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COASTAL FOREST ECOSYSTEM NEAR ROME

# Quantifying *Sus scrofa* rooting effects on the understorey of the deciduous broadleaf forests in Castelporziano Estate (Italy)

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**Abstract** Wild boar (*Sus scrofa*) rooting activities may affect several taxonomic groups. In hardwood forests, wild boar's diet is predominantly represented by plants of the ground layer. We here report a study conducted in two Mediterranean lowland forests in central Italy (the State Reserve of Castelporziano and the Circeo National Park). The aim of our study was to evaluate whether contrasting levels of rooting (high vs. low) determine different understorey species composition and diversity. Our results show that different rooting levels determine strong differences in the understorey composition. Furthermore, we found that the occurrence of different species (e.g. *Ruscus aculeatus*) was associated with contrasting rooting levels. Mediterranean species were significantly more frequent in plots with high levels of rooting. Plots sampled in the Castelporziano area were also characterised by species adapted to frequent disturbance and anthropogenic influence (e.g. *Piptatherum miliaceum*, *Conyza albida*); whereas species associated to low-rooting plots were typically related to deciduous forests. We found non-significant differences in diversity indices. This study demonstrates that wild boar activities cause substantial alterations in plant communities and underscores the need for long-term exclosure experiments.

**Keywords** Wild boar · Forest structure · Indicator species analysis · Species diversity indices

S. Burrascano and E. Giarrizzo contributed equally.

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## 1 Introduction

In Europe populations of the wild boar (*Sus scrofa*) substantially increased in the last decades. Indeed, the wild boar is included in the list of the 100 most invasive species at the global level in terms of impact on biological diversity and/or human activities (Lowe et al. 2000).

The wild boar can live in a wide range of habitats as it feeds opportunistically on plant and animal species. Consequently, the wild boar affects several taxa both directly (through predation) and indirectly (through the alteration of different ecosystems parameters). The wild boar activity that has the strongest effects on ecosystems is rooting, as this may alter soil and vegetation in areas up to hundreds of hectares (Welander 2000).

In hardwood forests, understorey species represent the great majority of wild boar diet and several authors agree that wild boar negatively affects the understorey composition (Ickes et al. 2005; Siemann et al. 2009) and abundance (Howe and Bratton 1976; Hone 2002; Pinna et al. 2007).

Nevertheless, results of previous research focused on the density of understorey species are contrasting (Massei and

Genov 2004), and, in particular, there is no information on which species in particular are strongly affected by wild boar rooting. The aim of our study is to investigate the impact of wild boar rooting activity on understorey vascular plants in two Mediterranean lowland forests in central Italy. We conducted our research in forests of high conservation concern (i.e. Mediterranean lowland forests dominated by the deciduous oaks *Quercus cerris* and *Q. frainetto*). Indeed, no data on the conservation status of the subtype Balkanic thermophilous oak woods are reported for Italy (http://www.bd.eionet.europa.eu/article17/chapter4) although these ecosystems are recognised by the Habitat Directive (Habitat 91M0 see Biondi et al. 2012).

## 2 Materials and methods

### 2.1 Study area

Our work was carried out in the Castelporziano Estate, which is included amongst the State Reserves since 1999. This area is located 25 km southwest from Rome along the Tyrrhenian coast of Lazio (central Italy), and it covers approximately 5,900 ha at an altitude of 0–85 m a.s.l. The climate is typically Mediterranean (Blasi et al. 1999): during the period 2004–2013 the average annual temperature was 17.1 °C, with minimum and maximum temperatures of, respectively, 9.8 and 20.4 °C; annual rainfall for the considered period was 784 mm. The substratum is mostly made up of pleistocenic and holocenic eolian sands, but is locally characterised by alluvial sediments and pyroclastic materials from Latium volcanic system (Badalì et al. 1999).

The Castelporziano Estate is a site of outstanding importance for the conservation of vascular plant species. Several species of conservation concern (regionally endangered or vulnerable according to the IUCN categories) have a distribution limited to the estate. The area is particularly important for the preservation of mesophilous woods, Mediterranean maquis and forests, as well as for wetlands that once covered extensive areas along the mid-Tyrrhenian coast. Furthermore, the area includes remnants of dunal complexes and temporary ponds of high conservation concern (Capotorti et al. 2013; Celesti-Grapow et al. 2013). Such habitats have now become very fragmented due to urban and agricultural pressure and land reclamations dating from the early twentieth century (Bertacchi and Lombardi 2014; Farris et al. 2013; Ricotta et al. 2001).

We focused on the most widespread forest type, which is dominated by the deciduous oaks *Q. cerris* L. and *Q. frainetto* L. (*Mespilo germanicae-Quercetum frainetto* Biondi, Gigante, Pignattelli et Venanzoni 2001).

In the area that is now occupied by Castelporziano Estate, the occurrence of ungulates (including the wild boar) is recorded since Roman times; in the last century, the wild boar population was relatively stable and increased after the Second World War reaching around 800 individuals in the late twentieth century (Mecella et al. 1999).

It was not possible to identify stands with low-rooting levels in Castelporziano Estate. For this reason, we compared data collected in the State Reserve of Castelporziano with data collected in the Circeo National Park forest (Fig. 1), where areas with different levels of rooting activity (low and high) occurred. The two study sites are very similar for climate, lithology and natural potential vegetation (*Mespilo germanicae-Quercetum frainetto*). Climatic parameters for the lowland forest in Circeo National Park are close to those of Castelporziano Estate: for the period 2004–2013, average annual temperature was 15.9 °C with minimum and maximum temperatures of, respectively, 9.6 and 22.9 °C; annual rainfall for the considered period is on average 808 mm (source of data: Pontinia meteorological station which is located 6 km from the sampled forest; source: http://www.arsial.it/portalearsial/agrometeo).

In the Circeo forest, the density of wild boar has fluctuated considerably since the 1930s with a steady increase in the last 50 years, in 2004 the number of individuals was estimated to be between 600 and 700.

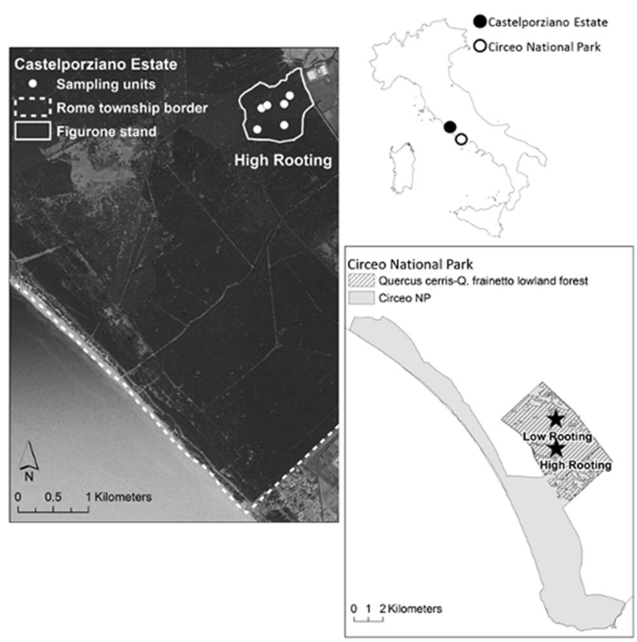


**Fig. 1** Study areas location in Italy and sampled stands

## 2.2 Data collection

Rooting intensity, forest structure and understorey species composition were sampled between May and July 2010. Sampling was conducted within forests co-dominated by the deciduous oaks *Q. cerris* and *Q. frainetto*. (site A: Figurone—Castelporziano Estate; site B: lowland forest in Circeo National Park).

To assess rooting intensity, we sampled 21 transects (100 m long and 5 m wide) in the site A, and 12 equal transects in the site B. The intensity of rooting was evaluated through counts of single rooting signs, defined as an approx. 15-cm-wide sign of rooting activity on the ground. Wider signs were evaluated as multiples of a single sign (i.e. a 30-cm-wide sign = 2 rooting signs), as described in Fagiani et al. (2014). We found a high-rooting intensity for the site A, while in the site B we found areas with contrasting rooting levels (high and low).

We conducted the understorey vegetation sampling in six square plots (400 $m^2$ each) in site A, and in 12 identical plots (six for each level of rooting) in site B; these were randomly selected from a dataset of 24 total plots (Burrascano et al. 2014).

The occurrence and the percentage cover value of each vascular plant taxon were recorded. To assess species cover in more detail, each sampling unit was divided into four subunits (10 × 10 m each one). Taxa were identified following the Flora d'Italia (Pignatti 1982) and the Flora Europaea (Tutin et al. 1968–1980, 1993). Nomenclature follows Conti et al. (2005) and Pignatti (1982).

As overstorey structure substantially influences understorey composition and diversity (Burrascano et al. 2011; Sabatini et al. 2014), we investigated forest structural attributes to verify the occurrence of similar conditions across all the sampling units in the two sites. Specifically, overstorey structure was sampled through a variable radius plot, using a wedge prism, centred on the square plots used for the vegetation sampling. The diameter at breast height (DBH) and the vitality class of all the standing living and dead trees included in the variable radius plot were recorded. We also recorded the mid-diameter, length and decay class (Hunter 1990) of every piece of lying deadwood with a diameter >10 cm in each plot. We calculated and included in the analysis seven structural variables that could be used as indicators of structural heterogeneity in mature and over-mature forests (Corona et al. 2010; Višnjić et al. 2013): number of diameter classes; number of standing trees with DBH >40 cm; diameter range; the proportion of standing dead trees; coarse woody debris volume; number of decay classes; and basal area.

## 2.3 Statistical analysis

We analysed differences in understorey species composition through permutational multivariate analysis of variance (Permanova—Anderson 2001). This analysis is an extension of the traditional analysis of variance that tests the simultaneous response of dependent variables (species) to one or more factors (site and rooting) on the basis of a resemblance matrix. Statistical significance is then assessed through permutations. We used Bray–Curtis similarity coefficient, and we tested the result for significance through 9,999 permutations under a reduced model. As the groups of plots belong to different sites, we included the site as a covariate in the model design. If covariates are included in the analysis, their effect is tested for significance in the first place, then the effect of the factors is analysed excluding the effect of the covariates. To visualise and compare the results yielded by Permanova, we performed a Principal Coordinates Analysis (PCoA). PCoA is a data ordination method that places the sampling units onto Euclidean axes on the basis of a resemblance matrix (the same used for Permanova) using the information provided by the variables (i.e. species abundances). Permanova and PCoA were performed with the software Primer-E (Clarke and Gorley 2006).

To further analyse the differences in species composition, the indicator values of the understorey vascular plant species of the three groups of plots were calculated by means of the Indicator Species Analysis (ISA—Dufrene and Legendre

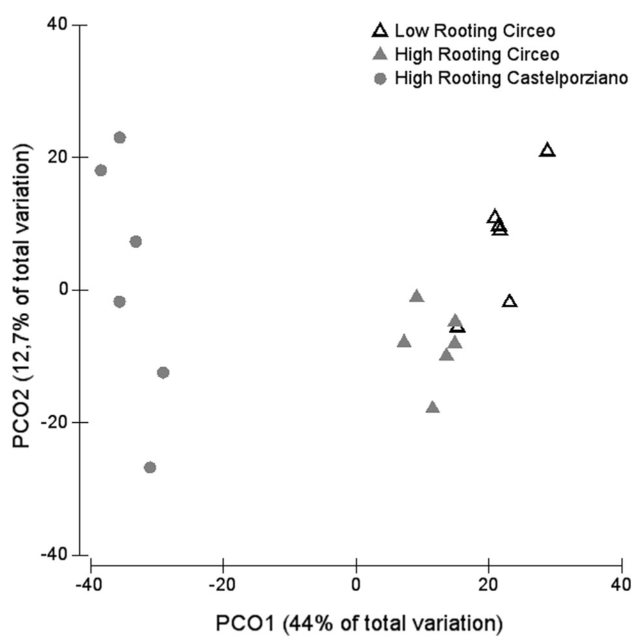


**Fig. 2** Principal coordinates analysis scatterplot along the first two axes. Sampling units belonging to different groups are represented by *different symbols*

1997), with 4,999 permutations using PC-Ord 5 (McCune and Mefford 2006). Species with an indicator value higher than 50 % and a *p* value lower than 0.05 were considered to be indicative of one out of the three groups of plots.

Finally, differences in species density, Shannon–Weaver diversity and evenness (diversity indices), and overstorey structure between the three groups of plots were tested for significance by means of Analysis of Variance (ANOVA) and the Tukey post hoc test in R 2.12.0 (R Core Team 2009).

## 3 Results

### 3.1 Species composition and indicator species

The species composition of the investigated plots was significantly different in areas with contrasting rooting levels. The first axis of the PCoA explained 44 % of the variance and highlighted differences related to the site. Nevertheless, part of the variance explained by axis 1 should be related to rooting levels (Fig. 2), since the Permanova returned highly significant differences between rooting levels, using the area as a covariate (Table 1).

The comparison of overstorey structure yielded non-significant results for most variables. Indeed, the ANOVA returned significant differences only relatively to the density of large living trees and the DBH range (Table 2), with a significantly higher density of large living trees resulting also in higher values of DBH range in site A (Table 3).

These results confirm that the overstorey structure is similar in the three groups of plots, with limited differences between the two study areas, and support our decision not to use forest structure as a further determinant of compositional differences in the Permanova analysis.

The indicator species analysis allowed us to characterise the differences in composition amongst the groups of plots (Table 4). In the low-rooting plots of site B, six species were found to have a significant indicator value with *Ruscus aculeatus* being the species with the highest indicator value; while in the high-rooting plots of site B, the ISA returned three indicator species (*Rubia peregrina*, *Rosa sempervirens*, *Melica uniflora*). The species that show a significant degree of association to the high-rooting plots of site A are more numerous and include also *Conyza albida* (=*Erigeron sumatrensis*), an invasive species from South America (Celesti-Grapow et al. 2009).

### 3.2 Diversity indices

Despite the marked differences in understorey composition, the contrasting levels of rooting do not determine significantly different levels of species density and of Shannon diversity indices (Table 5). Through the ANOVA, we found marginally significant differences only for the Shannon evenness index; however, such differences were not confirmed by the post hoc tests (Table 6).

**Table 2** ANOVA based on forest structural attributes

| | *df* | Sum sq | Mean sq | *F* value | *p* value |
|---|---|---|---|---|---|
| DBH classes (no) | 2 | 7.444 | 3.722 | 1.603 | 0.234 |
| Residuals | 15 | 34.833 | 2.322 | | |
| Large living trees (no) | 2 | 24.111 | 12.056 | 6.739 | **0.008** |
| Residuals | 15 | 26.833 | 1.789 | | |
| DBH range (cm) | 2 | 8,842.700 | 4,421.300 | 11.009 | **0.001** |
| Residuals | 15 | 6,024.000 | 401.600 | | |
| Dead standing trees (%) | 2 | 99.360 | 49.681 | 1.355 | 0.288 |
| Residuals | 15 | 549.800 | 36.653 | | |
| Coarse woody debris ($m^3$/ha) | 2 | 2.175 | 1.088 | 0.500 | 0.616 |
| Residuals | 15 | 32.623 | 2.175 | | |
| Decay classes (no) | 2 | 1.444 | 0.722 | 0.890 | 0.431 |
| Residuals | 15 | 12.167 | 0.811 | | |
| Basal area ($m^2$/ha) | 2 | 266.780 | 133.389 | 2.419 | 0.123 |
| Residuals | 15 | 827.310 | 55.154 | | |

*p* values lower than 0.05 are in bold

Degrees of freedom, Sum of squares, *F* statistic and *p* values are shown for each variable

**Table 1** Permanova results

| | *df* | Sum sq | Mean sq | Pseudo-*F* | *p* value | Permutations |
|---|---|---|---|---|---|---|
| Area | 1 | 10,327 | 10,327 | 12.518 | **0.0001** | 9,924 |
| Rooting | 1 | 1,792.9 | 1,792.9 | 2.1733 | **0.0092** | 9,912 |
| Res | 15 | 12,375 | 824.98 | | | |
| Total | 17 | 24,494 | | | | |

*p* values lower than 0.05 are in bold

Degrees of freedom, sum of squares, Pseudo-*F* statistic, *p* value and number of permutations are shown for the area (used as covariate) and rooting factors

**Table 3** Post hoc tests for the forest structural variables that resulted significantly different in the ANOVA

| | Difference | Lower bound | Upper bound | *p* adj |
|---|---|---|---|---|
| Large living trees (no) | | | | |
| Circeo high rooting vs. Circeo low rooting | 2.167 | 0.161 | 4.172 | **0.034** |
| Castelporziano vs. Circeo high rooting | 2.667 | 0.661 | 4.672 | **0.009** |
| Castelporziano vs. Circeo low rooting | 0.500 | −1.506 | 2.506 | 0.797 |
| DBH range (cm) | | | | |
| Circeo high rooting vs. Circeo low rooting | −0.498 | −30.551 | 29.555 | 0.999 |
| Castelporziano vs. Circeo high rooting | 46.767 | 16.714 | 76.820 | **0.003** |
| Castelporziano vs. Circeo low rooting | 47.265 | 17.212 | 77.318 | **0.003** |

*p* values lower than 0.05 are in bold

**Table 4** Species with an indicator value higher than 50 % and a *p* value lower than 0.05 for each of the three groups of plots

| Species | Life and growth form | Indicator value | *p* value |
|---|---|---|---|
| Circeo low rooting | | | |
| *Ruscus aculeatus* L. | G Rhiz | 85.7 | 0.0004 |
| *Lonicera etrusca* Santi | P Lian | 83.3 | 0.0018 |
| *Geranium purpureum* Vill. | T Scap | 69.7 | 0.0037 |
| *Asphodelus ramosus* L. | G Rhiz | 73.8 | 0.0253 |
| *Moehringia trinervia* (L.) Clairv. | T Scap | 63.1 | 0.0254 |
| *Luzula forsteri* (Sm.) DC. | H Caesp | 52.5 | 0.046 |
| Circeo high rooting | | | |
| *Rubia peregrina* L. | P lian | 58.5 | 0.0026 |
| *Rosa sempervirens* L. | Np | 70.3 | 0.0065 |
| *Melica uniflora* Retz. | H Caesp | 57.8 | 0.0323 |
| Castelporziano | | | |
| *Piptatherum miliaceum* (L.) Coss. | H Caesp | 100 | 0.0002 |
| *Carpinus orientalis* Miller | P Caesp | 93.7 | 0.0002 |
| *Conyza albida* Willd. | T Scap | 83.3 | 0.0021 |
| *Juncus effusus* L. | H Caesp | 83.3 | 0.0021 |
| *Rhamnus alaternus* L. | P Caesp | 83.3 | 0.0024 |
| *Brachypodium sylvaticum* (Hudson) Beauv. | H Caesp | 81 | 0.0033 |
| *Phillyrea latifolia* L. | P Caesp | 77.6 | 0.0043 |
| *Calamintha nepeta* (L.) Savi | H Scap | 66.7 | 0.0132 |
| *Cytisus scoparius* (L.) Link | P Caesp | 66.7 | 0.0132 |

**Table 5** ANOVA based on understorey diversity indices

| | *df* | Sum sq | Mean sq | *F* value | *p* value |
|---|---|---|---|---|---|
| Species density | 2 | 132.330 | 66.167 | 1.478 | 0.260 |
| Residuals | 15 | 671.670 | 44.778 | | |
| Shannon | 2 | 0.300 | 0.150 | 1.155 | 0.341 |
| Residuals | 15 | 1.949 | 0.130 | | |
| Evenness | 2 | 0.060 | 0.030 | 3.007 | 0.080 |
| Residuals | 15 | 0.150 | 0.010 | | |

Degrees of freedom, sum of squares, *F* statistic and *p* values are shown for each variable

## 4 Discussion

### 4.1 Wild boar determines strong differences in understorey species composition

The sampling areas of this study are characterised by the same vegetation type (*Mespilo germanicae-Quercetum frainetto*) and have similar overstorey structure; nevertheless, we found marked differences in the understorey composition. Therefore, rooting strongly affected the understorey of deciduous oak woodlands in our sampled areas, determining significant changes in the occurrence and abundance of several species.

The analysis of the species that resulted as potential indicators gives relevant insights on the processes that occur in the understorey in relation to rooting intensity, and on the mechanisms that favour or phase out species with different ecological requirements and adaptations.

The highest indicator value in the low-rooting areas of the Circeo forest (site B) is for *R. aculeatus*. Based on its life-history traits, this species could be favoured by wild boar rooting as it is by grazing. Indeed, it was demonstrated that *R. aculeatus* frequently occurs in grazed forests (Onaindia et al. 2004), where it can persist for at least 10 years after the ceasement of grazing disturbance (Debussche et al. 2001). The shoots of this species are less likely to be affected by rooting than those of non-spinescent

**Table 6** Post hoc tests for the understorey diversity index that resulted significantly different in the ANOVA

| | Difference | Lower bound | Upper bound | *p* adj |
|---|---|---|---|---|
| Evenness | | | | |
| Circeo high rooting vs. Circeo low rooting | −0.116 | −0.266 | 0.034 | 0.145 |
| Castelporziano vs. Circeo high rooting | 0.013 | −0.137 | 0.162 | 0.974 |
| Castelporziano vs. Circeo low rooting | 0.128 | −0.022 | 0.278 | 0.099 |

species. Moreover, *R. aculeatus* is a clonal species that rapidly sprouts after predation or mechanical damage.

The low-rooting areas are characterised also by the occurrence of *Asphodelus ramosus*, a Mediterranean species that is typically found in areas frequently disturbed either by grazing or fire. The presence of these two indicator species (*R. aculeatus* and *A. ramosus*) suggests that areas with low-rooting levels may have been intensely affected by wild boar feeding activities in the past. These previous activities may have determined major compositional and structural modifications resulting in the dominance of clonal, thorny, and unpalatable species. The current high cover values of these species, and especially of *R. aculeatus*, are likely to further inhibit feeding activities by wild boar, therefore, the areas where they are particularly abundant display low-rooting values.

The species with a significant indicator value in the Circeo groups of plots, both with low- and high-rooting levels, are highly consistent with the studied communities that are characterised by a combination of Mediterranean climbing species (*Lonicera etrusca*, *Rosa sempervirens*, *Rubia peregrina*), and of perennial tussocks typically occurring in deciduous forests (*Luzula forsteri*, *Melica uniflora*). These species are likely to result as indicators due to the fact that they do not occur at all in the Castelporziano plots. Indeed, species such as *Piptatherum miliaceum* (=*Oryzopsis miliacea*), *Erigeron sumatrensis* (=*Conyza albida*), *Juncus effusus* and *Calamintha nepeta*, which are indicators of Castelporziano plots (site A), may be considered not consistent with the vegetation type under study, whereas they are likely to be related to specific characteristics of the Castelporziano estate and to the abundance of wild boars in this area.

The species *P. miliaceum* was found to be strongly associated to recently urbanised areas under a Mediterranean climate (Dana et al. 2002) as is the area surrounding the Castelporziano estate. The proximity to urban environments may also be the reason of the occurrence of *Conyza albida* in site A. This species is native of America, but it is currently globally widespread and listed as invasive in Italy (Celesti-Grapow et al. 2009). The occurrence of *C. nepeta* and *J. effusus* in Castelporziano (site A) may be related to a higher presence of gaps where high light levels and high temperatures may affect the composition of the understorey, indeed both species have high Ellenberg indicator indices for light and temperature (Pignatti 2005). However, *J. effusus* may also be substantially favoured by the high density of wild boar in the Castelporziano forest since this species is effectively dispersed by wild boars both through endo- and ecto-zoochory (Schmidt et al. 2004).

The other indicator species of site A point to a great cover of evergreen (*Rhamnus alaternus*, *Phillyrea latifolia*) and deciduous (*Carpinus orientalis*, *Cytisus scoparius*) shrubs, also in relation to the death and senescence of very large and old trees in this forest (see also Tables 2, 3) together with the scarce recruitment of deciduous oak trees (Fanelli and Tescarollo 2006; Macuz et al. 2006).

Despite the fact that previous studies have demonstrated substantial effects of wild boar on the recruitment of oaks (Gomez and Hodar 2008), our results did not highlight this relationship. This may be a consequence of the fact that, we compared areas characterised by different levels of rooting intensity rather than rooted and unrooted areas and, as acorns represent an important part of wild boar's diet (Pinna et al. 2007), it is likely that oak recruitment is affected by wild boar also in areas where the intensity of rooting is low. The same explanation applies to *Cyclamen repandum* and *C. hederifolium* as both these species are amongst the most actively predated by wild boar; therefore, only experiments based on the total exclusion of rooting disturbance may allow the detection of wild boar effects on them.

### 4.2 Long-term exclosure experiments are needed to detect variation in species diversity

Our results highlight: (1) the occurrence of significant compositional changes in forest communities in response to wild boar activities and (2) that these changes are derived from present as well as from past disturbance by wild boar. Therefore, our study underscores the need of long-term experimental studies to be conducted through exclosures. We think that Castelporziano Estate represents a unique opportunity to perform such studies in an experimental forest of high biogeographical and conservation concern.

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## References

Anderson MJ (2001) Permutation tests for univariate or multivariate analysis of variance and regression. Can J Fish Aquat Sci 58:629–639. doi:10.1139/cjfas-58-3-626

Badalì M, Socciarelli S, Biondi FA, Gorga R (1999) Tenuta Presidenziale di Castelporziano: caratteristiche geologiche. Boll Soc It Sci Suolo 48:369–381

Bertacchi A, Lombardi T (2014) Diachronic analysis (1954–2010) of transformations of the dune habitat in a stretch of the Northern Tyrrhenian Coast (Italy). Plant Biosyst 148:227–236. doi:10.1080/11263504.2013.788572

Biondi E, Burrascano S, Casavecchia S, Copiz R, Del Vico E, Galdenzi D, Gigante D, Lasen C, Spampinato G, Venanzoni R, Zivkovic L, Blasi C (2012) Diagnosis and syntaxonomic interpretation of Annex I Habitats (Dir. 92/43/EEC) in Italy at the alliance level. Plant Sociol 49:5–37. doi:10.7338/pls2012491/01

Blasi C, Carranza ML, Filesi L, Tilia A, Acosta A (1999) Relation between climate and vegetation along a Mediterranean-Temperate boundary in central Italy. Glob Ecol Biogeogr 8:17–27. doi:10.1046/j.1365-2699.1999.00121.x

Burrascano S, Sabatini FM, Blasi C (2011) Testing indicators of sustainable forest management on understorey composition and diversity in southern Italy through variation partitioning. Plant Ecol 212:829–841. doi:10.1007/s11258-010-9866-y

Burrascano S, Del Vico E, Fagiani S, Giarrizzo E, Mei M, Mortelliti A, Sabatini FM, Blasi C (2014) Wild boar rooting intensity determines shifts in understorey composition and functional traits (submitted)

Capotorti G, Del Vico E, Lattanzi E, Tilia A, Celesti-Grapow L (2013) Exploring biodiversity in a metropolitan area in the Mediterranean region: the urban and suburban flora of Rome (Italy). Plant Biosyst 147:174–185. doi:10.1080/11263504.2013.771715

Celesti-Grapow L, Alessandrini A, Arrigoni PV, Banfi E, Bernardo L, Bovio M, Brundu G, Cagiotti M, Camarda I, Carli E, Conti F, Fascetti S, Galasso G, Gubellini L, La Valva V, Lucchese F, Marchiori S, Mazzola P, Peccenini S, Pretto F, Poldini L, Prosser F, Siniscalco C, Villani MC, Viegi L, Wilhalm T, Blasi C (2009) The inventory of the non-native vascular flora of Italy. Plant Biosyst 143:386–430. doi:10.1080/11263500902722824

Celesti-Grapow L, Capotorti G, Del Vico E, Lattanzi E, Tilia A, Blasi C (2013) The vascular flora of Rome. Plant Biosyst 147:1059–1087. doi:10.1080/11263504.2013.862315

Clarke KR, Gorley RN (2006) PRIMER v6: user manual/tutorial, 1st edn. PRIMER-E Ltd, Plymouth

Conti F, Abbate G, Alessandrini A, Blasi C (2005) An annotated checklist of Italian vascular flora, 1st edn. Palombi Editore, Roma

Corona P, Blasi C, Chirici G, Facioni L, Fattorini L, Barbati A (2010) Monitoring and assessing old-growth forest stands by plot sampling. Plant Biosyst 144:171–179. doi:10.1080/11263500903560710

Dana ED, Vivas F, Mota JS (2002) Urban vegetation of Almería city—a contribution to urban ecology in Spain. Landsc Urban Plan 59:203–216. doi:10.1016/S0169-2046(02)00039-7

Debussche M, Debussche G, Lepart J (2001) Changes in the vegetation of Quercus pubescens woodland after cessation of coppicing and grazing. J Veg Sci 12:81–92. doi:10.1111/j.1654-1103.2001.tb02619.x

Dufrene M, Legendre P (1997) Species assemblages and indicator species: the need for a flexible asymmetrical approach. Ecol Mon 67:345–366. doi:10.2307/2963459

Fagiani S, Fipaldini D, Santarelli L, Burrascano S, Del Vico E, Giarrizzo E, Mei M, Vigna Taglianti A, Boitani L, Mortelliti A (2014) Monitoring protocols for the evaluation of the impact of wild boar (*Sus scrofa*) rooting on plants and animals in forest ecosystems. Hystrix 25:1–8. doi:10.4404/hystrix-25.1-9314

Fanelli G, Tescarollo P (2006) Il rinnovamento delle specie arboree caducifoglie a Castelporziano. In: Il sistema ambientale della Tenuta Presidenziale di Castelporziano—Ricerche sulla complessità di un ecosistema forestale costiero mediterraneo. Seconda serie II:609–622

Farris E, Pisanu S, Ceccherelli G, Filigheddu R (2013) Human trampling effects on Mediterranean coastal dune plants. Plant Biosyst 147:1043–1051. doi:10.1080/11263504.2013.861540

Gomez JM, Hodar JA (2008) Wild boars (*Sus scrofa*) affect the recruitment rate and spatial distribution of holm oak (*Quercus ilex*). For Ecol Manag 256:1384–1389. doi:10.1016/j.foreco.2008.06.045

Gonzalez-Fernandez O, Queralt I, Manteca JI, Garcia G, Carvalho ML (2011) Distribution of metals in soils and plants around mineralized zones at Cartagena-La Unión mining district (SE, Spain). Environ Earth Sci 63:1227–1237. doi:10.1007/s12665-010-0796-8

Hone J (2002) Feral pigs in Namadgi National Park, Australia: dynamics, impacts and management. Biol Conserv 105:231–242. doi:10.1016/S0006-3207(01)00185-9

Howe TD, Bratton SP (1976) Winter rooting activity of European wild boar in the Great Smoky Mountain National Park. Castanea 41:256–264

Hunter ML (1990) Wildlife, forests and forestry: principles of managing forests for biological diversity. Prentice Hall, Englewood Cliffs

Ickes K, Paciorek CJ, Thomas SC (2005) Impacts of nest construction by native pigs (*Sus scrofa*) on lowland Malaysian rain forest saplings. Ecology 86:1540–1547. doi:10.1890/04-0867

Lowe S, Browne M, Boudjelas S, De Poorter M (2000) 100 of the world's worst invasive alien species. A selection from the global invasive species database, ISSG, SSC and IUCN

Macuz A, Lo Sterzo M, Giordano E, Scarascia Mugnozza G (2006) Rinnovazione naturale dei querceti caducifogli della Tenuta di Castelporziano: indagini strutturali ed ecofisiologiche. In: Il sistema ambientale della Tenuta Presidenziale di Castelporziano—Ricerche sulla complessità di un ecosistema forestale costiero mediterraneo. Seconda serie, vol II. pp 623–651

Massei G, Genov P (2004) The environmental impact of wild boar. Galemys 16:135–145

McCune B, Mefford MJ (2006) PC-ORD: multivariate analysis of ecological data (version 5.10). MjM software, Gleneden Beach, Oregon

Mecella G, Scandella P, Tinelli A, De Michelis A (1999) Descrizione dei principali aspetti storici ed ambientali della Tenuta Presidenziale di Castelporziano. Boll Soc It Sci Suolo 48:349–357

Onaindia M, Dominguez I, Albizu I, Garbisu C, Amezaga I (2004) Vegetation diversity and vertical structure as indicators of forest disturbance. For Ecol Manag 195:341–354. doi:10.1016/j.foreco.2004.02.059

Perrino EV, Tomaselli V, Costa R, Pavone P (2013) Conservation status of habitats (Directive 92/43 EEC) of coastal and low hill belts in a Mediterranean biodiversity hot spot (Gargano—Italy). Plant Biosyst 147:1006–1028. doi:10.1080/11263504.2013.860052

Pignatti S (1982) Flora d'Italia., 1st edn, vol 3. Edagricole, Bologna

Pignatti S (2005) Valori di bioindicazione delle piante vascolari della flora d'Italia. Braun-Blanquetia 39. 95 pp

Pinna W, Nieddu G, Moniello G, Cappai MG (2007) Vegetable and animal food sorts found in the gastric content of Sardinian Wild Boar (*Sus scrofa meridionalis*). J Anim Physiol Anim Nutr 91:252–255. doi:10.1111/j.1439-0396.2007.00700.x

R Development Core Team (2009) R: a language and environment for statistical computing. R foundation for statistical computing, Vienna, Austria. ISBN 3-900051-07-0. http://www.R-project.org

Ricotta C, Celesti-Grapow L, Avena G, Blasi C (2001) Landscape and urban planning 57:69–76. doi:10.1016/S0169-2046(01)00187-6

Sabatini FM, Burrascano S, Tuomisto H, Blasi C (2014) Ground layer plant species turnover and beta diversity in southern-european old-growth forests. PLoS One 9:1–13. doi:10.1371/journal.pone.0095244

Schmidt M, Sommer K, Kriebitzsch WU, Ellenberg H, von Oheimb G (2004) Dispersal of vascular plants by game in northern Germany. Part I: roe deer (*Capreolus capreolus*) and wild boar (*Sus scrofa*). Eur J For Res 123:167–176. doi:10.1007/s10342-004-0029-3

Siemann E, Carrillo JA, Gabler CA, Zipp R, Rogers WE (2009) Experimental test of the impacts of feral hogs on forest dynamics and processes in the southeastern US. For Ecol Manag 258:546–553. doi:10.1016/j.foreco.2009.03.056

Tutin TG, Heywood YH, Burges NA, Moore DM, Valentine DH, Walters SM, Webb DA (eds) (1968–1980): Flora Europaea, II–V. Cambridge University Press, Cambridge

Tutin TG, Burges NA, Chater AO, Edmondon JR, Heywood YH, Moore DM, Valentine DH, Walters SM, Webb DA (eds) (1993) Flora Europaea, I, 2nd edn. Cambridge University Press, Cambridge

Višnjić Ć, Solaković S, Mekić F, Balić B, Vojniković S, Dautbašić M, Gurda S, Ioras F, Ratnasingam J, Abrudan IV (2013) Comparison of structure, regeneration and dead wood in virgin forest remnant and managed forest on Grmeč Mountain in Western Bosnia. Plant Biosyst 147:913–922. doi:10.1080/11263504.2012.751064

Welander K (2000) Spatial and temporal dynamics of wild boar (*Sus scrofa*) rooting in a mosaic landscape. J Zool 252:263–271. doi:10.1111/j.1469-7998.2000.tb00621.x