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Bark-stripping damage by *Callosciurus finlaysonii* introduced into Italy

Emiliano Mori, Peter John Mazzoglio, Patrizia Carla Rima, Gaetano Aloise, Sandro Bertolino*

***Corresponding author: Sandro Bertolino,** Department of Agriculture, Forest and Food Sciences, University of Turin, Largo Paolo Braccini 2, 10095 Grugliasco (TO), Italy

Running title: Bark-stripping damage by *Callosciurus finlaysonii*.

Abstract: The Finlayson's squirrel *Callosciurus finlaysonii* was introduced into Italy during the 1980s and has established two viable populations. The diet of this species includes a high proportion of tree barks, suggesting an intensive debarking behaviour. We reported a severe bark-stripping impact in both colonized areas, and we tested whether a preference for some tree species existed. Results of this work show the presence of a wide spectrum of damaged species, without any strong preference, mainly with large wounds. Old deciduous plants and conifers, which presented a hard bark, were usually avoided.

Keywords: alien species; debarking; Finlayson's squirrel; tree species selection; Italy.

Introduction

Bark-stripping behaviour is commonly observed among herbivorous species, such as ungulates (Motta 1996; Månsson and Jarnemo 2013), lagomorphs (Allman 1946; Chapman et al. 1982) and rodents (Gill 1992; Sharma and Prasad 1992; Baxter and Hansson 2001). Concerning rodents, bark portions are often removed when other more preferred food resources are not available, e.g. during snow cover or during the warm season, as well as to reach the phloem sap, rich in sugary components (Kenward and Parish 1986; Baxter and Hansson 2001). In the latter case, debarking is markedly exerted during the spring, when the sap flow increases in deciduous plants (Kenward and Parish 1986). The reasons for bark-stripping behaviours are not always clear and a number of explanations have been proposed (e.g. Kenward 1983).

Bark removal can be exerted along the entire stem circumference or in a spiral pattern around the trunk/branches, with different consequences for the plant. Decortications affecting only a part of the circumference induce local diebacks; by contrast, when annular decortications interrupt the sap flow, the dieback of the distal portions and the death of the whole plant may occur. As a response to the damage, plants react with healing phenomena and with the formation of scar tissue around the lesions (Mullick 1977; Biggs et al. 1984). Trees irreparably damaged are easily blown down by wind or attacked by pathogens (e.g. cryptogams), which may easily invade the plant through bark wounds (Tubeuf 1897; Purohit et al. 2001); in case of completely healed wounds, reductions in the commercial quality of wood also occur because of the presence of defects. Bark-stripping of selective tree species also alters the composition of forests, as well as hinder the establishment of new woodlands (Gill et al. 1995; Kerr and Niles 1998).

Among arboreal rodents, many squirrel species strip barks, e.g. Eurasian red squirrel *Sciurus vulgaris* (Pulliainen and Salonen 1963), fox squirrel *S. niger* (Allen 1943), Eastern grey squirrel *S. carolinensis* (Kenward and Parish 1986; Mountford 2006), American red squirrel *Tamiasciurus hudsonicus* (Sullivan and Vyse 1987) and red-bellied tree squirrel *Callosciurus erythraeus* (Zhu et al. 1990).

In Europe, the native red squirrel only occasionally causes a significant damage to forest vegetation or to arboriculture systems (Moller 1983; Gurnell 1987). By contrast, although in Italy and in its native range the damage is limited (Kenward 1989; Signorile and Evans 2007; Bertolino 2008), the introduced Eastern grey squirrel is responsible for severe damage to the timber industry and forests in Great Britain and Ireland (Williams et al. 2010; Mayle and Broome 2013). Considering the differences in bark-stripping behaviour among areas of introduction, if the species will be left to expand in Europe, predicting the severity of its impact to forestry is challenging (Bertolino et al. 2008, 2014; Di Febbraro et al. 2013). The Eastern grey squirrel is not the only squirrel species introduced into Europe; at least three other species have established viable populations in one or more countries (red-bellied tree squirrel, Finlayson's squirrel *C. finlaysonii* and Siberian chipmunk *Tamias sibiricus*, Bertolino 2009; Bertolino and Lurz 2013). Therefore, an evaluation of the possible damage by introduced tree squirrels is particularly needed to better draw a complete assessment of their impacts to biodiversity and human activities.

The Finlayson's squirrel is a species naturally distributed in Indochina, from Myanmar to Vietnam (Thorington et al. 2012). Introduced populations are currently recorded in Singapore, Japan and Italy (Bertolino et al. 1999; Oshida et al. 2007; Bertolino and Lurz 2013). In Italy, two populations are present in the Northern and Southern parts of the peninsula; a study on the diet of this species in one of those areas already highlighted a bark-stripping behaviour in winter (Bertolino et al. 2004). Aims of this study were to evaluate (i) the impact of bark stripping by the Finlayson's squirrels in the areas of presence in Italy, and (ii) the preference for some plant species.

Materials and Methods

Study areas

Field work was carried out at both areas of occurrence of the Finlayson's squirrel in Italy (Figure 1). In the north of the country, the species is localized in the city of Acqui Terme (Province of Alessandria, Northern Italy) and its suburbs. In the south, the Finlayson's squirrel expanded its range along the coastline, both northwards and southwards of Maratea (Province of Potenza, Southern Italy), the city of first introduction (Aloise and Bertolino 2005). The study site in Northern Italy is an urban park (2 ha), located in the city center of Acqui Terme; here the survey was conducted in the years 1998-1999. The most represented tree species were *Celtis australis*, *Platanus* sp., *Tilia cordata*, *Pinus* spp. and *Cedrus* spp. (Table 1). In Southern Italy, nine wooded areas were surveyed along the coast in the year 2004 (Supplementary Figure 1): 1 site in the point of the first introduction, 3 sites within 5.25 km northwards and 5 sites within 6.50 km southwards (Supplementary Figure 2). At that time, the species had spread 9 km northwards and 7 km southwards. These areas include a narrow belt of coastal woods, mainly composed of *Pinus halepensis*, *Quercus ilex* and *Ceratonia siliqua* (Table. 2). Valleys connect these coastal woodlands with the deciduous woodlands (*Quercus cerris*, *Q. virgiliana*, *Castanea sativa*) of the hinterland.

Data collection

All the plants of the study sites were identified at the species or genus level, counted and checked for the presence of debarking damage on the trunk and branches by Finlayson's squirrels. We differentiated the damage to the trunk or to the branches, because a different impact on the survival of the plant may occur. The extension of the damage was assessed on a sliding scale: no damage, less than 50 cm^2 of debarked surface, 50-500 cm^2, > 500 cm^2. A chi-square test was then applied to assess differences in the percentage of damage extension within and between the two study areas. In Northern Italy, the extent of the damage was also evaluated after one and nine months from an intervention of phytosanitary cutting on 42 littleleaf lindens *Tilia cordata*, 9 European hackberries *Celtis australis*, 1 Northern white cedar *Thuja occidentalis* and 1 Norway spruce *Picea excelsa*, to assess whether they had any effect on the debarking activity. During these interventions, some trees were removed and all branches were cut in the others, thus we expected a reduction on the debarking activity by *C. finlaysonii* on these species, at least before new branches had grown.

In Southern Italy, we also assessed whether the damage decreased in the various plots with an increasing distance from the centre of first introduction of the species (Maratea).

The Ivlev's Electivity Index (E, Ivlev 1961) was computed to assess the selection of Finlayson's squirrel for tree species, through the statistical software R 3.1.1, package *gplots* (Chiatante 2014). The values of this index range from -1 to +1, with values between -1 and 0 indicating avoidance and values from 0 to +1 indicating preference for a certain resource. We followed the suggestion by Lazzaro (1987) and Lückstädt and Reito (2002), who showed that a true selection or avoidance can be claimed only at values > 0.3 or < -0.3 respectively. Species represented by one individual were excluded from the analysis.

Results

Northern Italy

A total of 308 trees were monitored, and bark stripping occurred in 242 (78.6%) trees. Finlayson's squirrel completely avoided *Pinus strobus, Celtis australis, Tilia cordata, Cercis siliquastrum, Ilex aquifolium*, *Acer saccharinum*, and *Platanus* sp. (all, E = -1, Table 1) at the level of the trunk; whereas *Picea excelsa, C. siliquastrum, A. saccharinum* and *Platanus* sp. were avoided at the branch level. All the other species were selected for bark-stripping, with E values generally > 0.8 (Table 1).

Overall, 5.05% of all damaged trees appeared affected on a small area, 71.21% (mainly on *Celtis australis* and *Tilia cordata*) fell into the intermediate category, and the remaining 23.74% showed extensive decortications; the intermediate extension was significantly higher than the other categories (all species, trunks: $\chi^2_{(2)} = 5.57$, $P < 0.05$; branches: $\chi^2_{(2)} = 266$, $P < 0.001$) (Table 1, Figure 4).

The phytosanitary cutting affected the behaviour of the Finlayson's squirrels (Figure 2). For the first month after the intervention (T_1), squirrels intensified debarking on evergreen species, while those on the deciduous plants decreased; nine months after the management intervention (T_2), the damage decreased on evergreen plants and increased again on broadleaves ($\chi^2_{(2)} = 90.28$, $P < 0.001$).

Southern Italy

A total of 209 trees belonging to six species were surveyed and checked for debarked areas (Table 2). Bark stripping by Finlayson's squirrel occurred on 107 (51.2%) trees, mainly *Ceratonia siliqua* trunk (E = 0.63) and branches (E = 0.77) and *Olea europaea* (E = 0.35 trunk, E = 0.85 branches). *Quercus ilex* was avoided both at the trunk (E = -0.86) and at the branch level (E = -0.51). *Quercus* *virgiliana* (E = 0.52) and *Pinus halepensis* (E = 0.39) were only selected at the branch level; all the other species were used proportionally to their availability. Overall, about 43% of the damage occurred on a surface of over 500 cm^2 and mainly on *Ceratonia siliqua*, while the damage on the other species was always of a smaller extent (Table 2) (all species, trunks: $\chi^2_{(2)} = 6.89$, $P < 0.05$; branches: $\chi^2_{(2)} = 6.77$, $P < 0.05$, Figure 4).

The percentages of trees with damage on trunks, branches or both, were not correlated with the distance from the site of introduction (all, $P > 0.05$, Figure 3, see also the Supplemental Figure 2).

Overall, the damage was higher in Northern than in Southern Italy at the branches ($\chi^2_{(2)} = 69.13$, $P < 0.001$) but not at the trunk level ($\chi^2_{(2)} = 2.06$, $P < 0.36$; Figure 4).

Discussion and Conclusions

The Finlayson's squirrel has been introduced into two areas of Italy during the 1980s (Bertolino et al. 1999; Aloise and Bertolino 2005). Twenty years later, the damage produced to trees through bark-stripping was severe at both sites. In particular, all the species with few exceptions were debarked in a urban park in Acqui Terme (Northern Italy), with a marked preference for deciduous plants. The damage in natural woodlands of Southern Italy involved a smaller number of plants and was preferentially exerted on *Olea europaea* and *Ceratonia siliqua*, as well as on branches of *Quercus virgiliana* and *Pinus halepensis*. In several of the cases observed, bark stripping was likely to jeopardize the survival of part of the plant or even of the whole tree.

The Finlayson's squirrel is a frugivorous species, although its diet may vary according to the season and to the environmental availability of food resources (Bertolino et al. 2004). Bark-stripping occurs mainly during late autumn and winter, when the availability of seeds, fruits and blossoms decreases (Bertolino et al. 2004). In Northern Italy, where the population is still restricted to a small area, decortications occur also during the warm seasons, when other food sources may be less available. Mills (1938) suggested that sap would not be a survival food, but it would be consumed because of its tasty sugary flavour. Our results confirmed the presence of a large spectrum of plant species damaged by the Finlayson's squirrel in Italy, which does not seem to show any strong preference. The few avoided species presented hard barks or, as in the case of *Acer saccharinum* in Northern Italy, a species usually debarked by squirrels (Brenneman 1954), they were isolated plants which may be reached by squirrels only by moving on the ground. Finlayson's squirrel is mostly arboreal and does not like to move on the ground (Lekagul and McNeely 1988; Thorington et al. 2012), a behaviour even discouraged by the presence of dogs in the park. As for plane trees *Platanus* sp., their bark peels off in large plates also after a slight contact with the teeth of the squirrel: so, clear young bark is brought to the surface, but it is not directly attacked by squirrels.

Most of the wounds caused by this tree squirrel affected tree portions larger than 50 cm^2 and often larger than 500 cm^2, resulting in serious damage. The attacked plants may only heal moderate wounds and the bark removal determines a lower resistance of the trees to mechanical stresses and to parasite attacks. Behavioural and ecological reasons inducing Finlayson's squirrel to consume bark are not completely understood yet. Some species, such as *Celtis australis* and *Tilia cordata*, were debarked mainly during the autumn, when the sap flow is minimal, and for a small extent; wounds were mainly located on the branches where the bark may be more tender with respect to the trunk. Furthermore, only a few scraps were left on the ground, suggesting a direct interest towards the bark, thus not to the sap, as a food resource. In autumn and winter, consistently, fruit consumption was lower than in the rest of the year (Bertolino et al. 2004). By contrast, other species have been frequently used during spring when the sap flow is greatest; in these cases, the portions of removed bark were conspicuous and many scraps were found on the ground, in analogy with the behaviour of grey and red-bellied squirrels (Kuo et al. 1982; Kenward and Parish 1986).

Silvicultural interventions on lindens and hackberries carried out in Northern Italy influenced the debarking activities: after one month, a reduction of damage to the hardwood and a heavier damage on evergreen species has been recorded. Fruits of hackberries and lindens are an important part of the diet of the Finlayson's squirrel (Bertolino et al. 2004); therefore, the cutting of 50 trees belonging to these species may have led the squirrels to feed on bark as an alternative food source.

Overall, despite a more localized distribution range in Italy, the debarking damage by Finlayson's squirrels seems to be higher with respect to that by grey squirrels (Signorile and Evans 2007). Considering the vegetation characteristics of the areas of occurrence of the Finlayson's squirrel, the density of population and the likelihood of expansion (Bertolino et al. 2004; Aloise and Bertolino 2005), it is likely that this type of damage will increase in the next future, with a higher impact in Southern Italy, where the range expansion is recorded both along the coastline and towards the hinterland (Aloise and Bertolino 2005; Aloise and Bertolino 2008; Aloise et al. 2011). Furthermore, the amount of damage seems not to decrease with the distance from the site of first introduction, thus depending on local ecological factors, such as food resources and different attractiveness/palatability of tree species.

As far as we know, this work represents the first report of bark-stripping damage produced by the Finlayson's squirrel (cf. Bertolino et al. 2015); however, this is probably due to the absence of specific studies on the species. In fact, the congener red-bellied tree squirrel is known to produce severe damage both in the native range and in many areas of introduction (Zhu et al. 1990; Bertolino and Lurz 2013)

Once an alien species has spread over large areas, eradication and numerical or spatial control are generally hard programmes to be carried out (Genovesi and Shine 2004; Bertolino et al. 2015). Currently, the eradication of the Finlayson's squirrel from Italy seems to be still possible, and should be undertaken before the species spreads further, resulting in extensive damage. It must be remarked that both populations are close to one of the most productive hazelnut-growing areas (Langhe and Roero in Northwestern Italy, Salerno and Avellino provinces in Southern Italy). Moreover, in Northern Italy, the hazelnut-growing area is already menaced by the grey squirrel (Bertolino 2014). The introduction of this tree squirrel in Italy is due to intentional releases or escapes of animals kept in captivity by private citizens; being the complete avoidance of such escapes almost impossible, restrictive measures in the trade of exotic species should be adopted.

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Tables

Table 1 Incidence of damage caused by bark stripping of the Finlayson's squirrel in Northern Italy and results of Ivlev's Electivity Index analysis (E) for plant species selection on trunk and branches.

Species	**Trees**		**Damage on trunks**			**Surface of exposed wood (%)**			**Damage on branches**			**Surface of exposed wood (%)**		
	N	**N (%)**	**N**	**N (%)**	**E**	**<50 cm^2**	**51-500 cm^2**	**>500 cm^2**	**N**	**N (%)**	**E**	**<50 cm^2**	**51-500 cm^2**	**>500 cm^2**
Abies alba	5	1.6	5	100	0.97	20.0	80.0	0.0	5	100	0.97	0.0	100	0.0
Picea excelsa	12	3.9	1	8.3	0.36	0.0	8.3	0.0	0	0.0	-1.00	0.0	0.0	0.0
Cedrus atlantica	3	0.9	1	33.3	0.94	0.0	0.0	33.3	3	100	0.98	0.0	66.7	33.3
Cedrus deodara	16	5.2	3	18.8	0.57	0.0	0.0	18.8	13	81.3	0.88	0.0	25.0	56.3
Pinus strobus	5	1.6	0	0.0	-1.00	0.0	0.0	0.0	5	100	0.98	0.0	80.0	20.0
Pinus nigra	14	4.6	14	100	0.91	0.0	78.6	21.4	14	100	0.91	42.9	57.1	0.0
Pinus laricio	19	6.2	13	68.4	0.83	0.0	26.3	42.1	19	100	0.88	31.6	36.8	31.6
Libocedrus decurrens	4	1.3	2	50.0	0.94	0.0	0.0	50.0	4	100	0.97	25.0	0.0	75.0
Thuja occidentalis	4	1.3	4	100	0.97	0.0	0.0	100	4	100	0.97	0.0	100	0.0
Cephalotaxus cuspidata	14	4.6	10	71.4	0.88	0.0	21.4	50.0	14	100	0.91	0.0	42.9	57.1
Celtis australis	91	29.6	0	0.0	-1.00	0.0	0.0	0.0	91	100	0.54	0.0	100	0.0

Prunus sp.	11	2.3	11	100	0.96	100	0.0	0.0	11	100	0.96	0.0	100	0.0
Tilia cordata	56	18.2	0	0.0	-1.00	0.0	0.0	0.0	56	100	0.69	0.0	100	0.0
Quercus ilex	2	0.7	0	0.0	-1.00	0.0	0.0	0.0	2	100	0.99	0.0	100	0.0
Cercis siliquastrum	4	1.3	0	0.0	-1.00	0.0	0.0	0.0	0	0.0	-1.00	0.0	0.0	0.0
Ilex aquifolium	2	0.7	0	0.0	-1.00	0.0	0.0	0.0	0	0.0	-1.00	0.0	0.0	0.0
Ginkgo biloba	2	0.7	1	50.0	0.97	50.0	0.0	0.0	1	50.0	0.97	50.0	0.0	0.0
Acer saccharinum	2	0.7	0	0.0	-1.00	0.0	0.0	0.0	0	0.0	-1.00	0.0	0.0	0.0
Platanus sp.	42	13.6	0	0.0	-1.00	0.0	0.0	0.0	0	0.0	-1.00	0.0	0.0	0.0
TOTAL	**308**		**65**	**21.1**		**4.2**	**7.8**	**9.1**	**242**	**78.6**		**4.6**	**64.9**	**9.1**

Table 2 Results of Ivlev's Electivity index analysis (E) for plant species selection on trunk and branches, and incidence of damage caused by bark stripping of the Finlayson's squirrel in the sites in the Southern area of introduction.

Species			**Damage on trunks**			**Surface of exposed wood (%)**			**Damage on branches**			**Surface of exposed wood (%)**		
	N	**N(%)**	**N**	**N(%)**	**E**	**<50 cm^2**	**51-500 cm^2**	**>500 cm^2**	**N**	**N(%)**	**E**	**<50 cm^2**	**51-500 cm^2**	**>500 cm^2**
Pinus halepensis	27	12.9	5	18.5	0.18	0.0	14.8	3.7	8	29.6	0.39	11.1	7.4	11.1
Pinus sp.	12	5.7	1	8.3	0.18	0.0	8.3	0.0	1	8.3	0.18	8.3	0.0	0.0
Quercus ilex	91	43.5	3	3.3	-0.86	1.1	1.1	1.1	13	14.3	-0.51	3.3	6.6	4.4
Quercus virgiliana	44	21.1	4	9.1	-0.40	2.3	2.3	4.6	29	65.9	0.52	9.1	29.6	27.3
Ceratonia siliqua	25	12.0	13	52.0	0.63	4.0	24.0	24.0	23	92.0	0.77	8.0	16.0	68.0
Olea europaea	10	4.8	1	10.0	0.35	0.0	10.0	0.0	6	60.0	0.85	40.0	20.0	0.0
TOTAL	**209**		**27**	**12.9**		**1.4**	**6.7**	**4.8**	**80**	**38.3**		**8.1**	**12.9**	**17.2**

Figure legends

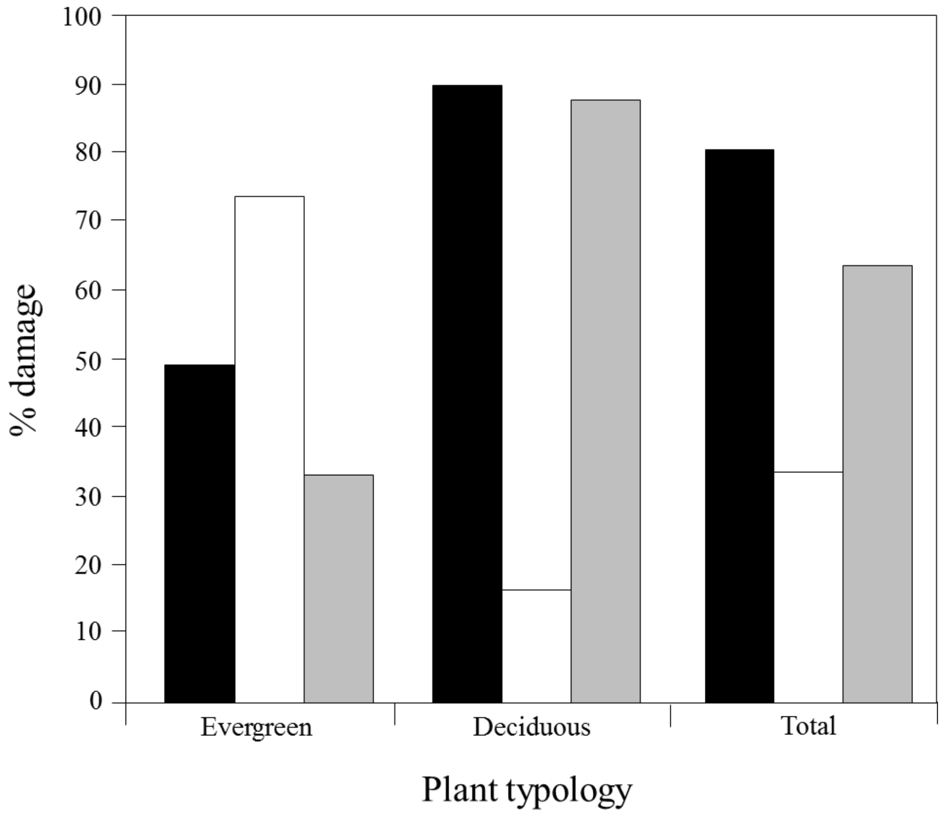
Figure 1 Distribution of the Finlayson's squirrel in Italy.

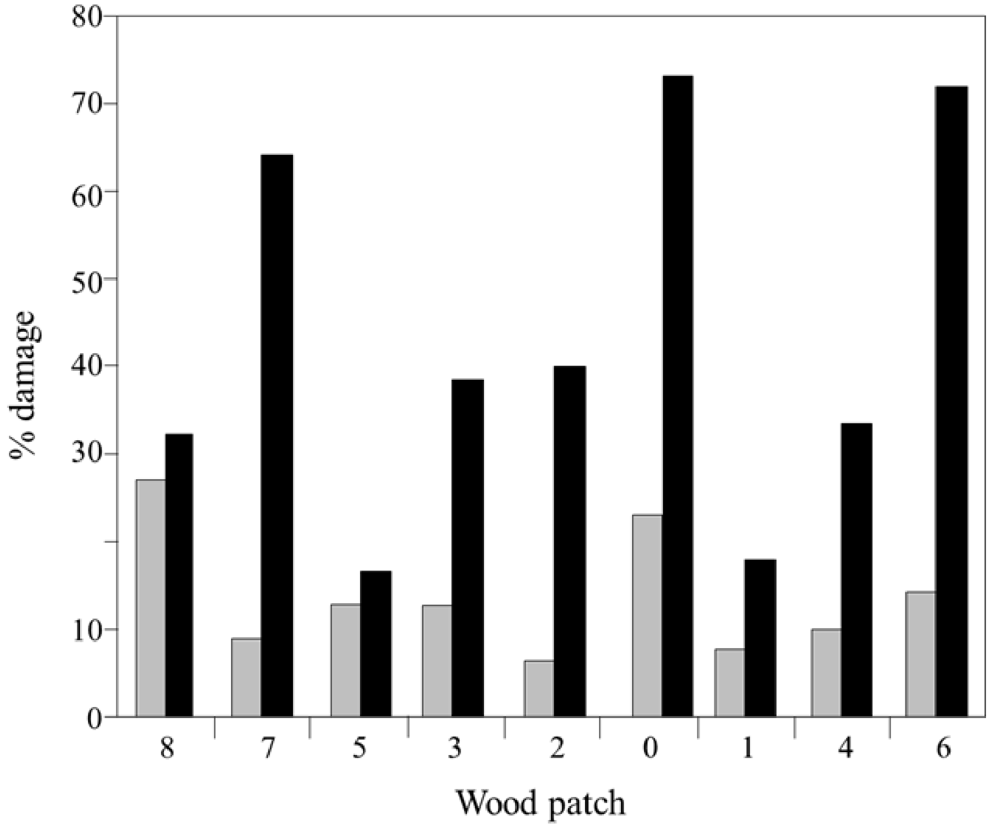
Figure 2 Trend of bark-stripping damage by Finlayson's squirrel to different plant categories, before (T_0, black bars), one month after (T_1, white bars) and nine months after the phytosanitary intervention at Acqui Terme (T_2, grey bars).

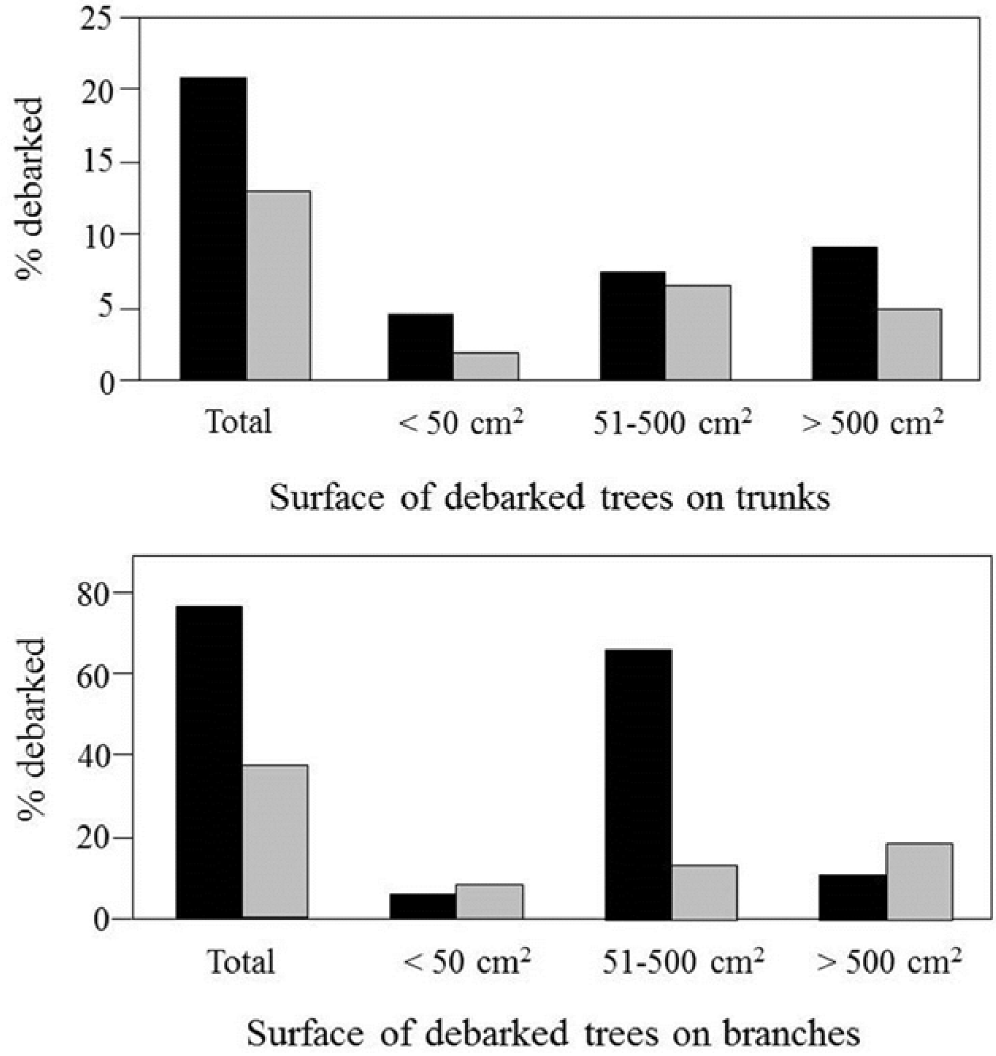
Figure 3 Percentages of bark-stripping damage in nine wood patches in Southern Italy; black bars refer to branches, grey ones to the trunk. Location 0 refers to the site of first introduction of the Finlayson's squirrel; sites 1, 4, 6 are northwards, the others are southwards.

Figure 4 Percentage of bark-stripping at trunk and branch levels. Black bars refer to the Northern Italy study site, grey ones to Southern Italy.


Acqui Terme
Maratea


100
90
80
70
60
50
40
30
20
10
0
% damage
Evergreen
Deciduous
Total
Plant typology


% damage
80
70
60
50
40
30
10
0
8
7
5
3
2
0
1
4
6
Wood patch


25
20
15
10
5
0
% debarked
Total
< 50 cm²
51-500 cm²
> 500 cm²
Surface of debarked trees on trunks
80
60
40
20
0
% debarked
Total
< 50 cm²
51-500 cm²
> 500 cm²
Surface of debarked trees on branches