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Plant species selection and impact on tree resprouts by semi-free ranging pigs in a temperate deciduous forest

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Abstract Silvopastoral systems with grazing pigs are mainly concentrated in Mediterranean regions, for instance in Iberian *dehesas* and *montados*. Conversely, in European deciduous forests, outdoor pig farming has almost disappeared, despite it could provide several environmental and socioeconomic benefits. For instance, pig grazing could be used for habitat restoration and conservation, while providing high quality meat products and promoting local breeds. In this study, we investigated (i) the plant species selection and (ii) the impact on tree resprouts (after a silvicultural cut) by semi-free ranging pigs in a degraded oak temperate forest in Northwestern Italy. We monitored pigs foraging behavior by direct observations and discriminated the plant species into three groups: preferred, indifferently consumed and avoided plants. The impact on the resprouts of six tree species was assessed by modeling the percentage of damaged shoots and their height through time using Generalized Linear and Additive Mixed Models. Swine expressed a selective foraging behavior, which was likely influenced by the forage quality and toxicity of plant species. The leaves and resprouts of *Corylus avellana* and *Castanea sativa* were highly consumed, whereas *Acer* and *Quercus* species and *Fraxinus ornus* were avoided. Mature leaves of *Robinia pseudoacacia* were highly preferred while its young resprouts were only slightly impacted, suggesting that pig grazing may not be effective to control this alien invasive species. Contrarily, pigs consumed *Rubus* sp. abundantly, suggesting they could be used to clear the understory in degraded forests.

Keywords Silvopastoral system · Pig grazing · Feeding preferences · Coppicing · Bramble · Black locust

Giampiero Lombardi and Michele Lonati have contributed equally to this work.

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Introduction

Silvopastoralism has a long tradition in Europe, being practiced in the past in all the countries and biogeographic regions, from boreal forests to Mediterranean evergreen oak wood-pastures (Rigueiro-Rodríguez et al. 2009). With the intensification of agriculture in the mid-twentieth century, silvopastoral systems declined in many regions and nowadays they are mainly concentrated in the Mediterranean area (Mosquera-Losada et al. 2016). However,

during the last 20 years, a novel interest has grown in this multifunctional system, due to the numerous ecosystem services that it provides to society (Moreno et al. 2018). For instance, there is evidence that forest grazing by livestock can enhance plant biodiversity, control shrub encroachment, and counteract the invasion of alien species (Mayle 1999; McEvoy et al. 2006; Öllerer et al. 2019). Moreover, it has also proven to be an efficient and cost-effective fire prevention tool (see for instance 'RAPCA', the network of grazed fuel breaks in Andalucia; Varela et al. 2018). As a consequence, the European Union has recognized the importance of silvopastoralism for the sustainability of farming systems, supporting it with the Common Agricultural Policy measures (Mosquera-Losada et al. 2016).

Among present silvopastoral systems, those based on pigs are mainly located in Mediterranean oak forests and wood-pastures. For instance, the farming of Iberian pigs in the Spanish *dehesas* and Portuguese *montados* is an excellent example of a multifunctional agroforestry system, whose value is well-recognized by the consumers of the derived animal products (Silva and Nunes 2013). Conversely, in temperate deciduous forests, outdoor pig farming has almost disappeared (Jørgensen 2013; Molnár et al. 2021), despite it could provide multiple environmental and socioeconomic benefits in these habitats as well: pig grazing might be used for habitat conservation and restoration in degraded and abandoned forests (Mayle 1999; Molnár et al. 2021); pig farming systems can support the conservation of local breeds, which are more suitable for forest farming than the commercial ones (Miao et al. 2004); last but not least, meat products could be highly valued on the market due to their quality (Silva and Nunes 2013) and could respond to the increasing demand for higher animal welfare standards (Brownlow et al. 2005).

Despite the potential positive effects of pig grazing in the deciduous forests of Europe, their foraging behavior in these environments has been poorly documented (but see Molnár et al. 2021), while forest sustainable management and habitat conservation actions would profit from this knowledge. Indeed, the selection of plant species by livestock has direct consequences on vegetation composition and structure (e.g., Pittarello et al. 2017; Pauler et al. 2020). Moreover, when silvicultural practices are applied to woodlands (e.g., in coppice systems), the knowledge on how pig browsing affects tree regeneration would be relevant.

In this context, pig grazing was introduced in a degraded oak (*Quercus robur* L.) stand in Northwestern Italy, where nowadays this type of management is not a common practice, as part of the pilot project 'Food for Forest' (Rural Development Programme—RDP, measure 16.2 of Piedmont Region). The aim of the project was to test whether pig grazing could be suitable for the restoration and sustainable management of the forest. The forest was degraded due to the abandonment of silvicultural management, which led to the worsening of the tree composition (reduction of valuable autochthonous tree species, such as oaks) and structure (reduction of large adult trees), the invasion by undesirable and alien plant species, and the reduction of its economic value. Specifically, pig grazing was targeted to reduce the abundance of undesirable shrubs in the understory, such as bramble (*Rubus* sp.), and of alien plant species, such as *Robinia pseudoacacia* L. Bramble tends to expand in degraded woodlands, causing a reduction of biodiversity (McEvoy et al. 2006; Harmer et al. 2016). Moreover, it severely limits silvicultural interventions due to the expensive mechanical clearance needed to remove it. *Robinia pseudoacacia* is a N-fixing legume which alters soil characteristics and affects biodiversity and plant community composition in native forest ecosystems (Vítková et al. 2017). Besides the introduction of pig grazing, the pilot project 'Food for Forest' also included silvicultural interventions to improve the composition and structure of the forest tree layer.

In the present study, we aimed at assessing the foraging behavior of semi-free ranging pigs in a degraded temperate forest. Particularly, we investigated (a) the plant species selection of swine grazing in the forest understory and (b) the impact of browsing on the resprouts of six tree species (*Acer pseudoplatanus* L., *Castanea sativa* Mill., *Corylus avellana* L., *Fraxinus ornus* L., *Prunus avium* L., and *R. pseudoacacia*) after silvicultural cuts.

Methods

Study area

The study was carried out in a hill woodland stand in Piedmont Region, Italy (45° 19′ 59.2″ N 7° 53′ 52.3″ E; Fig. 1a). The area was included in Natura 2000 network (Special Area of Conservation IT1110009 'Bosco del Vaj e Bosc Grand'). The elevation was 500 m a.s.l. and the average slope was 20°. Average annual temperature and precipitation were 13 °C and 938 mm, respectively (average of the period 2004–2018, climatic station S3098, Castagneto Po; ARPA Piemonte 2021). Soil texture was sandy loam and the reaction was neutral. The forest had a two-layers vertical structure, with an oak (*Q. robur*) top layer (about 20 m height) and a second coppice layer (about 10 m height) dominated by *C. sativa* and by the alien invasive species *R. pseudoacacia*. Other mesophilous species in the copse were *A. pseudoplatanus*, *P. avium*, and *F. ornus*. Cumulative canopy cover of both tree layers was about 90%. The coppice wood volume was 180 m^3/ha. The shrub layer included species such as *C. avellana*, *Ligustrum vulgare* L., *Hedera helix* L., and *Rubus* sp., and had an average cover of about 40%. Herbaceous species were sparse and their average cover was < 10%.

The traditional management of the forest was coppice with standards, with the coppice layer (*C. sativa*) managed for firewood and wooden poles production and the top layer (*Q. robur*) managed by high forest for industrial timber production. The coppice was cut every 10–15 years, while the oaks were cut when they reached a minimum size of about 50 cm of diameter. The management of the forest has been abandoned since about the early 1990s.

Grazing management and silvicultural interventions

Rotational grazing was implemented in the study area with the 'Nero di Parma' breed in 2019. Three paddocks (A, B, and C; Fig. 1b) of 2.8, 3.9 and 5.5 ha in size, respectively, were electrically fenced. Paddocks were adjacent one to another and comparable in terms of vegetation composition and structure. A total of 22 barrows exploited the paddocks in rotation from late March to October 2019. Grazing days of rotation periods depended on each paddock size, on the forage availability inside them, and on the animal weight (Table 1). The farmer moved the pigs from one paddock to another ensuring that grazing pressure was

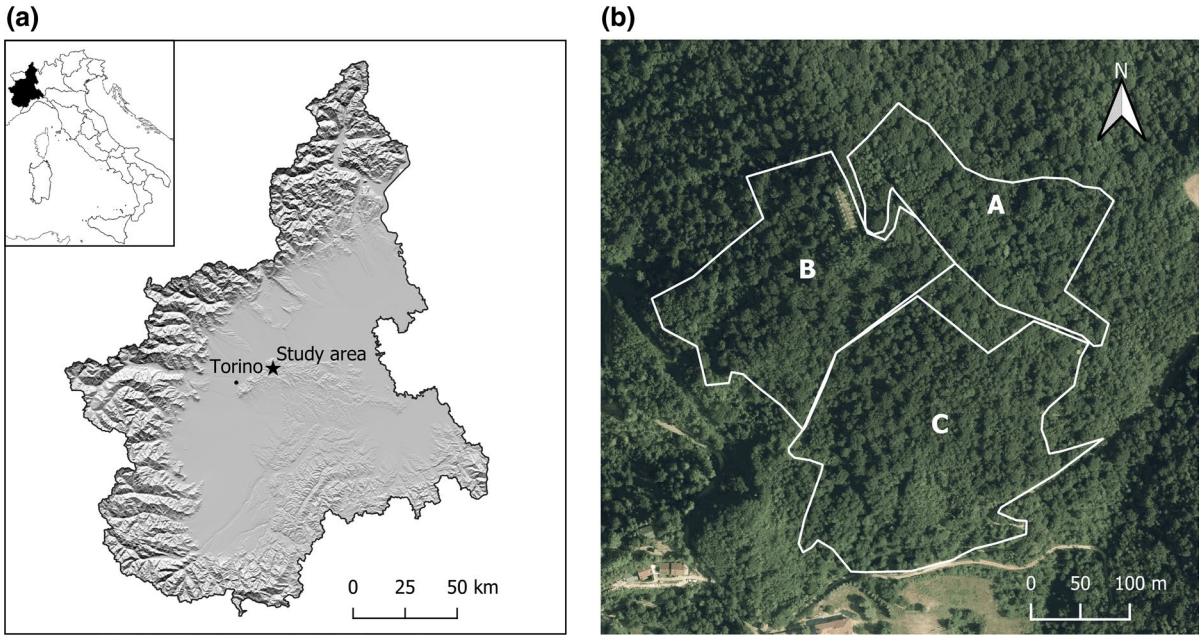

Fig. 1 **a** Location of the study area in Piedmont region, Northwestern Italy, and **b** paddocks set up for pig grazing

Table 1 Paddock size, number of pigs, and grazing dates and days in the three paddocks in 2019, and in paddock A in 2020

	Paddock size [ha]	Number of pigs	Start–end dates	Grazing days
2019				
Paddock A	2.8	22	28th March–30th May	64
Paddock B	3.9	22	31st May–04th July	35
Paddock C	5.5	22	05th July–12th October	99
2020				
Paddock A	2.8	29	22nd May–20th August	90

uniform among paddocks. During winter 2019–2020, a coppicing treatment extracted 37% of the copse wood volume of the second tree layer (corresponding to 68 m^3/ha) in paddock A, while trees of the top layer were not cut. Tree cutting involved the most abundant species in the paddock, i.e. *A. pseudoplatanus*, *C. sativa*, *C. avellana*, *F. ornus*, *P. avium*, and *R. pseudoacacia*. From late May to August 2020, 29 barrows grazed in paddock A after tree cutting for 90 days (Table 1). Grazing days in paddock A were extended in 2020 compared to 2019 because of the additional forage provided by the resprouts after the silvicultural cutting (Table 1). In both years, the swine were 6 months old and weighed around 60 kg at the start of the grazing period, and reached around 160 kg at the end of the season. To meet pig needs, animals were fed daily with a concentrate with 16.5% of dry matter of crude protein, at a dose increasing during the season from 2 to 3 kg pig^{-1} day^{-1}, according to the barrow weight. Water was supplied ad libitum using a tank with drinkers, which was regularly moved over the paddock to favor a more homogeneous exploitation of the area. Swine were fitted with nose rings to avoid excessive soil rooting.

Plant species selection

In the first year of the study (2019), we used direct observations to assess the plant species selection by pigs exploiting the understory. Direct observations are commonly used to study livestock feeding preferences in woody-dominated habitats (e.g., Rodríguez-Estévez et al. 2009; Elias and Tischew 2016). Pigs were accustomed to humans, so that observers were allowed to stay close to them without affecting their behavior. Each observer monitored the behavior of a randomly chosen animal during 30″ observation sessions followed by 2′:30″ breaks between each observation. For each observation, the activity of the pig was attributed to one of the following categories: grazing, rooting, searching for food, walking, resting, and others (including all other activities such as drinking, defecation, social interactions etc.). For the purpose of this study, the grazing activity referred to the consumption of any green tissue (leaves, stems and inflorescences) belonging to both herbaceous and woody plant species. Identifying the consumption of other resources such as tree fruits, roots, invertebrates, etc. was not possible. For each grazing observation session, we identified and recorded (i) the plant species consumed by the pig, and (ii) the plants that were not consumed within a 50-cm buffer area around the head of the pig and at a maximum above ground height of 1 m. We assumed that all the plants available in this buffer area were detectable by the pig and that a 1-m height corresponded to the layer that animals could exploit (threshold set according to our field observations). The nomenclature of plant species followed Pignatti et al. (2017).

The monitoring was carried out from May to August 2019, i.e. during the vegetation growing season, for a total of 10 monitoring days: 2 days in paddock A, four in paddock B, and four in paddock C. Total monitoring hours were 134: 41 h in paddock A, 49 in paddock B, and 44 in paddock C. The observations were carried out approximately from 12:00 to 17:00, i.e. avoiding the morning hours when the farmer provided the feed supplements.

Browsing on post-cut tree resprouts

In the second year of the study (2020), we assessed the impact of pig browsing on tree regeneration of *A. pseudoplatanus*, *C. sativa*, *C. avellana*, *F. ornus*, *P. avium*, and *R. pseudoacacia*, for a total of 86 stumps randomly distributed over paddock A. Specifically,

we monitored (i) the damages to tree shoots sprouted after the silvicultural cuts and (ii) the shoot growth along the growing season. The monitoring of shoot development was carried out at 2-week intervals throughout the growing season, for a total of seven survey dates. On the first date, corresponding to the day before barrows entered the paddock, we checked the presence and development of suckers emitted by the stumps after the cutting. The six subsequent surveys were used to assess the effect of pig browsing on shoot development. We attributed to each stump an identification code and assessed its post-cut diameter. The variables measured at each survey date were: number of shoots per stump, presence/absence of browsing damage to leaves and to apical buds, and individual shoot height. From these data we computed the percentage of damaged shoots and the average shoot height per each stump and survey date.

Statistical analyses

To assess the plant species selection, we computed for each species the number of 'consumption' events (i.e., the number of grazing observations when the plant species was consumed) and the number of 'no consumption' events (i.e., the number of grazing observations when the plant species was available but not consumed). Then, a Chi-square test on the frequencies of 'consumption' vs 'no consumption' events was performed for each species to discriminate three groups of plants: preferred, indifferently consumed, and avoided plants. The null hypothesis was that there were no statistical differences between the number of 'consumption' and 'no consumption' events. In case of acceptance of the null hypothesis, the species was considered 'indifferently consumed' by the pigs. In case of rejection of the null hypothesis (at $p < 0.05$), the species was considered as 'preferred' when the number of 'consumption' events was higher than that of 'no consumption' events, while it was considered as 'avoided' when it was lower. According to Chi-square assumptions, only the plant species being recorded in at least ten grazing observation sessions were tested. All grazing observations from the three paddocks were joined in the analysis.

To assess the impact of pig browsing on the post-cut tree resprouts throughout time, we performed a Generalized Linear Mixed Model (GLMM) with a beta distribution to model the percentage of damaged shoots in function of: (i) time by species interaction, to test the hypothesis that the damage to tree shoots changed linearly over time but differed by species; (ii) stump diameter, to test the hypothesis that damage rate decreased with larger stumps; and (iii) shoot density, to test the hypothesis that browsing rate decreased as the number of shoots increased, i.e. a density-dependent economy of scale. Specifically, time by species interaction, shoot density, and stump diameter were set as fixed factors, while stump was set as random factor to account for the repeated measurements over time. Shoot density and stump diameter were standardized (z-score). A second model was built to assess the impact of pig browsing on shoot height throughout time. In this case we used a Generalized Additive Mixed Model (GAMM) since shoot heights might increase and decrease non-linearly through time, according to the initial resprouting vigor and browsing effect. Specifically, shoot height was assumed to follow a Gaussian distribution after log-transformation, and was modeled in function of time by species interaction as fixed factor and stump as random factor to account for the repeated measurements over time.

The R software (R Core Team 2018) was used for statistical analysis. The GLMM and GAMM were run with the 'glmmTMB' and 'mgcv' packages, respectively. The 'visreg' package was used to graphically visualize the relationship between the response and the explanatory variables.

Results

In total, we recorded 2435 observations of animal behavior, among which, rooting (30% of the total) and grazing (24%) were the prevailing ones, followed by resting (17%), walking (13%), searching for food (10%), and others (6%).

According to the Chi-square tests, three plant species in the understory were preferred, nine species were consumed indifferently, and 18 species were avoided (Table 2). *Robinia pseudoacacia* showed the highest percent consumption (84%), whereas *Ruscus aculeatus* L., *Euonymus europaeus* L., *Carex sylvatica* Huds., *Crataegus monogyna* Jacq., *Asphodelus albus* Mill., *Lonicera caprifolium* L., and *Viburnum lantana* L. were never eaten by pigs.

Table 2 Plant life form (W = woody, H = herbaceous), number of 'Consumption' events, number of 'No Consumption' events, percent consumption, and Chi-square statistic and significance of 30 plant species recorded during the observation sessions

Species	Plant life form	'Consumption' events (*n*)	'No consumption' events (*n*)	Percent consumption (%)	Chi square
Preferred					
Robinia pseudoacacia L.	W	32	6	84	16.45***
Corylus avellana L.	W	147	47	76	50.52***
Rubus sp.	W	142	90	61	11.21***
Indifferently consumed					
Castanea sativa Mill.	W	20	11	65	2.06
Hedera helix L.	W	224	208	52	0.52
Prunus avium L.	W	21	25	46	0.20
Molinia arundinacea Schrank	H	5	6	45	0.00
Clematis vitalba L.	W	26	35	43	1.05
Humulus lupulus L.	W	9	13	41	0.41
Cornus sanguinea L.	W	29	42	41%	2.03
Ulmus minor Mill.	W	28	42	40	2.41
Fraxinus excelsior L.	W	2	8	20%	2.50
Avoided					
Tamus communis L.	H	11	25	31	4.69*
Acer campestre L.	W	13	35	27	9.19**
Acer pseudoplatanus L.	W	7	19	27	4.65*
Solidago gigantea Aiton	H	4	35	10	23.08***
Quercus cerris L.	W	2	20	9	13.14***
Physospermum cornubiense (L.) DC.	H	1	12	8	7.69**
Quercus robur L.	W	5	74	6	58.53***
Quercus pubescens Willd.	W	1	22	4	17.39***
Viola riviniana Rchb.	H	1	35	3	30.25***
Fraxinus ornus L.	W	2	130	2	122.19***
Ligustrum vulgare L.	W	1	95	1	90.09***
Ruscus aculeatus L.	H	0	31	0	29.03***
Euonymus europaeus L.	H	0	26	0	24.04***
Carex sylvatica Huds.	H	0	16	0	14.06***
Crataegus monogyna Jacq.	W	0	13	0	11.08***
Asphodelus albus Mill.	H	0	12	0	10.08**
Lonicera caprifolium L.	W	0	11	0	9.09**
Viburnum lantana L.	W	0	11	0	9.09**

Plant species are grouped by feeding selection into 'preferred', 'indifferently consumed' and 'avoided'. *, $p < 0.05$; **, $p < 0.01$; ***, $p < 0.001$

The total number of stump shoots monitored after the silvicultural cut was 987, on average, at each survey date. The percentage of shoots damaged by pig browsing significantly increased through time for *C. sativa*, *C. avellana*, *P. avium*, and *R. pseudoacacia*, with higher slopes for the first three species than for *R. pseudoacacia* (Table 3, Fig. 2). At the end of the grazing season, damaged shoots were > 75% for *C. sativa*, *C. avellana* and *P. avium* and around 25% for *R. pseudoacacia* (Fig. 2). *Acer pseudoplatanus* and *F. ornus* showed the lowest damage on shoots (< 25%) and no significant changes throughout time. The shoot density (mean = 12, min = 1, max = 74) and stump diameter (mean = 15 cm, min = 2 cm, max = 40 cm) did not affect the percentage of damaged shoots (Table 3). Shoot height (mean = 36 cm,

Table 3 Generalized Linear Mixed Model (GLMM) and Generalized Additive Mixed Model (GAMM) performed on the percentage of damaged shoots and on shoot height, respectively, of six tree species after the silvicultural cutting

Response variable	Percentage of damaged shoots		Shoot height	
Model form	GLMM		GAMM	
	Beta coeff.	sig	edf	sig
Predictors				
Time × Species				
Time × ACPS	+0.028	ns	**1.00**	**(s)*** **
Time × CASA	**+0.471**	***	**3.78**	**(s)*** **
Time × COAV	**+0.614**	***	**1.00**	**(s)*** **
Time × FROR	+0.012	ns	**2.98**	**(s)*** **
Time × PRAV	**+0.415**	***	**4.04**	**(s)*** **
Time × ROPS	**+0.103**	**	**5.01**	**(s)*** **
Shoot density	+0.022	ns		
Stump diameter	−0.022	ns		
Deviance explained	0.43		0.83	
R square	0.78		0.79	

Beta coefficient values and significance for the GLMM, edf value and smoother significance for the GAMM, and fitness metrics (deviance explained and R square) are reported. Significant predictors are in bold. Species codes: ACPS, *Acer pseudoplatanus*; CASA, *Castanea sativa*; COAV, *Corylus avellana*; FROR, *Fraxinus ornus*; PRAV, *Prunus avium*; ROPS, *Robinia pseudoacacia*. ns, $p \geq 0.05$; **, $p < 0.01$; ***, $p < 0.001$

min = 1 cm, max = 3.38 m) significantly changed along the monitoring period for all the plant species (significant smoothers, Table 3). For *A. pseudoplatanus*, *F. ornus* and *R. pseudoacacia*, shoot height increased with time (Fig. 3), with *R. pseudoacacia* reaching the highest value at the end of the season (159 cm, on average). The height of *P. avium* shoots increased at the beginning of the season and was more stable in the second half, while that of *C. sativa* increased and decreased in the first and second half of the season, respectively. The height of *C. avellana* shoots, instead, decreased during the season (from 11.0 to 6.6 cm, on average).

Discussion

The results of our study showed that swine were selective both in the consumption of plant species in the understory and in browsing post-cut tree resprouts. Indeed, only three plant species (*R. pseudoacacia*, *C. avellana*, and *Rubus* sp.) out of 30 were preferred in the understory while more than half (18) were avoided. Concerning the resprouts, *C. avellana*, *C. sativa* and *P. avium* were more impacted than the other three tree species, resulting in poor or no growth throughout time.

The plant species whose resprouts were highly impacted by pigs (i.e., *C. avellana*, *C. sativa*, and *P. avium*) were also eaten with a high rate in the understory (consumption > 45%). Specifically, *C. avellana* was the second preferred plant species in the understory and its post-cut resprouts were the most affected, suggesting that this species could represent an important forage source for pigs in temperate forests. *Corylus avellana* foliage is considered of intermediate quality and livestock browse it in many silvopastoral systems (Hejcmanová et al. 2014; Vandermeulen et al. 2018a). The leaves and resprouts of *C. sativa* were also considerably eaten by pigs, despite the high tannin content (Pistoia et al. 2009). Tannins generally reduce the palatability of forage, but in some circumstances livestock feed on tannin-rich species to wane gastrointestinal parasites (Villalba et al. 2010). The impact on this plant species by swine was also reported by Pistoia et al. (2009), even though at a lower rate (< 30% of leaves and apexes damaged). The selection for *P. avium* leaves and resprouts was slightly lower than for *C. avellana* and *C. sativa*, but still remarkable. *Acer pseudoplatanus* and *F. ornus*, instead, were avoided by pigs in the understory and resprouts were only slightly affected. The avoidance for *A. pseudoplatanus* can be related to its low forage quality (Ravetto Enri et al. 2020) and/or to toxicity issues. The toxicity of *A. pseudoplatanus* non-woody parts has been linked to atypical myopathy in other monogastric species, like horses (Aboling et al. 2020). *Fraxinus ornus* is a common fodder plant for goats and sheep in Mediterranean environments and its forage quality is characterized by low crude protein and fiber content (Papachristou 1997; Papachristou et al. 1999). Swine avoided it probably because of the presence of specific chemical compounds, but further research on this topic is needed.

From the point of view of forest management, these results provide useful information about the possible use of free-ranging pigs in coppice systems, particularly in *C. sativa* and *F. ornus* stands. *Castanea sativa* woodlands occur over large areas in Italy, where *C. sativa* is the third tree per volume (9%

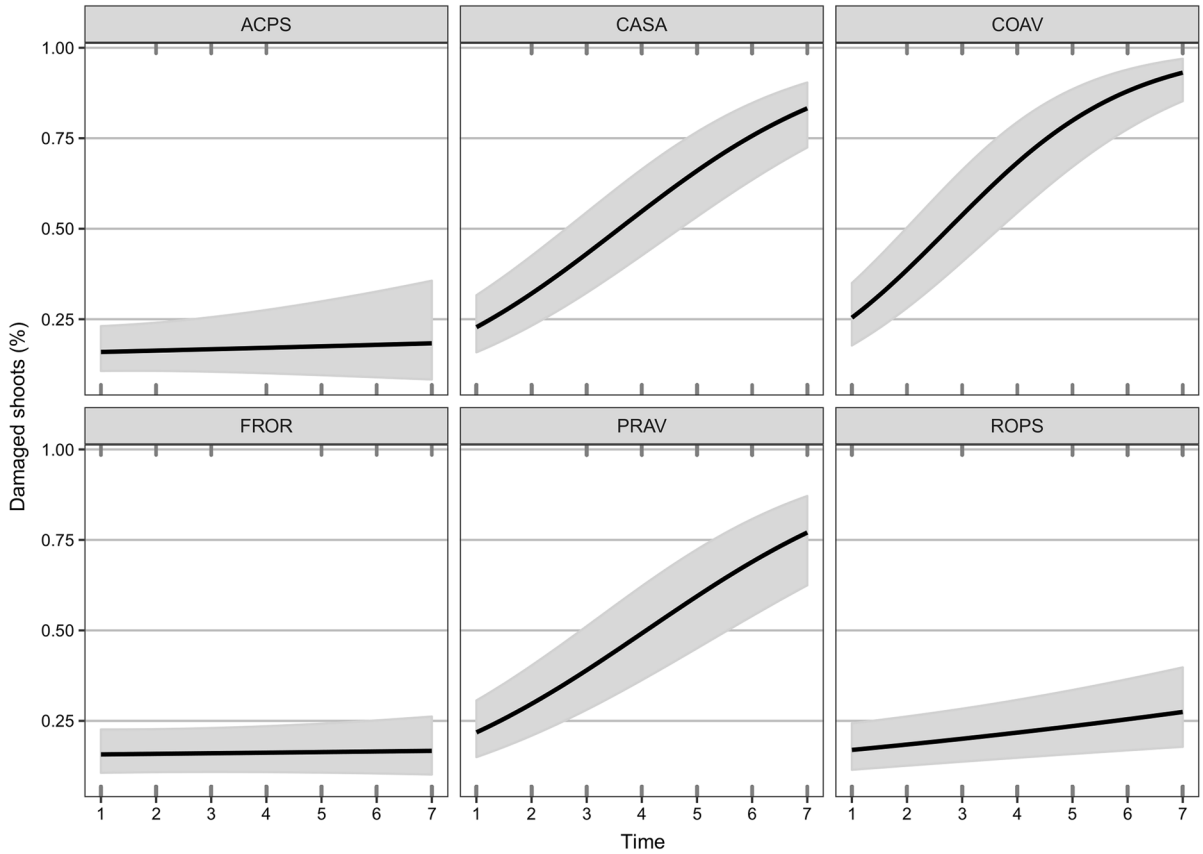

Fig. 2 Relationship between the percentage of damaged shoots and time (survey dates) for each plant species, according to the Generalized Linear Mixed Model. Species codes: ACPS, *Acer pseudoplatanus*; CASA, *Castanea sativa*; COAV, *Corylus avellana*; FROR, *Fraxinus ornus*; PRAV, *Prunus avium*; ROPS, *Robinia pseudoacacia*

of total volume; De Laurentis et al. 2021). They are traditionally managed with short rotation coppice to provide various timber assortments. The high impact on *C. sativa* resprouts by pigs suggests avoiding pig grazing after a renovation cut until regrowth is above browse height (i.e., about 1 m height). The exploitation of *F. ornus* coppice stands, typical of the Mediterranean regions, might be instead a feasible option also during the first post-cut years, due to the marked avoidance of this plant by swine.

Unlike other tree species, the preference for *R. pseudoacacia* was different in the understory and on post-cut resprouts. Indeed, it was the first preferred species in the former, whereas its resprouts were only slightly impacted in the latter. These differences might be determined by the different ages of leaves and shoots, which were older in the understory plants and younger in the post-cut resprouts. Indeed, it is possible that the young tissues contain a higher fraction of toxic compounds, such as robin, robinine, and robitin (Michalska et al. 2019). Poisoning by *R. pseudoacacia* was documented in other livestock species, such as horses (Vanschandevijl et al. 2010), whereas goats are able to forage on this protein-rich species, likely due to their greater ability to detoxify plant secondary metabolites (Papachristou and Papanastasis 1994; Giger-Reverdin et al. 2020). Interestingly, also Molnár et al. (2021) reported that swine did not consume *R. pseudoacacia*. Consequently, the resprouts of this fast-growing alien species can be hardly controlled by pigs, at least in the first season after cutting. However, the relationship among consumption, age of the plant tissues, and toxicity of *R. pseudoacacia* needs further and thorough investigation.

The impact on tree regeneration is a crucial issue in forest grazing, since the young seedlings and plants

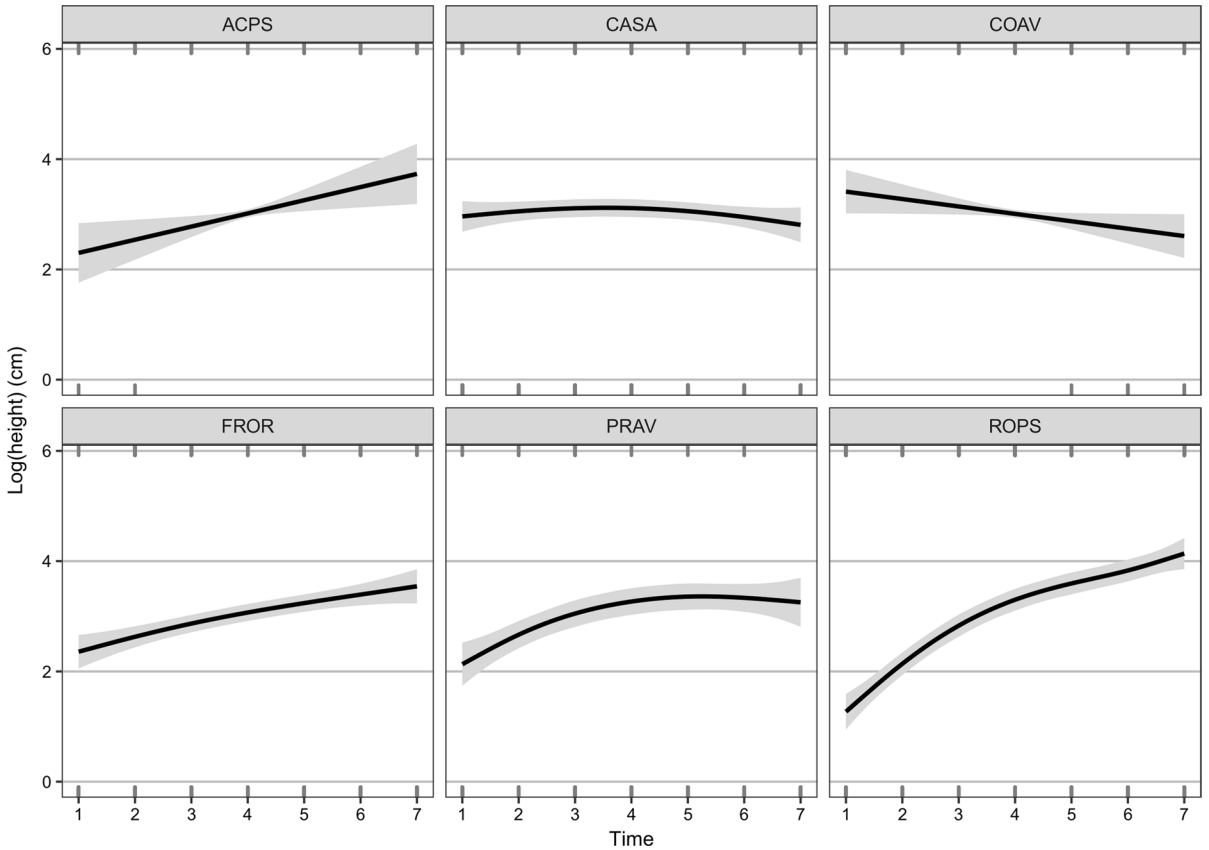

Fig. 3 Relationship between shoot height (log-transformed) and time (survey dates) for each plant species, according to the Generalized Additive Mixed Model. Species codes: ACPS, *Acer pseudoplatanus*; CASA, *Castanea sativa*; COAV, *Corylus avellana*; FROR, *Fraxinus ornus*; PRAV, *Prunus avium*; ROPS, *Robinia pseudoacacia*

can be damaged by browsing (López-Sánchez et al. 2016; Öllerer et al. 2019). At the same time, livestock can also facilitate seedling establishment through seed burial and removal of outcompeting vegetation (Kirby et al. 1994; Öllerer et al. 2019). In this study, all oak species (*Quercus cerris* L., *Q. robur*, and *Quercus pubescens* Willd.) were avoided by pigs in the understory (consumption 4–9%), likely due to their low forage quality (Papachristou and Papanastasis 1994; Pistoia et al. 2009; Hejcmanová et al. 2014). These findings agree with Pistoia et al. (2009) and Vandermeulen et al. 2018b, who observed that *Q. robur* was slightly consumed by pigs and cattle, respectively. Although the impact on oak plants in the understory was very limited, the exclusion of pigs for 2–3 years after renovation cuts would be advisable to avoid acorn consumption and allow undisturbed seedling growth.

Forest grazing is acknowledged for its role in reducing woody vegetation of the understory by both the consumption and trampling (McEvoy et al. 2006; Öllerer et al. 2019). In our study, *Rubus* sp. was abundant in the understory and it was among the plant species preferred by swine. This result agrees with the preliminary research of Pistoia et al. (2009), suggesting that pig grazing might be a valuable tool to counteract bramble proliferation in temperate abandoned forests, where this species is a major threat to plant diversity for its ability to suppress woodland species (Van Uytvanck and Hoffmann 2009; Harmer et al. 2016). However, specific research is necessary to assess the impact of pig grazing on bramble cover over time in such environments. *Hedera helix* L. was another abundant woody species in the forest, and despite the presence of toxic saponins (Wink 2010) it was moderately consumed by pigs (consumption

52%). *Hedera helix* is an important component of roe deer, red deer, and fallow deer diets, especially in autumn and winter (Metcalfe 2005). Being its leaves evergreen, it may thus represent an important forage source for swine from autumn to early spring, when other forages are not available. Shrub species such as *L. vulgare* and *E. europaeus*, instead, were avoided by pigs in the understory (consumption ≤ 1%), probably because of the presence of toxic compounds (secoiridoid glycosides in *L. vulgare* and cardenolides in *E. europaeus*; Wink 2010). Also *C. monogyna* was avoided by pigs contrary to the findings of Molnár et al. (2021), who reported, however, that this species was eaten only when leaves were young and spikes were soft.

Herbaceous plant species can benefit from the reduction of shrubs and the increase in light conditions induced by livestock, while on the other hand they can be sensitive to selective consumption, trampling or nutrient addition through urine and faeces (McEvoy et al. 2006; Öllerer et al. 2019). For instance, the palatable *Hyacinthoides non-scripta* (L.) Chouard ex Rothm. was adversely affected by grazing in Irish temperate forests (McEvoy et al. 2006) and *Anemone nemorosa* L., although being favored by the reduction of bramble cover, was sensitive to cattle grazing and trampling (Van Uytvanck and Hoffmann 2009). In this study, all the recorded herbaceous species typical of the forest flora, i.e., *A. albus*, *C. sylvatica*, *Physospermum cornubiense* (L.) DC., and *Viola riviniana* Rchb., were never or only occasionally eaten by pigs, suggesting that they would likely not be threatened by direct consumption. However, long-term studies appear necessary to assess the response of the forest typical flora to the complex integration of grazing, trampling and nutrient addition and to the modification of the shrub-herbs competition induced by pig grazing.

Conclusions

Our research provided novel results concerning the implementation of silvopastoral management practices in degraded deciduous forests, particularly adopting pig grazing. The outcomes of this study revealed a selective foraging behavior of pigs, highlighting contrasting preferences for understory plant species. Indeed, some species were preferred (*C. avellana*, *R. pseudoacacia*, and *Rubus* sp.), others were indifferently consumed (e.g. *C. sativa* and *H. helix*), while others were avoided (e.g. *Acer* spp. and *Quercus* spp.), likely due to differences in the forage quality and toxicity of plant species. The selection for *Rubus* sp. suggested that pig grazing might be a valuable tool to control this species in temperate abandoned forests. Conversely, even though *R. pseudoacacia* leaves from mature plants were highly preferred, its resprouts were not effectively controlled in the first season after the cut.

The outcomes provided by this pilot project could be applied in similar ecological and management conditions and plant species composition all over temperate Europe. Future studies should investigate the effects of pig grazing on bramble cover and on the plant diversity and composition of temperate deciduous forests over time.

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Data availability The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest The authors declare no conflict of interest.

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