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Questa è la versione dell'autore dell'opera:*

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[*Mammalia* , *nov* 2015, ISSN (Online) 1864-1547, ISSN (Print) 0025-1461,
DOI: [10.1515/mammalia-2015-0107](https://doi.org/10.1515/mammalia-2015-0107)]

The definitive version is available at:

La versione definitiva è disponibile alla URL:

[<https://www.degruyter.com/view/j/mamm.ahead-of-print/mammalia-2015-0107/mammalia-2015-0107.xml>]

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

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

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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

27 the damage, plants react with healing phenomena and with the formation of scar tissue around the
28 lesions (Mullick 1977; Biggs et al. 1984). Trees irreparably damaged are easily blown down by
29 wind or attacked by pathogens (e.g. cryptogams), which may easily invade the plant through bark
30 wounds (Tubeuf 1897; Purohit et al. 2001); in case of completely healed wounds, reductions in the
31 commercial quality of wood also occur because of the presence of defects. Bark-stripping of
32 selective tree species also alters the composition of forests, as well as hinder the establishment of
33 new woodlands (Gill et al. 1995; Kerr and Niles 1998).

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

39 In Europe, the native red squirrel only occasionally causes a significant damage to forest
40 vegetation or to arboriculture systems (Moller 1983; Gurnell 1987). By contrast, although in Italy
41 and in its native range the damage is limited (Kenward 1989; Signorile and Evans 2007; Bertolino
42 2008), the introduced Eastern grey squirrel is responsible for severe damage to the timber industry
43 and forests in Great Britain and Ireland (Williams et al. 2010; Mayle and Broome 2013).
44 Considering the differences in bark-stripping behaviour among areas of introduction, if the species
45 will be left to expand in Europe, predicting the severity of its impact to forestry is challenging
46 (Bertolino et al. 2008, 2014; Di Febbraro et al. 2013). The Eastern grey squirrel is not the only
47 squirrel species introduced into Europe; at least three other species have established viable
48 populations in one or more countries (red-bellied tree squirrel, Finlayson's squirrel *C. finlaysonii*
49 and Siberian chipmunk *Tamias sibiricus*, Bertolino 2009; Bertolino and Lurz 2013). Therefore, an
50 evaluation of the possible damage by introduced tree squirrels is particularly needed to better draw
51 a complete assessment of their impacts to biodiversity and human activities.

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

59

60 **Materials and Methods**

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62 *Study areas*

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

78

79 ***Data collection***

80

81 All the plants of the study sites were identified at the species or genus level, counted and checked
82 for the presence of debarking damage on the trunk and branches by Finlayson's squirrels. We
83 differentiated the damage to the trunk or to the branches, because a different impact on the survival
84 of the plant may occur. The extension of the damage was assessed on a sliding scale: no damage,
85 less than 50 cm² of debarked surface, 50-500 cm², > 500 cm². A chi-square test was then applied to
86 assess differences in the percentage of damage extension within and between the two study areas. In
87 Northern Italy, the extent of the damage was also evaluated after one and nine months from an
88 intervention of phytosanitary cutting on 42 littleleaf lindens *Tilia cordata*, 9 European hackberries
89 *Celtis australis*, 1 Northern white cedar *Thuja occidentalis* and 1 Norway spruce *Picea excelsa*, to
90 assess whether they had any effect on the debarking activity. During these interventions, some trees
91 were removed and all branches were cut in the others, thus we expected a reduction on the
92 debarking activity by *C. finlaysonii* on these species, at least before new branches had grown.

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

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

102

103 **Results**

104

105 ***Northern Italy***

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

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

118 The phytosanitary cutting affected the behaviour of the Finlayson's squirrels (Figure 2). For the
119 first month after the intervention (T₁), squirrels intensified debarking on evergreen species, while
120 those on the deciduous plants decreased; nine months after the management intervention (T₂), the
121 damage decreased on evergreen plants and increased again on broadleaves ($\chi^2_{(2)} = 90.28$, P <
122 0.001).

123

124 ***Southern Italy***

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126 A total of 209 trees belonging to six species were surveyed and checked for debarked areas (Table
127 2). Bark stripping by Finlayson's squirrel occurred on 107 (51.2%) trees, mainly *Ceratonia siliqua*
128 trunk (E = 0.63) and branches (E = 0.77) and *Olea europaea* (E = 0.35 trunk, E = 0.85 branches).
129 *Quercus ilex* was avoided both at the trunk (E = -0.86) and at the branch level (E = -0.51). *Quercus*

130 *virgiliana* ($E = 0.52$) and *Pinus halepensis* ($E = 0.39$) were only selected at the branch level; all the
131 other species were used proportionally to their availability. Overall, about 43% of the damage
132 occurred on a surface of over 500 cm² and mainly on *Ceratonia siliqua*, while the damage on the
133 other species was always of a smaller extent (Table 2) (all species, trunks: $\chi^2_{(2)} = 6.89$, $P < 0.05$;
134 branches: $\chi^2_{(2)} = 6.77$, $P < 0.05$, Figure 4).

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

137 Overall, the damage was higher in Northern than in Southern Italy at the branches ($\chi^2_{(2)} = 69.13$,
138 $P < 0.001$) but not at the trunk level ($\chi^2_{(2)} = 2.06$, $P < 0.36$; Figure 4).

139

140 **Discussion and Conclusions**

141

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

150 The Finlayson's squirrel is a frugivorous species, although its diet may vary according to the
151 season and to the environmental availability of food resources (Bertolino et al. 2004). Bark-
152 stripping occurs mainly during late autumn and winter, when the availability of seeds, fruits and
153 blossoms decreases (Bertolino et al. 2004). In Northern Italy, where the population is still restricted
154 to a small area, decortications occur also during the warm seasons, when other food sources may be
155 less available. Mills (1938) suggested that sap would not be a survival food, but it would be

156 consumed because of its tasty sugary flavour. Our results confirmed the presence of a large
157 spectrum of plant species damaged by the Finlayson's squirrel in Italy, which does not seem to
158 show any strong preference. The few avoided species presented hard barks or, as in the case of *Acer*
159 *saccharinum* in Northern Italy, a species usually debarked by squirrels (Brenneman 1954), they
160 were isolated plants which may be reached by squirrels only by moving on the ground. Finlayson's
161 squirrel is mostly arboreal and does not like to move on the ground (Lekagul and McNeely 1988;
162 Thorington et al. 2012), a behaviour even discouraged by the presence of dogs in the park. As for
163 plane trees *Platanus* sp., their bark peels off in large plates also after a slight contact with the teeth
164 of the squirrel: so, clear young bark is brought to the surface, but it is not directly attacked by
165 squirrels.

166 Most of the wounds caused by this tree squirrel affected tree portions larger than 50 cm² and
167 often larger than 500 cm², resulting in serious damage. The attacked plants may only heal moderate
168 wounds and the bark removal determines a lower resistance of the trees to mechanical stresses and
169 to parasite attacks. Behavioural and ecological reasons inducing Finlayson's squirrel to consume
170 bark are not completely understood yet. Some species, such as *Celtis australis* and *Tilia cordata*,
171 were debarked mainly during the autumn, when the sap flow is minimal, and for a small extent;
172 wounds were mainly located on the branches where the bark may be more tender with respect to the
173 trunk. Furthermore, only a few scraps were left on the ground, suggesting a direct interest towards
174 the bark, thus not to the sap, as a food resource. In autumn and winter, consistently, fruit
175 consumption was lower than in the rest of the year (Bertolino et al. 2004). By contrast, other species
176 have been frequently used during spring when the sap flow is greatest; in these cases, the portions
177 of removed bark were conspicuous and many scraps were found on the ground, in analogy with the
178 behaviour of grey and red-bellied squirrels (Kuo et al. 1982; Kenward and Parish 1986).

179 Silvicultural interventions on lindens and hackberries carried out in Northern Italy influenced
180 the debarking activities: after one month, a reduction of damage to the hardwood and a heavier
181 damage on evergreen species has been recorded. Fruits of hackberries and lindens are an important

182 part of the diet of the Finlayson's squirrel (Bertolino et al. 2004); therefore, the cutting of 50 trees
183 belonging to these species may have led the squirrels to feed on bark as an alternative food source.

184 Overall, despite a more localized distribution range in Italy, the debarking damage by
185 Finlayson's squirrels seems to be higher with respect to that by grey squirrels (Signorile and Evans
186 2007). Considering the vegetation characteristics of the areas of occurrence of the Finlayson's
187 squirrel, the density of population and the likelihood of expansion (Bertolino et al. 2004; Aloise and
188 Bertolino 2005), it is likely that this type of damage will increase in the next future, with a higher
189 impact in Southern Italy, where the range expansion is recorded both along the coastline and
190 towards the hinterland (Aloise and Bertolino 2005; Aloise and Bertolino 2008; Aloise et al. 2011).
191 Furthermore, the amount of damage seems not to decrease with the distance from the site of first
192 introduction, thus depending on local ecological factors, such as food resources and different
193 attractiveness/palatability of tree species.

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

199 Once an alien species has spread over large areas, eradication and numerical or spatial control
200 are generally hard programmes to be carried out (Genovesi and Shine 2004; Bertolino et al. 2015).
201 Currently, the eradication of the Finlayson's squirrel from Italy seems to be still possible, and
202 should be undertaken before the species spreads further, resulting in extensive damage. It must be
203 remarked that both populations are close to one of the most productive hazelnut-growing areas
204 (Langhe and Roero in Northwestern Italy, Salerno and Avellino provinces in Southern Italy).
205 Moreover, in Northern Italy, the hazelnut-growing area is already menaced by the grey squirrel
206 (Bertolino 2014). The introduction of this tree squirrel in Italy is due to intentional releases or

207 escapes of animals kept in captivity by private citizens; being the complete avoidance of such
208 escapes almost impossible, restrictive measures in the trade of exotic species should be adopted.

209

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326 **Tables**

327

328 **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
 329 (E) for plant species selection on trunk and branches.

330

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
<i>Abies alba</i>	5	1.6	5	100	0.97	20.0	80.0	0.0	5	100	0.97	0.0	100	0.0
<i>Picea excelsa</i>	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
<i>Cedrus atlantica</i>	3	0.9	1	33.3	0.94	0.0	0.0	33.3	3	100	0.98	0.0	66.7	33.3
<i>Cedrus deodara</i>	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
<i>Pinus strobus</i>	5	1.6	0	0.0	-1.00	0.0	0.0	0.0	5	100	0.98	0.0	80.0	20.0
<i>Pinus nigra</i>	14	4.6	14	100	0.91	0.0	78.6	21.4	14	100	0.91	42.9	57.1	0.0
<i>Pinus laricio</i>	19	6.2	13	68.4	0.83	0.0	26.3	42.1	19	100	0.88	31.6	36.8	31.6
<i>Libocedrus decurrens</i>	4	1.3	2	50.0	0.94	0.0	0.0	50.0	4	100	0.97	25.0	0.0	75.0
<i>Thuja occidentalis</i>	4	1.3	4	100	0.97	0.0	0.0	100	4	100	0.97	0.0	100	0.0
<i>Cephalotaxus cuspidata</i>	14	4.6	10	71.4	0.88	0.0	21.4	50.0	14	100	0.91	0.0	42.9	57.1
<i>Celtis australis</i>	91	29.6	0	0.0	-1.00	0.0	0.0	0.0	91	100	0.54	0.0	100	0.0

<i>Prunus</i> sp.	11	2.3	11	100	0.96	100	0.0	0.0	11	100	0.96	0.0	100	0.0
<i>Tilia cordata</i>	56	18.2	0	0.0	-1.00	0.0	0.0	0.0	56	100	0.69	0.0	100	0.0
<i>Quercus ilex</i>	2	0.7	0	0.0	-1.00	0.0	0.0	0.0	2	100	0.99	0.0	100	0.0
<i>Cercis siliquastrum</i>	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
<i>Ilex aquifolium</i>	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
<i>Ginkgo biloba</i>	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
<i>Acer saccharinum</i>	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
<i>Platanus</i> 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

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339 **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
 340 stripping of the Finlayson's squirrel in the sites in the Southern area of introduction.

341

Species	Damage on trunks			Surface of exposed wood (%)			Damage on branches			Surface of exposed wood (%)					
	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			
<i>Pinus halepensis</i>	27	12.9	0.18	5	18.5	0.18	0.0	14.8	3.7	8	29.6	0.39	11.1	7.4	11.1
<i>Pinus sp.</i>	12	5.7	0.18	1	8.3	0.18	0.0	8.3	0.0	1	8.3	0.18	8.3	0.0	0.0
<i>Quercus ilex</i>	91	43.5	-0.86	3	3.3	-0.86	1.1	1.1	1.1	13	14.3	-0.51	3.3	6.6	4.4
<i>Quercus virgiliana</i>	44	21.1	-0.40	4	9.1	-0.40	2.3	2.3	4.6	29	65.9	0.52	9.1	29.6	27.3
<i>Ceratonia siliqua</i>	25	12.0	0.63	13	52.0	0.63	4.0	24.0	24.0	23	92.0	0.77	8.0	16.0	68.0
<i>Olea europaea</i>	10	4.8	0.35	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

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345 **Figure legends**

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

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

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

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

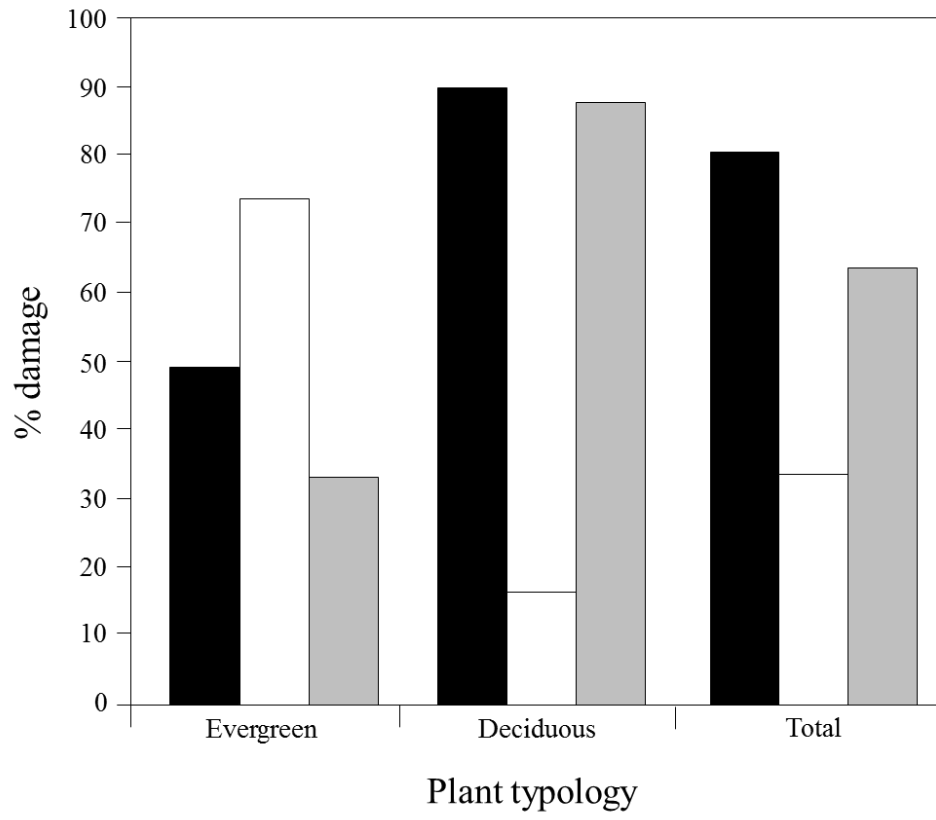
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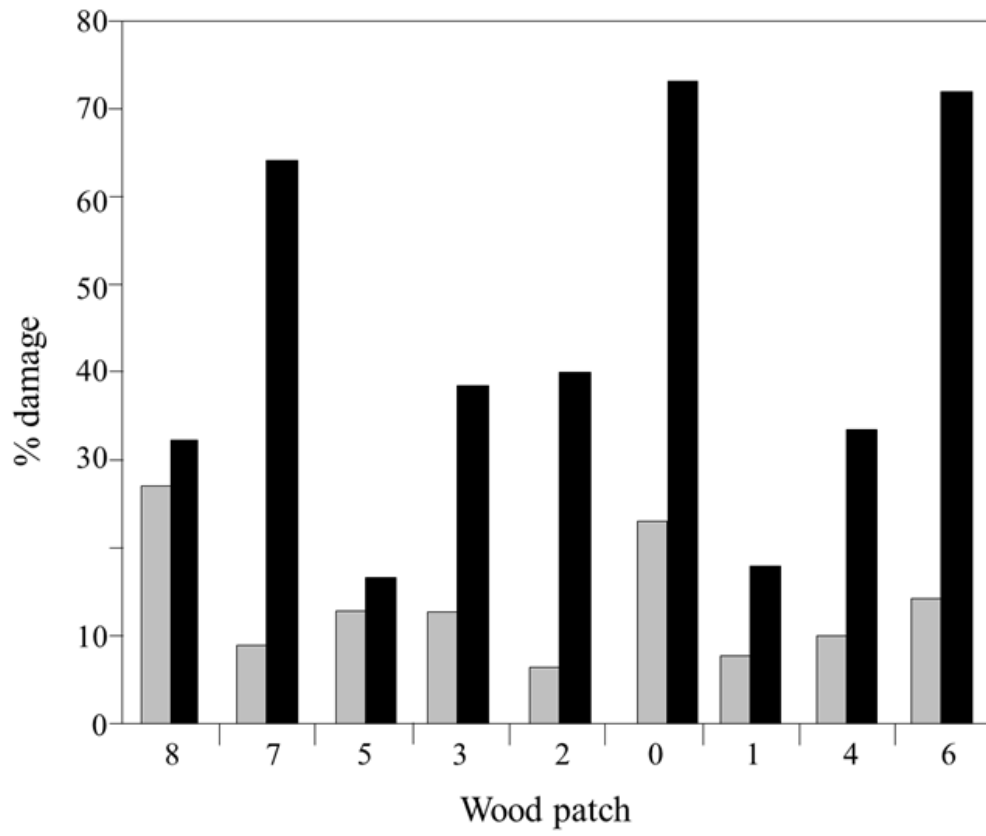
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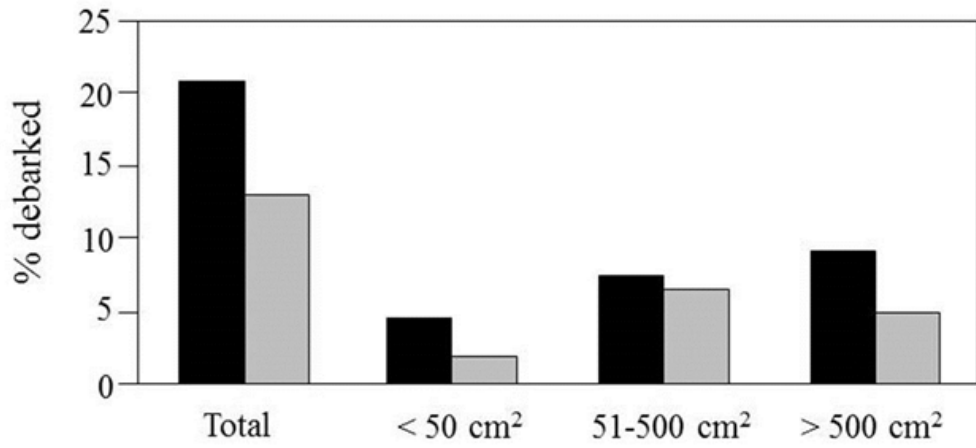
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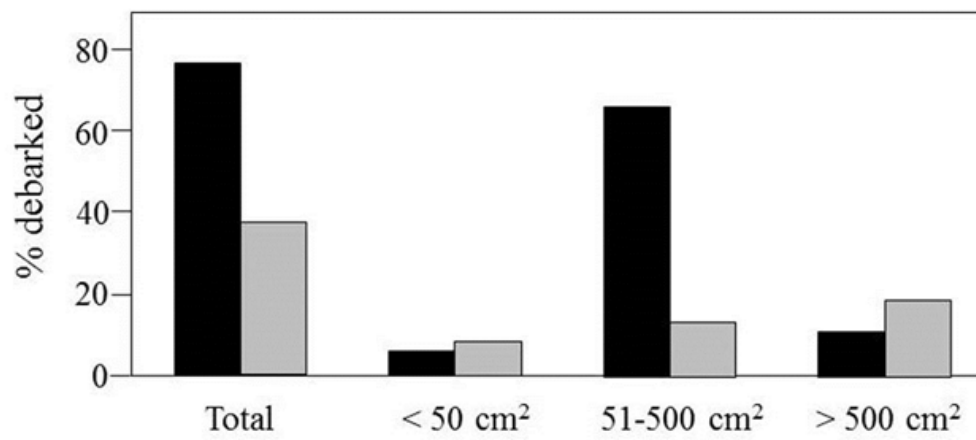


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Surface of debarked trees on trunks



Surface of debarked trees on branches

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