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ORIGINAL ARTICLE

Does wild boar rooting affect spatial distribution of active burrows of meadow-dwelling voles?

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Abstract

Soil overturn by wild boar *Sus scrofa* is known to affect biodiversity, from plant communities to invertebrates, reptiles and small mammals. Rooting activity has been shown to be particularly intensive in open areas and particularly on fallows and meadows located on hill or mountain tops. In these habitat types, the impact of wild boar on small mammal assemblies has never been assessed. In this work, we evaluated whether rooting activity affected the spatial distribution of the Savi's pine vole *Microtus savii* in a hilly area of Central Italy, throughout four seasons. The spatial distribution of this vole has been determined through the open-hole index, i.e. by assessing the vole propensity to reopen tunnel entrances which we previously closed with soil. Rooting intensity was the highest in cold months, i.e. when drive hunting may increase wild boar occurrence within protected areas and outside wooded areas. According to our GLMM, reopening of vole burrow entrances increased with increasing distances from rooted areas and with increasing geophytic diversity. Meadow-dwelling voles living on shallow underground burrow systems seem to avoid soil overturn by wild boar and that they prefer creating their tunnels where plant diversity building up the staple of their diet is the highest. Our results furtherly emphasized the importance of wild boar monitoring also in open areas and hill grasslands, particularly when rooting intensity is the highest, i.e. in cold months.

Keywords Environmental alteration · Management · *Microtus savii* · Open areas · *Sus scrofa*

Introduction

Animal species which significantly alter or modify a habitat, influencing local species richness and landscape heterogeneity, e.g. elephants, wild boar, ibex, porcupines, beavers and termites are defined as "ecosystem engineers" (e.g. Dangerfield et al. 1998; Wright et al. 2002; Fritz 2017). Digs and shallow burrows by these species may (*i*) increase soil oxygenation and (*ii*) build up new microhabitats able to capture runoff rain water and to increase plant germination and renewal (Gutterman and Herr 1981; Gutterman 1997). Wild boar rooting is also a natural soil-altering factor (Sondej and Kwiatkowska-Falińska 2017), although it may dramatically affect understorey composition and ecosystem functional traits, as overturning extensive areas, often irreversibly (Cuevas et al. 2012; Burrascano et al. 2015). Given the wide distribution range of the wild boar, its activity has been reported to affect biotic and abiotic components, including soil properties, animal communities and plant species diversity (Barrios-Garcìa and Ballari 2012; Bengsen et al. 2013; Genov et al. 2017). High rooting intensity affects abundance and distribution of ground-dwelling forest rodents and shrews up to their local disappearance (Singer et al. 1984; Fagiani et al. 2014; Amori et al. 2016; Mori et al. 2020), whereas effects on arboreal and semiarboreal species are rarely evident and mostly due to competition for food (Focardi et al. 2000; Mori et al. 2020). Open areas including meadows and grasslands (e.g. hill and mountain tops) are suggested to be the most sensitive habitat types to damage by wild boar (Cocca et al. 2007; Bueno et al. 2009). The general ongoing increase in wild boar density throughout Europe (Apollonio et al. 2010) is likely to increase the intensity of damages by this ungulate, thus enhancing the importance of research study to quantify it.

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Among rodents, meadow-dwelling voles *Microtus* spp. (Rodentia: Cricetidae) play pivotal roles in food chains and they also represent environmental bio-indicators (Chassovnikarova et al. 2005; Bertolino et al. 2015a; Ranchelli et al. 2016). Amongst the eight Italian *Microtus* species, the Savi's pine vole *Microtus savii* de Selys-Longchamps, 1838 is the most widespread (Dell'Agnello et al. 2019a; Loy et al. 2019). This semifossorial rodent is typical of open areas including fallows and croplands between 0 and 2800 metres a.s.l. (Patriarca and Debernardi 1997; Mori et al. 2019; Dell'Agnello et al. 2019b), where it digs systems of shallow underground burrows (about 10–15 cm below the ground level: Dell'Agnello et al. 2018; Mori et al. 2019).

In this work, we aimed at assessing whether the spatial dispersion of active burrows of the Savi's pine vole on a grassland located on a hill top was related with wild boar (*Sus scrofa* Linnaeus, 1758) rooting activity and its intensity throughout the year. Given the extensive soil overturn provoked by wild boar rooting (Brunet et al. 2016), an effect on spatial dispersion of Savi's pine vole active burrows would be expected (prediction *i*). We also predicted that, given the wide trophic spectrum of the Savi's pine vole (Dell'Agnello et al. 2019b), most active burrows would occur where the highest plant diversity occurred (prediction *ii*).

Materials and methods

Study area

We carried out all of our work within the Special Area of Conservation "Poggi di Prata", a rural hilly area (1100 ha, 650–903 m a.s.l.) in the North-East of the province of Grosseto (Central Italy). Field work was conducted in the framework of field-activities to prepare the management plan of this site (IT51A002, Temi s.r.l., Roma 19/06/2019, Prot. N. 23/18), by one of the authors (EM). However, direct manipulation of free-ranging animals was not included in our project; therefore, no permits were required apart from a communication to the local vigilance.

Most of the study area (67%) was covered by mixed deciduous woodlands (*Quercus cerris, Castanea sativa* and *Carpinus betulus*), surrounded by a shrub belt (*Rubus* spp., *Erica scoparia* and *Spartium junceum*: 3%). Fallows counted for 27%, coniferous woodlands (*Pinus nigra* and *Cupressus arizonica*) for 2%, and human settlements for the remaining 1% (Mori et al. 2014). Average annual rainfall (± SD) was 873 ± 92 mm; the average annual temperature was 14 ± 2.6 °C (Mori et al. 2014). In this area, although no reliable density estimation is available and no climatic factors may be tested for wild boar – vole interactions (cf. Mysterud et al. 2007), the wild boar is the most widespread mammal species (Mori et al. 2014) and its management occurred through drive hunting in cold months (November-January). The Savi's pine vole is the only meadow-dwelling vole recorded in this area and it mostly occurs on grasslands on hill tops (Battisti et al. 2019).

Assessment of rooting intensity and active vole burrows

Field work was carried out between June 2019 and June 2020 on meadows occurring on the top of the highest hills of the study area (Poggione, 9.12 hectares, 860–914 m a.s.l.; Poggio Croce di Prata, 7.40 hectares, 771–812 m a.s.l.). Rooting intensity was measured as the percentage of rooted area on the total meadow on grasslands located on the top of the Poggione hill: no rooting occurred in Poggio Croce di Prata, which showed similar terrain conditions. We did not detect vole burrows in any other meadows of the study area, apart from Poggione and Poggio Croce di Prata (i.e. in the surrounding areas of hill tops). Therefore, we used Poggio Croce di Prata as a control area without wild boar rooting. We used ortophotos (i.e. lack of grass cover: ©Google Earth) at the start and at the middle of every season (i.e. in July, October, January and April), to identify areas of wild boar fresh rooting activity. Then, we verified through direct investigations on the field ($n = 3$ field investigations/season), to estimate the percentage of freshly rooted areas on the total grassland surface (by calculating the % of rooted areas on the total) through QGIS 3.6 - Noosa (QGIS Development Team 2016). At the start of every astronomical season, vole presence was evaluated as the occurrence of reopened tunnel entrances counted along 17 transects (50 × 2 m) separated one another by 50–96 m, opportunistically selected along animal trails in the grassland (Bertolino et al. 2015b), in both Poggione and Poggio Croce di Prata hills (i.e., with and without boar rooting respectively). The same 17 transects ($n = 10$ in the area with rooting, $n = 7$ in the area without rooting) were travelled in all seasons, and were evenly distributed within the study site. We closed with soil and georeferenced with a GPS (®Garmin, Kansas City, USA) all the vole tunnel entrances we were able to detect and we measured the activity of vole burrows by relying on the vole propensity to reopen them after 24 and 48 hours (Bertolino et al. 2015b; Dell'Agnello et al. 2019a). For all the vole holes we closed in the rooted meadow (Poggione), we determined (*i*) the linear distance from the nearest rooted area through QGIS 3.6 - Noosa, (*ii*) the distance from the woodland edge, (*iii*) the number of only geophytes and hemicryptophytes (i.e. the most affected by wild boar rooting) located on a circular plot (radium, 10 cm) around the hole. We run Generalized Linear Mixes Models (GLMM) to analyse the effects of all these variables and of the astronomical season (i.e. spring, summer, autumn and winter) on the reopening success of vole burrows (binomial model: 0, inactive; 1, active), by using the software R (version

3.5.1., R Foundation for Statistical Computing, Vienna, Austria), package lme4 (Bates et al. 2014). The transect nested with season was included as a random factor, so to allow for repetition. Before running the model, we tested for multicollinearity among variables (i.e., $r > |0.6|$). All the variables were included in a total model (Online Resource 1).

Results

Rooting intensity peaked in cold months (October-March), but it was over 8% throughout the year (Fig. 1). We closed a total of 182 vole holes (46 in summer, 38 in autumn, 55 in winter and 43 in spring), 90 in the meadow with rooting (mean ± SD per transect: 9.00 ± 4.64), 92 in the one without rooting (mean ± SD per transect: 13.14 ± 3.48). We closed a similar number of vole holes throughout the four seasons in both meadows ($\chi^2 = 0.75–0.86$, df = 3, $p >> 0.05$).

A total of 44 vole holes were reopened in 24–48 hours (8 in summer, 14 in autumn, 13 in winter and 9 in spring) in the meadow with rooting; conversely, 68 holes were reopened in the area without rooting. Re-openings were more likely to occur with increasing distance from wild boar rooted areas and where the number of geophytes increases (Table 1).

Discussion

Reopening of Savi's pine vole burrows increased with increasing distance from wild boar rooting and with increasing number of geophytes, thus fulfilling our predictions (i) and (ii). Wild boar activity disrupts shallow vole burrows, therefore forcing them to move towards areas where no (or little) soil overturn occurs. Accordingly, in the area without rooting, number of reopened holes was about 50% higher. This result may provide further evidence to what Mori et al. (2020) already observed in woodlands, where rooting by wild boar reduced population densities of the bank vole *Myodes glareolus* (Schreber, 1780). However, other studies e.g. within experimental fenced areas including Savi's pine voles but excluding wild boars are needed. Vole abundance has been suggested to be the highest where the highest diversity of plant species is recorded (see also Dell'Agnello et al. 2019b).

In our study area, wild boar rooting increased in cold months and it was the lowest in summer (see Mysterud et al. 2007). In autumn and winter, wild boars are drive hunted in woodlands located in the surrounding of our study area (Mori et al. 2014). Hunting may thus force wild boar to search for food in reserves, where hunting is not allowed (Tolon et al. 2009, but see also Brogi et al. 2020), thus increasing rooting in protected open areas near the woodland. The Savi's pine vole is active throughout the 24 hours and throughout the year, with polyphasic activity triggered by a fast metabolic rate implying constant food consumption (Dell'Agnello et al. 2019a); accordingly, number of reopened holes did not differ over the seasons.

On hill and mountain tops, as in our study area, rooting effect may dramatically alter the ecosystem. The habitat where we conducted our research is characterized by perennial meadows of arid or hemicryptophytic grasses, very rich from a floristic point of view (in particular orchids and other bioindicator species). This habitat is listed as a prior habitat (habitat classification ID: 6210), according to the European Habitat Directive (92/43/EEC). This habitat is also maintained by local animal communities which may disperse seeds through faeces or improve soil oxygenation e.g. through digging, thus keeping a high floral diversity (Gutterman 1997).

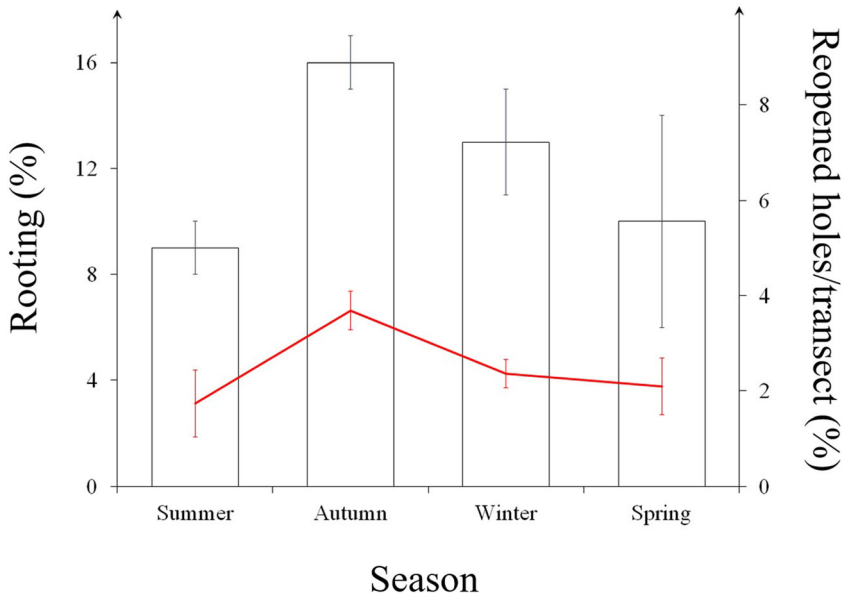

Fig. 1 Seasonal trend of wild boar rooting intensity (white bars) and reopened holes per transect (red line) in the area with wild boar rooting

Table 1 Results of the GLMM

Fixed effects	Estimate	Standard Error	*Z* value	*p* value
Intercept	-6.154	1.647	-3.736	0.0002**
Distance from woodland	-0.057	0.0159	-0.357	0.721
Distance from rooting	0.076	0.018	2.175	0.00001**
Number of geophytes	0.828	0.381	2.175	0.029*

*significant values; **highly significant values

An excessive load of wild boar rooting represents a threat to this environment, favouring soil alteration and compaction, as well as the diffusion of nitrophilous and ruderal plant species, which may in turn reduce the space for other species (Angelini et al. 2016). Despite Italian law prevents to feed wild boar and other wildlife species, it has been shown that feeding supply by humans may locally limit the impact of wild boar on ecosystems (Tryjanowski et al. 2017, for Central Europe), but the local population of this ungulate should also be managed to limit damages (cf. Apollonio et al. 2010; Scillitani et al. 2010). Alteration of local animal community by rooting activity may also bring to secondary effects which need to be furtherly studied. Primary excavators directly dig burrows and include both strictly fossorial species and semifossorial ones, such as the Savi's pine vole. Digging burrows require high energetic costs (Covell et al. 1996; Zelová et al. 2010). Therefore, once a burrow is dug, it is kept active for several years, and for several generations (up to tens or hundreds of years: Kruuk 1989).

Our work is the first assessing the impact of wild boar on meadow-dwelling rodents. In woodlands, previous works showed that vole abundance declines when wild boar rooting intensity increases (Singer et al. 1984; Mori et al. 2020). This may be due to the fact that vole tunnels are shallow and can be easily destroyed by rooting. Therefore, voles might be forced to dig their burrows far from rooted areas. Furthermore, rodents may occur in wild boar diet, although their occurrence is rare (Schley and Roper 2003; Ballari and Barrios-Garcia 2014). Although we are not aware of Savi's pine vole densities in our sampled open areas, we showed that rooting activity by wild boar may strongly influence and modify the spatial dispersion of vole burrows. Given the pivotal role played by burrowing rodents in prairie ecosystem functioning (Davidson et al. 2008; Bertolino et al. 2015a), with our study, we may infer that also open areas could be threatened by boar activity.

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Authors' contributions Both authors carried out field work and statistical analyses, and wrote the draft.

Data availability Data are available in Online Resource 1.

Compliance with ethical standards

Conflicts of interest The authors declare that they have no conflict of interest.

Ethics approval All procedures performed in studies were in accordance with the ethical standards of the institutional and/or national research committee and with the Helsinki declaration and its later amendments or comparable ethical standards. Even if voles are excluded from the Italian laws protecting wildlife (Art. 4 National Law 157/1992; Annexes of the Tuscan Regional Law 56/2000) and their captures would require permits only in National Parks and Reserves, our field-work did not include any manipulation of living animals, nor captures. Therefore, following the Italian law, no permit was necessary.

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