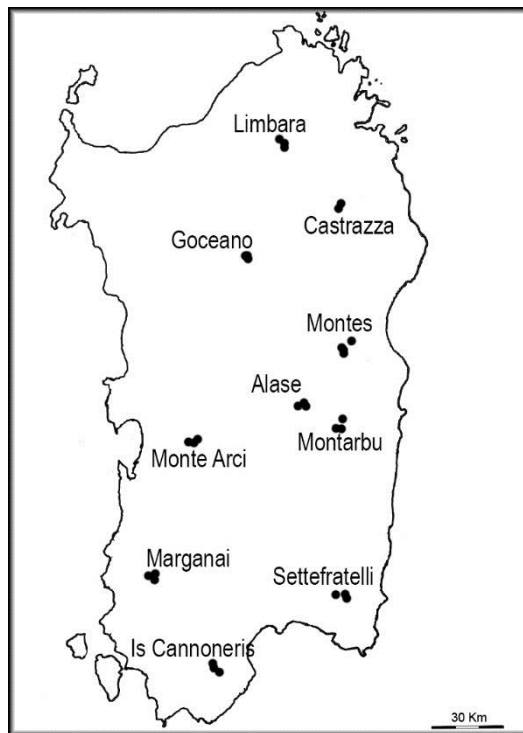


Figure 1.— Map of Sardinia, showing the 10 study areas and the 30 transects.

(Blasi *et al.*, 2005). The types of wood are as follows: (i) plantations of conifers (both young and mature), (ii) natural woodland of holm oak, downy oak and cork oak (managed and unmanaged), (iii) chestnut.

b) *density of trees*. This variable is well known to affect populations of forest rodents. For example, low density of trees following excessive coppicing may be disadvantageous to the persistence of populations of dormice (*Glis glis* and *Eliomys quercinus*) in central Italy (Capizzi & Santini, 2007).

c) *litter depth (cm)*. This variable may influence activities of feeding nesting and breeding of rodents (Bowman *et al.*, 2000; Carey & Harrington, 2001). We evaluate the variability of the litter depth over the 5 squares mentioned above.

d) *tree diversity*. For the same reasons given for the variable (a), it is believed that this variable is important for the populations of forest rodents. In general, tree diversity may result in diverse food resources through time, with possible positive effects on mice populations. For each transect, we calculated the Shannon diversity index on the count of the different species of trees.

e) *tree size*. This variable was showed to have a very clear role in the distribution of ecological forest rodents in peninsular Italy, with certain species with high environmental requirements (*Glis glis*) whose presence is linked to the presence of very large trees (Capizzi *et al.*, 2003). Tree size was measured as the diameter of each trunk at breast height.

f) *number of stumps*. The presence of stumps could positively affect populations of forest rodents by providing nest sites resistant to disturbance. In fact, these animals often build their nests at the foot of these structures (G. Amori *et al.*, unpublished data).

g) *ground cover* (bare ground, litter, grass, mosses, slashings and rocks), measured as % coverage by visual estimation. In the cover "rocks" were considered rocky outcrops and boulders resting on the ground. Such structures can promote the establishment of small mammals by providing nest sites resistant to disturbance.

h) *shrub cover*. Understorey vegetation has been shown to affect Wood Mouse populations in other studies (Marsh & Harris, 2000; Rosalino *et al.*, 2011) and was measured here as % of ground covered by shrubs, with the following categories: a) absent, b) covering up to 30 %, and c) more than 30 %.

i) *dead wood*. Logs (dead wood on the ground) and snags (standing dead trees) may positively affect Wood Mouse densities (Marsh & Harris, 2000). We measured the number of logs, as well as the length and diameter of all logs found with a portion inside the sampling units (5x5 m squares). Regarding snags, they were considered if sought within a radius of about 15 meters around the sampling unit, and height and diameter were measured.

STATISTICAL ANALYSES

Since we did not recapture any individual across distinct (spring and autumn) surveys but many individuals were recaptured within each survey (i.e. across the five trapping nights), to estimate population sizes at each transect we used closed capture-recapture models (Nichols, 1992). For all transects, we applied the following models: (i) Equal catchability (M_0 ; Pollock *et al.*, 1990); (ii) Schnabel-Petersen (S-P, Krebs, 1999); (iii) Chao's model with capture probability varying individually (M_{hi} ; Chao, 1988); (iv) Chao's model with capture probability varying with time (M_{ti} ; Chao, 1988); and (v) Chao's model with capture probability varying with both individuals and time (M_{th} , Chao *et al.*, 1992). Confidence intervals of the estimates of population sizes were obtained for the five demographic models cited above.

In some transects (i.e. all transects at Is Cannoneris, Crastazza, and Settefratelli study areas) we did not recapture any individual. Hence, population sizes of wood mice were not estimated in these transects by capture-recapture models. In these cases, instead, the number of individuals counted was used as best estimate of population size for the analysis of the relationships between population size and environmental variables.

Differences in catchability across individuals were analysed by a Poisson 'zero-truncated' test, and the differences in catchability between temporal surveys (spring versus autumn) were analysed by a Leslie's equal catchability test, using the software Simply Tagging (version 1.31; Henderson & Seaby, 2002). When in a given transect population size differed remarkably (i.e. when the various estimates differed for more than 10 % in terms of generated population sizes), depending on the various demographic models, we used the most reliable model as selected by the software CAPTURE (White *et al.*, 1982) according to a 'model selection' algorithm (Otis *et al.*, 1978).

Observed-versus-expected chi square tests were used to analyse the inter-seasonal differences in the number of captured rodents in each transect and study area. A one-way ANOVA was performed in order to analyse the differences in terms of number of individuals captured by habitat type (wood type), with 4 transects belonging to the category chestnut wood, 13 to ilex grove, 8 to pinewood, and 5 in *Quercus suber* forests.

Data relative to spring surveys were statistically analysed distinct from data coming from autumn surveys. Alpha was set at 5 %, and all performed tests were two-tailed.

RESULTS

GENERAL CONSIDERATIONS

Over a total of 6000 trap nights, we captured 127 different specimens of *Apodemus sylvaticus*, with 85 recaptures. There were no statistically significant differences in terms of number of captured specimens by trap type once the different number of traps of the various types was taken into account (χ^2 test, $df = 2$, $P > 0.135$) (Fig. 2). There were significant inter-seasonal differences in terms of number of captured specimens ($\chi^2 = 30.3$, $df = 1$, $P < 0.0001$), with 60.6 % of the individuals captured during the springtime. The distribution of the number of captured specimens by transect and by study area, during both spring and autumn, is given in Table I. There were no significant differences among wood types in terms of number of captured individuals per transect (one-way ANOVA: $F_{3,26} = 0.911$, $P = 0.449$).

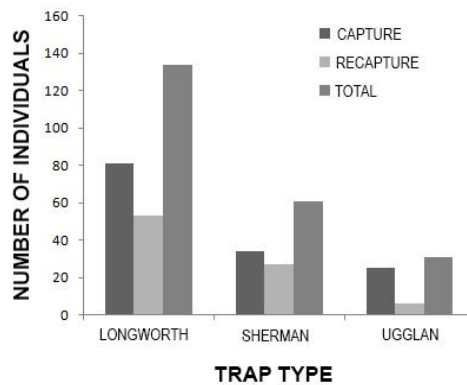


Figure 2.— Numbers of mice captured by trap type as recorded during the present study.

TABLE I

Distribution of the number of captured Apodemus sylvaticus specimens by transect and by study area (Regional government property forests), during both spring and autumn. Recaptures are not included in this table.

Study area	Transect	Spring captures	Autumn captures
Montes	MO1	0	1
	MO2	2	0
	MO4	12	0
Alase	AL1	4	0
	AL2	2	0
	AL3	6	3
Montarbu	MA1	2	0
	MA2	9	4
	MA3	3	0
	MA4	11	0
Monte Arci	AR1	1	13
	AR2	1	13
	AR4	2	6
Marganai	MG1	0	2
	MG2	0	2
	MG3	0	3
Limbara	LI1	2	0
	LI2	0	0
	LI3	1	4
Monte Pisano	GO1	0	0
	GO2	1	0
	GO3	3	0
Castrazza	TE1	0	0
	TE2	0	0
Is Cannoneris	IC1	0	0
	IC2	0	0
	IC3	8	2
Settefratelli	SF1	2	1
	SF2	4	0
	SF3	0	0

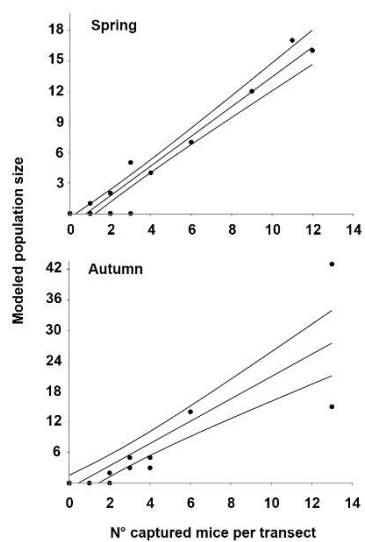


Figure 3.— Relationships (with 95 % confidence intervals) between used simple indices of relative abundance (number of individuals per sampling effort per line) and modelled population sizes. For statistical details, see the text.

TABLE II

Spring estimates of population size by transect, according to the five demographic models used in the text. Standard error of the estimate is presented in parenthesis. Abbreviations for the demographic models: Equal catchability = M_o ; Schnabel-Petersen = S-P; Chao's model with capture probability varying individually = M_h ; Chao's model with capture probability varying with time = M_t ; Chao's model with capture probability varying with both individuals and time = M_{th} .

Study area	Transect	M_o	S-P	M_h	M_t	M_{th}
Montes	MO1	0	0	0	0	0
	MO2	2 (0.277)	2 (0.277)	2 (0)	2 (0)	2 (0.525)
	MO4	10 (1.213)	10 (0.343)	16 (7.552)	14 (3.772)	11 (0)
Alase	AL1	4 (0.392)	4 (0.392)	4 (1.323)	4 (1.323)	4 (0)
	AL2	0	0	0	0	0
	AL3	7 (0)	7 (0.004)	7 (0.535)	7 (0.462)	7 (0)
Montarbu	MA1	0	0	0	0	0
	MA2	11 (1.738)	10 (0.551)	12 (2.646)	11 (1.569)	11 (1.704)
	MA3	4 (1.983)	4 (1.983)	5 (3.742)	3 (0.816)	3 (5.468)
	MA4*	13 (2.622)	13 (1.679)	17 (6.481)	15 (3.512)	12 (2.025)
Monte Arci	AR1	0	0	0	0	0
	AR2	0	0	0	0	0
	AR4	2 (0.484)	2 (0)	2 (0)	2 (0)	2 (0)
Marganai	MG1	0	0	0	0	0
	MG2	0	0	0	0	0
	MG3	1 (0.342)	1 (0)	1 (0)	1 (0)	1 (0.0001)
Limbara	LI1	0	0	0	0	0
	LI2	0	0	0	0	0
	LI3	0	0	0	0	0
Goceano	GO1	0	0	0	0	0
	GO2	0	0	0	0	0
	GO3	3 (0.856)	3 (0.856)	3 (0)	3 (0)	4 (7.949)

*denotes that software CAPTURE was used to select the best model.

Despite intensive trapping, only 3 specimens of non-target species were captured (2 *Rattus rattus* and 1 *Crocidura pachyura*).

POPULATION SIZE BY STUDY AREA

There were significantly positive relationships between used simple indices of relative abundance (number of individuals per sampling effort per line) and modelled population sizes at each transect (spring: $r^2 = 0.939$, $P < 0.0001$; autumn: $r^2 = 0.769$, $P < 0.0001$; Fig. 3).

The summary of the estimates of population size by transect, and according to the five demographic models, is presented in Tables II (spring) and III (autumn). Overall, the transects showing the highest population sizes were situated in the study areas of Montes (MO4) and Marganai (MA2, MA4) during spring (Tab. II), and of Monte Arci (AR1, AR2, AR4) during autumn (Tab. III).

Modelled population sizes were not influenced significantly by the elevation of the study site (Pearson's $r = -0.205$, $P > 0.05$).

RELATIONSHIPS BETWEEN POPULATION SIZE AND ENVIRONMENTAL VARIABLES

Concerning the variables regarding the amount of dead wood on the ground (number of logs, diameter, and length), these were statistically inter-correlated (Pearson's correlation coefficient; multiple $r = 0.893$, $F = 153.15$, $P < 0.000001$).

TABLE III

Autumn estimates of population size by transect, according to the five demographic models used in the text. Standard error of the estimate is presented in parenthesis. Abbreviations for the demographic models: Equal catchability = M_o ; Schnabel-Petersen = S-P; Chao's model with capture probability varying individually = M_h ; Chao's model with capture probability varying with time = M_t ; Chao's model with capture probability varying with both individuals and time = M_{th} .

Study area	Transect	M_o	S-P	M_h	M_t	M_{th}
Montes	MO1	0	0	0	0	0
	MO2	0	0	0	0	0
	MO4	0	0	0	0	0
Alase	AL1	0	0	0	0	0
	AL2	0	0	0	0	0
Montarbu	AL3	3 (0.410)	3 (0)	3 (0)	3 (0)	3 (0.536)
	MA1	0	0	0	0	0
	MA2	3 (0.183)	3 (0.003)	3 (0)	3 (0)	3 (0)
	MA3	0	0	0	0	0
Monte Arci	MA4	0	0	0	0	0
	AR1*	38 (22.17)	31 (14.86)	43 (28.64)	30 (13.14)	14 (2.24)
	AR2	15 (2.583)	15 (0.971)	15 (4.84)	15 (2.279)	15 (0)
	AR4*	8 (2.366)	7 (0.845)	14 (11.66)	9 (4.00)	7 (1.61)
Marganai	MG1	2 (0.277)	2 (0.277)	2 (0)	2 (0.277)	2 (0)
	MG2	0	0	0	0	0
	MG3	4 (1.983)	3 (0.002)	5 (3.742)	3 (0.811)	3 (1.087)
Limbara	LI1	0	0	0	0	0
	LI2	0	0	0	0	0
Goceano	LI3	5 (0.615)	5 (0.003)	5 (0.535)	5 (0.447)	5 (0.572)
	GO1	0	0	0	0	0
	GO2	0	0	0	0	0
	GO3	0	0	0	0	0

*denotes that software CAPTURE was used to select the best model.

TABLE IV

Summary of the sign and the statistical significance of the correlations of the individual variables descriptive of ground cover in relation to the scores of the first two factors extracted from a PCA. Symbols: 0 = no correlation, - = significantly negative correlation between variable and factor; + = significantly positive correlation between variable and factor.

Variable	Factor 1	Factor 2
Litter height	0	0
% of leaf litter	+	0
Height of the slashings	+	0
% of the slashings	0	0
% of grass	0	0
% of soil	0	+
% of moss	0	0
Number of stumps	0	+
Diameter of stumps	0	+

TABLE V

Summary of the sign and significance of the correlations of the individual variables descriptive of shrub cover in relation to the scores of the first two factors extracted from a PCA. Symbols: 0 = no correlation, - = significantly negative correlation between variable and factor; + = statistically significant correlation between variable and factor

Variable	Factor 1	Factor 2
Height of <i>Rubus</i>	0	+
<i>Rubus</i> %	0	+

Height of <i>Pyrus</i>	+	0
<i>Pyrus</i> %	+	0
Height of <i>Erica</i>	+	0
<i>Erica</i> %	+	-

Therefore, we proceeded to perform a PCA in order to compute the scores to be used for the analysis of correlation with the population size of wood mice. The scores derived from the first two components of this multivariate analysis were not significantly correlated with the modelled population size of wood mice per transect ($r = 0.036$, $P = 0.692$). The scores derived from the same multivariate analysis were not significantly correlated with the modelled population size of wood mice in each of the various types of wood (in all cases, at least $P > 0.710$ at Pearson's correlation coefficient).

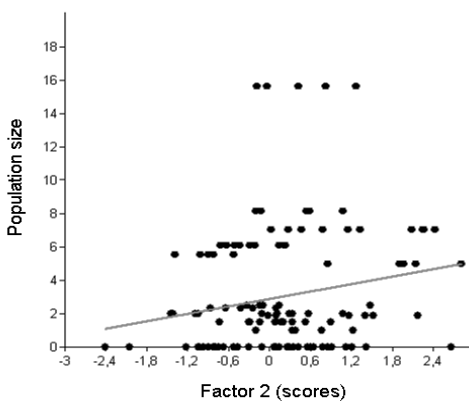


Figure 4.— Relationship between the ground cover (scores related to Factor 2 of the initial PCA) and density of rodents by transect. For statistical details, see the text.

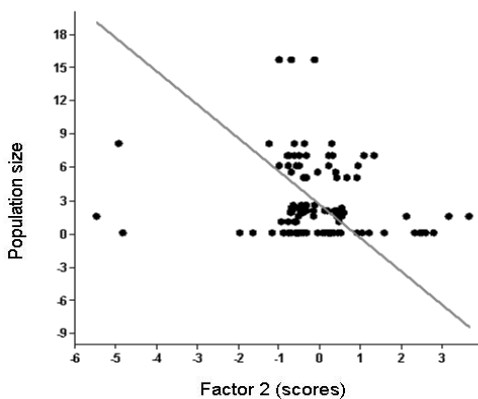


Figure 5.— Relationship between shrub cover (scores related to Factor 2 of the PCA of departure) and density of rodents by transect. For statistical details see the text.

Using the same type of analysis with the variables related to the amount of standing dead wood (number of snags, diameter, and height), it resulted that dead wood did not influence the modelled population size of rodents either overall ($r = 0.096$, $P = 0.293$) or in each of the various wood types (in all cases, at least $P > 0.155$ at Pearson's correlation coefficient).

Even the variables relative to ground cover were statistically collinear with each other (e.g. height in cm of litter against slashings: $r = 0.20$, $P < 0.05$, height in cm of litter against grass %: $r = 0.40$, $P < 0.01$). Therefore, also in this case, were recovered (and used for the analysis) the PCA scores between all the variables descriptive of the ground cover. The modelled population size of the mice was not significantly correlated with the scores relating to Factor 1 ($r = -0.028$, $P = 0.753$), while it was positively correlated with the scores relating to Factor 2 ($r = 0.194$, $P = 0.031$; Fig. 4) (see Tab. IV for the variables correlating with the various factors). However, when we excluded outliers from the analysis, the correlation became weaker ($r = 0.0255$, $P = 0.251$).

Overall, the population size of rodents was influenced positively by only two variables ground cover and number of stumps (Tab. IV).

As regards the variables describing the tree cover (tree diversity and type of wood) of the various transects, also in this case they were significantly collinear ($r = 0.349$, $F = 2.414$, $P < 0.00001$). Therefore, we recovered the factorial scores obtained by a PCA inclusive of all variables. The modelled population size of mice was not correlated with the scores of each of the two factors extracted from the PCA (Factor 1: $r = 0.019$, $P = 0.826$; Factor 2: $r = -0.0053$, $P = 0.953$; see Tab. IV for the variables explaining each factor).

The variables that describe shrub cover were also significantly collinear ($r = 0.614$, $F = 11.41$, $P < 0.0131$). Therefore, we recovered the factorial scores obtained by a PCA inclusive of all variables in question. The modelled population size of mice was not related to scores related to Factor 1 ($r = -0.055$, $P = 0.542$), whereas it was marginally significant (and thus adversely affected) by the scores related to Factor 2 ($r = -0.175$, $P = 0.051$; Fig. 5). Once more, the significance of this relationship disappeared when outliers were taken into account ($r = 0.023$, $P = 0.712$).

If we examine the statistical significance and the sign of the correlation of the individual variables of shrub cover with the two factors extracted from the PCA, it appeared that the modelled population size of rodents was negatively affected by the height and percentage of *Rubus ulmifolius* in each transect, while it was positively influenced by the percentage of *Erica arborea* and of *Pyrus* sp. (Tab. V).

DISCUSSION

Our study showed that there was a widespread presence of *A. sylvaticus* in Sardinia throughout all the types of wood and sites surveyed during the present study. Apparently, the ecological distribution of this species was more homogeneous in Sardinia than in woodlands of mainland Italy. In these latter regions, inner forests are often occupied by *Apodemus flavicollis* (species absent in Sardinia; Amori *et al.*, 2008). Thus, our data are consistent with the hypothesis that *A. sylvaticus* may fully occupy the forest ecological niche in Sardinia because of the concurrent absence of its potential competitor *A. flavicollis*. The same pattern also occurred in Western France, where *A. sylvaticus* widely occurs in mature forests because of the concurrent absence of *A. flavicollis* (Butet *et al.*, 2006). Nonetheless, our data would verify experimental manipulations of wild populations in order to reach definite answers.

In addition, we observed that the study species was also widespread in forest habitats.

An interesting result obtained in our study was the lack of effect of forest type on the number of captured *A. sylvaticus*. This evidence does not agree with what has been shown in the literature (Capizzi & Luiselli, 1996; Marsh & Harris, 2000; Pearce & Venier, 2005). However, it should be

stressed that ours is the only study of its kind carried out in typically Mediterranean environment and insular context. Because the abundance of rodents is highly dependent on the availability of seeds of forest plants (Montgomery *et al.*, 1991), it could be argued that such availability may not vary significantly among the four types of forests sampled, but of course this point needs verification.

Overall, our study revealed that the population size of *Apodemus sylvaticus* varied remarkably across the various study transects in Sardinia, even when transects were situated very close to each other. Thus, it is clear that small scale factors may be responsible for the observed patterns in population size. We observed that the population size of this species was positively influenced by (i) ground cover, (ii) number of stumps, and (iii) % *Erica arborea*. On the other hand, it was negatively influenced by (a) height of *Rubus ulmifolius* bushes and (b) by % *Rubus ulmifolius*.

From the forestry management point of view, it is noteworthy that our study did not reveal any direct effect of the presence of dead wood on the ground or standing on the population size of *A. sylvaticus* in the various transects. Even if it is well known that different species respond differently to forest management and keystone structures (Bogdziewicz & Zwolak, 2013; Paillet *et al.*, 2010; Tews *et al.*, 2004), this result is somehow surprising if one takes into account the role of dead wood for forest ecosystems (Bengtsson *et al.*, 2000; Harmon *et al.*, 1986; Lombardi *et al.*, 2008), and of previous findings on the Wood Mouse (Marsh & Harris, 2000). Further research should be aimed at evaluating experimentally this pattern. In fact, from the data obtained in this study, it seems that generally in terms of quantity (on average 0.3 logs and 0.4 snags per plot) and quality (average diameter was 17 and 30 cm per logs and snags respectively) dead wood is scarce in the surveyed forests. The absence of a relationship between the presence of dead wood and small mammal population size could then be linked to the absence of dead wood in adequate quantity and quality to provide measurable benefits for small mammals populations at the stand level (e.g. refuges). However, it should also be emphasized that the number of stumps has positively affected small mammal population size. It seems plausible to assume that the stumps provide rodents with a large amount of areas suitable for shelters and dens, particularly important in the absence of large amounts of dead wood, and that this aspect favours an increased population density. Generally associated with the stumps are in fact portions of dead wood with cavities. The positive effect of *Erica arborea* on the rodent population size could be also due to the provision of shelters and dens to these animals. *Erica arborea* burl, a tumour-like structure growing between the roots and stem of the shrub creates abundant refuges for mice populations. As an alternative hypothesis, it can be stressed that wood mice preferred sites with *Erica arborea* because of the seeds produced by this plant species. Indeed, there are studies showing that seeds of *Erica* spp. are intensively foraged by Wood Mouse (see Butet, 1986). Also the positive association of wood mice with *Pyrus* sp. may be due to trophic reasons, as these rodents are seed-dispersers of these plants (Fedriani & Delibes, 2009). In contrast, the negative association between *Rubus ulmifolius* and small mammal population size is surprising and not explained here, given that the rodents in general, and the species of the genus *Apodemus* in particular, feed regularly on blackberries (Moreno & Kufner, 1988). We suggest that *Rubus* plants were no more interesting at the trapping dates because there were no berries available. Our analyses also showed a significant positive effect of the ground cover on the population size of small mammals. It is believed here that this is due to the fact that abundant soil layers favour the excavation of rodents.

We suggest that population surveys at other periods of the year would have perhaps showed different distribution. For example, it has been demonstrated that, in agricultural landscapes of western France, mice move intensively from hedgerows to crop fields according to seasons (see Ouin *et al.*, 2000).

We also observed a number of captured specimens larger in spring than in autumn. This pattern is not surprising, as it has previously been pointed out in several studies on the same species (e.g., Moreno & Kufner, 1988; Montgomery *et al.*, 1991; Capizzi & Luiselli, 1996).

At last, we would also remark that our analyses are based on only two seasons in the same year, that may hide population movements between habitats (e.g., Ouin *et al.*, 2000) as well as important fluctuations of population size between years (e.g., Pucek *et al.*, 1993). Furthermore the whole study has been carried out at the scale of the Sardinian island which leads to a significant disproportion between this scale of study and the sample size (127 individuals).

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