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Research paper

Early and long-term impacts of browsing by roe deer in oak coppiced woods along a gradient of population density

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Abstract - Over the last few decades, wild ungulate populations have exhibited relevant geographic and demographic expansion in most European countries; roe deer is amongst the most widespread ungulate species. The increasing roe deer densities have led to strong impact on forest regeneration; the problem has been recently recognized in coppice woods, a silvicultural system which is widespread in Italy, where it amounts to about 56% of the total national forested area.
In this study we investigated the effect of roe deer browsing on the vegetative regeneration of Turkey oak few years after coppicing, along a gradient of roe deer density. A browsing index revealed that browsing impact was high at any given roe deer density but increased at higher density, with the browsing rate ranging from 65% to 79%. We also analyzed the long-term impact of browsing six and eleven years after coppicing under a medium roe deer density. Results indicated the early impact are not ephemeral but produced prolonged impacts through time, with an average reduction in volume of -57% and -41% six and eleven years after coppicing, respectively. Based on these results we proposed integrating browsing monitoring with roe deer density estimation to allow identifying ungulate densities which are compatible with silvicultural and forest management objectives. The proposed browsing index can be regarded as an effective management tool, on account of its simplicity and cost-effectiveness, being therefore highly suitable for routine, large scale monitoring of browsing impact.

Keywords - *Capreolus capreolus*, Turkey oak, forest damage, stool, coppice forest

Introduction

The coexistence of ungulates and forest ecosystems has gaining growing attention, mainly because of the steady increase in wild ungulate populations observed in the last few decades. This is a particularly relevant issue for roe deer (*Capreolus capreolus* L.), i.e., the most widespread European deer species, with an estimated 10 million individuals occurring in the continent (Apollonio et al. 2010, Linnell et al. 1998). Roe deer population densities have been growing notably during the last few decades (Cederlund et al. 1998, Gill 1990) due to the abandonment of rural areas, changes in human land use, restocking and lack of predators (Apollonio et al. 2010). In addition, changes in silvicultural systems have entailed a general decline in wood exploitation, improving productivity, biomass accumulation and structural complexity of forest ecosystems (Cutini et al. 2013). The reduced pressure on wood also resulted in a lower human disturbance on ungulates in general and roe deer in particular.

The increasing roe deer densities have led to conflicting interests between game and forest management (Apollonio et al. 2010, Cutini et al. 2011, Gill 1992). A land-owner aiming at silviculture and wood production may see his goals frustrated by high densities of ungulates permitted on neighbouring grounds (Kramer et al. 2006). The problems of deer browsing have long been recognized in conifer species (Gill 1992, Motta 1996, Mysterud and Ǿstbye 1999). Recently, the problem of deer impact has also been observed in coppice woods (Cutini et al. 2011), a silvicultural system which is widespread over Mediterranean countries. In Italy, coppice is the most frequently adopted silvicultural system in private forests, and it amounts to about 56% of the total forested areas in Italy (National Forest Inventory, www.infc.it). Deciduous Turkey oak (*Quercus cerris* L.) occupies the intermediate vegetation belt between sclerophyllous and mountain broadleaved forest over one million hectares (Di Matteo et al. 2014). This species represent an economically relevant species with regard to coppice management and also a potentially key food resource for roe deer (Cutini et al. 2011). Despite such a large diffusion

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and importance, few studies have focused on roe deer browsing on coppice wood, probably because the problem of deer impact on coppice regeneration in Italy is relatively recent (Cutini et al. 2011). After coppicing, stems are cut down close to ground level, where the growing shoots are exposed to deer browsing, expecially during the early years following cutting. Because the browsing incidence can heavely be influenced by ungulate density (Chevrier et al. 2011) it is important to evaluate density-related effects of browsing. In addition, because browsing can delay the growth of vegetative regeneration (Motta 2003), it is important to evaluate the long-term browsing influence on coppice growth. Indeed, as browsing impact are expected to be limited to the early phase of coppice rotation, since shoots are more exposed to browsing, an important question is whether the effects of browsing are likely to be permanent, or simply ephemeral due to changes associated with stand maturity (Gill and Beardall, 2001).

The objective of this study is twofold:

i) to assess the effects of roe deer browsing on vegetative regeneration of Turkey oak (stands after coppicing, along a gradient of ungulate density;

ii) to evaluate the long-term effects of browsing through time (i.e., six and eleven years after coppicing).

Both information are nowadays strongly needed for sustainable planning of deer density and for assessing economic impact of deer on coppice (e.g., for refunding purposes).

Material and Methods

The study was carried out in the Province of Arezzo (Tuscany, Italy). Suitable study areas were individuated by integrating a series of information on roe deer densities and forest data available in the Province. Roe deer densities were obtained by means of drive censuses conducted by the Fish and Wildlife Service of the Province of Arezzo (Cutini et al. 2013, Mattioli et al. 2004, Davis et al. 2012). Data were collected from 2011 to 2013 on a network of 187 permanent sample plots (43.9 ± 26.0 S.D. ha of mean surface and 8116 ha of total area) uniformly distributed along the Province. Roe deer density at local scale was calculated by spatial interpolation using the inverse distance weighting method (Li and Heap 2008) in ARCMAP 9.2 ESRI package. The setting used was: $p = 2$ and the minimum number (n) of sampled points used for estimation was 5, within a radius of 5 Km, and the pixel size of the output was 1 ha. Roe deer density was calculated for each study area as a mean of the values of each hectare included in the area, and for each plot inside the study areas was calculated as a mean of the values in a buffer of 1 km around the centre of the plot. Data of geographical distribution and size of coppiced areas were obtained from "ARTEA" dataset of Regional Administration (www.artea.toscana.it).

Study areas were only deemed suitable if other deer species influence was absent. Also, a similar wooded and coppice coverage were considered to ensure comparability between the study areas; this was a major determinant in the choice of study areas and consequently after experimental design. Three study areas were selected representing a gradient of roe deer population densities which was representative of hilly and mountain areas of Central Italy (hereafter scenarios; Tab. 1). The observed mean roe deer densities were comparable to that indicated by the Italian National Institute for Environmental Protection and Research (ISPRA) as low (i.e., between 10 and 15 individuals per km^2) , medium (i.e., between 20 and 25 individuals per km^2) and high (i.e, more than 25 individuals per km^2) roe deer densities in Apennines and Mediterranean environments.

Within each study area, a number of oak coppice stands aged 0-2 years with minimum size of 2500 m^2 were individuated. Within these plots, we randomly sampled 744 stools, of which half stools were located near the centre of each stand and half stools were located along the border of each stand. The observation period ran between October 15 and November 15, i.e. close to the end of the growing season. For each stool, we recorded the number of sprouts, top height of sprouts (i.e., the height of the tallest sprout of each stool), and number of recently browsed sprouts. The cover area of each stool was estimated by the geometric mean of the maximum and minimum diameter of projected area (assuming an elliptical shape). The browsing index was calculated as the ratio of browsed sprouts over the total number of sprouts for each surveyed stool. Browsing estimates were then averaged for each plot. Differences in oak browsing, top height, and cover area in the three different scenarios were compared by means of ANOVA. If ANOVA indicated that a significant difference existed between them in the variable of interest then Tukey's pair-wise comparison test was used to compare results from the three scenarios. We used R version 3.0.2 (R Development Core Team 2013).

To evaluate the impact of browsing on

Table 1 - Study areas

Study area	Average roe deer (n km-2)	Scenario
Valdambra	38.3 (2.6)	High
Alpe di Poti	13.9 (0.9)	Low
Alpe di Catenaia	22.6 (0.5)	Medium

Table 2 - Mean value of browsing ratio, top height and cover area in the different roe deer density scenarios.

Roe deer density	Browsing	Top height (cm)	cover area (m^2)
Low	0.65 (0.02)	110.0 (3.3)	1.28 (0.1)
Medium	0.77 (0.01)	88.1 (3.2)	1.18 (0.1)
High	0.79 (0.01)	90.2 (3.0)	0.99 (0.1)

Table 3 - Main mensurational parameters in protected (P) and non-protected (NP) Turkey oak coppiced areas.

Year	area	N (shoots)	dm (cm)	hm (m)	G (m^2ha^{-1})	V V (m^3ha^{-1})
2008	P	6768	3.8 (0.1)	3.5 (0.2)	8.83 (0.10)	27.61 (2.23)
	NP	3330	3.8 (0.1)	3.2 (0.3)	3.75 (0.07)	11.95 (1.27)
2013	P	6907	5.6 (0.1)	6.5 (0.2)	18.11 (0.22)	57.07 (5.12)
	NP	4826	6.0 (0.1)	6.2 (0.2)	14.23 (0.13)	33.76 (3.51)

the long term, additional data were collected from permanent monitoring plots previously established in the Alpe di Catenaia (Cutini et al. 2011), i.e., the medium density scenario. The permanent plots were located within three 1-ha stands dominated by Turkey oak, which were coppiced in 2002. Two sampling plots sized about 200 m^2 were established within each stand, one of which was fenced (protected, P), while the other was left accessible to browsing (non-protected, NP). Within each plot, we measured diameter at breast height and total height of sprouts. Volume was then estimated by applying a formula developed in a previous study for Turkey oak coppices in Tuscany (Amorini et al. 1998). We compared difference in growing stock (basal area and volume) between P and NP by two inventories made in 2008 (i.e., 6 years after coppicing) and 2013 (11 years after coppicing).

Results

The incidence of ungulate browsing was high in all the three different scenarios. The percentage of browsed sprouts ranged from 65% to 79% (Table 2). Damage was not uniformly distributed over all height classes of sprouts, but rather concentrated in those at the browsing height, i.e. between 20 and 130 cm (Figure 1). Moreover, browsing was negatively correlated with top height ($r=-0.46$, $p<0.001$) and cover area ($r=-0.35$, $p<0.001$).

ANOVA and Tukey's test indicated that browsing was significantly higher and height and cover area were significantly lower in the higher density scenario, compared with the others (Tukey's HSD test, $p < 0.05$). By contrast, medium and higher density scenarios did not exhibit significant differences in these attributes (Table 2).

Analysis of browsing impact 6 years after coppicing in Alpe di Catenaia (2008) revealed that growing stock in not-fenced areas was lower than that in fenced areas, with an average reduction in basal area and volume of -58% and -57% respectively, a consequence of the steady reduction in the number of shoots (Table 3). These differences were lower 11 years after coppicing (2013), even though browsing still reduced basal area and volume by- 21 % and -41 %, respectively (Table 3).

Discussion

The study revealed that browsing by roe deer has a significant impact on oak during the early years after coppicing. The observed browsing pressure was noticeably high even at lowest deer density, in which about two third of the sprouts were browsed. The browsing impact showed a density-dependency because significantly higher impacts were observed at medium and high density, compared with the low density scenario. Results are in agreement with previous studies, which reported a strict relationship between browsing and deer density (Chevrier et al. 2011). The negative relationship trend observed between browsing incidence and top height of sprouts further confirmed that the early years after coppicing are particularly critical, because the emerging shoots grow beneath the browsing height and are therefore exposed to sustained and prolonged impacts (Rooke et al. 2004).

On the other hand, we demonstrated that the effects of early browsing were not ephemeral but produced prolonged impacts through time; although the trend decreased between 2008 and 2013, the average reduction in volume observed eleven years after coppicing is noticeably high to heavily retard shoot growth, with relevant ecological as well as economic consequences. Based on the observed

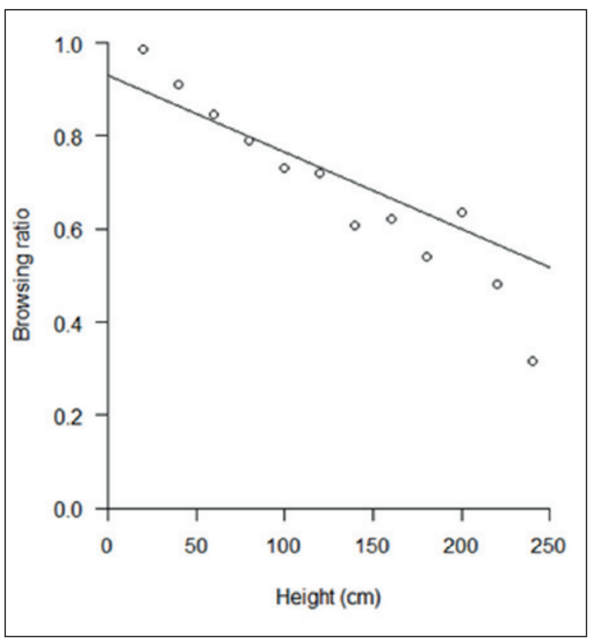

Figure 1 – Relationship between browsing ratio and top height of stools.

impacts and trends we could expect a reduction of -25% in volume at the end of the coppice rotation period, which may also imply a prolongation in the minimum rotation period (which is 18 years in Tuscany according to regional laws) to achieve a profitable harvesting, under the observed medium roe deer density.

Regardless economic considerations, both the early and long-term results indicated the browsing impacts are sustained in a range of roe deer density regarded as "normal" (ISPRA 2013) and regularly occurring in Apennines. In addition, roe deer in Italy is frequently sympatric with other deer species, e.g., fallow deer and red deer; hence, taking into account the current deer densities and their browsing pressure, we could expect that browsing intensity can seriously compromise forest dynamics in coppice woods. In these situations, the sustainable planning of ungulate densities should consider all the deer species on the whole. For example, Mattioli (2010) proposed a general ungulate density threshold based on roe-deer-equivalent conversion factors. The author individuated a maximum carrying capacity of 18 roe-deer equivalent individuals in Apennines, with red deer and fallow deer having a roe-deer-equivalent factor of 4.5 and 2.3, respectively (i.e., 1 red deer = 4.5 roe deer; 1 fallow deer = 2.3 roe deer. However, as Reimoser and Putman (2011) correctly noted, if a relationship between deer density and browsing impacts exists, the relationship is complex and not linear, making the identification of a critical ungulate density complex. Indeed, at any given deer density, sustained impact levels are affected by a wide range of other factors such as site conditions, landscape mosaic, availability and quality of alternative food resources, ungulate sympatry etc. (Ward et al. 2008, Gill and Morgan 2010, Reimoser and Putman 2011). Therefore, it is important to move beyond single-factor approach (e.g., ungulate density) to embrace the complexity of fauna-forest interactions (Weisberg and Bugmann 2003). An integrated forest-fauna management is frequently advocated by many authors as an effective way to consider the interactions among ungulates and vegetation (Bianchi et al. 2014, Cutini et al. 2013, Weisberg and Bugmann 2003). To accomplish this purpose, there is a need for rapid and objective indicators to monitor the impact of roe deer on vegetation (Reimoser et al. 1999). The browsing index proposed in this study can be regarded as an useful management tool on account of its fast, simple and cost-effective procedures, it being therefore highly suitable for large scale monitoring of the effects of deer browsing on vegetative regeneration. Integrating browsing monitoring with deer density estimation can be regarded therefore as an effective option for sustainable forest-fauna management (Cutini et al. 2013), i.e., to determine whether the relationships between ungulates and forest ecosystems are consistent with meeting silvicultural and forest management targets (Keigley and Frisina 2011, Reimoser et al. 1999). We also advocate the need to collect information on deer impact over large areas because ungulate effects on forests cannot be generalized to the spatial and temporal scales that are relevant to management. Integrating information on deer impact and deer density in e.g., regional and national forest inventory alongside with the definition of rigorous and systematic long-term monitoring programs to measure the interaction forest-ungulates can be a decisive step towards the definition of appropriate protection measures in landscape and large scale planning.

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