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Damage to the wood of forest species caused by the debarking of Pallas´s squirrel introduced into Argentina

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Abstract

Aim of study: Pallas´s squirrel (*Callosciurus erythraeus*) is a harmful and generalist invasive mammal species that causes different problems in the forestry sector. The aim of this study was to evaluate the damage on the wood in three commercial tree species in Argentina, *Eucalyptus dunnii*, *Populus deltoides* and *Pinus elliottii*, due to debarking caused by this squirrel species.

Area of study: ¨Liebres Fue¨ forest plantation, located in Luján District (Province of Buenos Aires, Argentina).

Materials and methods: We analyzed affected tissues and internal defects of wood associated with debarking signs. We randomly collected 74 stems of the three forest species with (N=62) and without debarking (N=12) between October 2016 and December 2017. Transversal cuttings (N=37) and longitudinal cuttings (N=37) of the stems were analyzed.

Main results: The defects inside the wood related to the damage due to the debarking caused by Pallas´s squirrels are described. All the damaged samples presented affected wood tissues, with unfavorable healing forming ribbed cracks and ram`s horn scars and/or presence of some internal defect (crack, crack with abnormal coloration, crack with kino/resin or crack with bark included). None of the damaged pieces, according to the rules of visual classification of sawn woods, showed the highest quality grade (Premium).

Research highlights: Pallas´s squirrel action causes wounds on the trees, leading to different responses by the trees that are transferred internally, showing abnormalities in the wood which diminish its value from a commercial point of view.

Additional key words: *Callosciurus erythraeus*; red-bellied squirrel; biological invasions; bark stripping; wood quality; alien species.

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Introduction

Wooded ecosystems provide numerous environmental services and contributions to the human welfare (Rodríguez García et al., 2016). These environments can be affected by biotic factors like insects and mammal pests. Regarding this, many invasive mammal species may have great consequences on these kinds of systems in the invaded area, not just by the frugivorous or defoliating action, but also due to the wounds caused by debarking, territorial marking, ripping or scratching (Nevrelova & Ruzickova, 2015; Lim, 2016). Several introduced squirrel species (Rodentia: Sciuridae) have become invasive in different countries causing negative impacts in forest plantations due to their debarking with economic consequences for the forestry industry (Mendes et al., 2019).

Generally, trees defend themselves against pest organisms that affect them with different resistance mechanisms to prevent damage, either mechanical or chemical (Richter & Priend, 2015; González et al., 2020); and they also respond with tolerance mechanisms when the damage is already done (Vacek et al., 2020). For example, when the stem is damaged, the wound can close itself leaving scars with different shapes and features. Some scars manage to isolate the exterior of the bark but still leave cracks inside the stem (ribbed cracks), while others do not close the whole wound done, leaving an open crack in the bark, and the scar tissue takes the shape of ram's horns (Mattheck & Breloer, 1994).

Other symptoms associated with damage is the production of resin as a resistance mechanism in conifers, creating resin bags which cause a detriment in the wood quality; or the secretion of kino in eucalyptus (Vignote Peña et al., 2013; García & Mastrandrea, 2018). As mentioned above, sometimes wounds do not close perfectly and they leave cracks on wood pieces with or without bark included (Vignote Peña et al., 2013). Also, some trees react with a morphologic, histological and biochemical defense, producing changes in the pigmentation or stains of the wood and higher levels of humidity retention, which ultimately causes the death of the attacked tissue (González et al., 2020). All the symptoms mentioned above affect the quality of the wood, leading to economic losses. For this reason, it is necessary to manage harmful animals that affect forest tree species in order to avoid or reduce these consequences (Vignote Peña et al., 2013; Richter & Priend, 2015).

The promotion of afforestation in Argentina since 1999 allowed the production of goods with a higher degree of elaboration. Pine, eucalyptus and poplar woods are used for lumber, furniture, openings, molding and paper boards (Von Haeften, 2019). This type of diversified timber industry demands a good quality wood which will determine, ultimately, its destination and price (INTA, 2018). Generally, the base of the stem is the most valuable in the forest industry because it usually has the best quality, being higher its price when defects are absent or scarce (Vignote Peña et al., 2013; Ritcher & Priend, 2015; INTA, 2018). Damages affect the quality of the wood and have an impact on the utilization of that wood; however, the presence of certain and limited defects in the healthy parts that are going to be used is acceptable, and they will be used to classify the wood (Arriaga et al., 2003).

According to the USA National Hardwood Lumber Association (NHLA, 1998), woods with a lower number in the classification (grade 1) are woods with higher commercial value used for fine carpentry; while woods with higher numbers within the classification (up to grade 4), are woods for common carpentry, in which the aesthetic appearance is not a relevant aspect (Cassens & Serrano, 2006). Achieving a good quality of wood makes possible to get products that fulfill the conditions stablished according to their use, decreasing economic losses associated with a lower quality of wood.

In this context, monitoring and controlling animal pests and fungi diseases that could affect the quality of the wood to be commercialized, is essential. The action of these biotic agents cause different symptoms like substance secretion, cells disintegration and collapse; while rotting and other problems will appear in greater or lesser degree, depending on the intensity of the damage (Baldini et al., 2006).

As previously mentioned, squirrels can cause several damages on trees due to the debarking they carry out (Nichols et al., 2016; Zarco et al., 2018). The cracking of the bark destroys the defense barriers of the tree (Mayle et al., 2009; Mori et al., 2015); and the wounds on branches or stem made by squirrels can alter the normal growth of the wood, with a formation of scar tissue, resulting in a loss of the quality of the wood and commercial value (Sullivan et al., 1993; Yuan, 2011). Studies made in many countries about the grey squirrel (*Sciurus carolinensis*) and about other squirrels (among them *Callosciurus* squirrel species), show that debarking causes a negative impact in forest industry. The initial damage caused by squirrels can generate secondary damages like a decrease in the growth of the tree, affecting its diameter and height, depending on the intensity of the damage and the vegetative organs that are affected (Sullivan et al., 1993; Rayden, 2002; Mayle & Broome, 2013; Van Lerberghe, 2015). These damages cause a decrease in the wood quality and a reduction of the performance and cause economic losses up to 70% of its commercial value due to the high costs related to the control or mitigation of the damage (Mayle & Broome, 2013).

The red bellied squirrel or Pallas's squirrel, *Callosciurus erythraeus* (Pallas 1779), was introduced in Argentina in 1970 and is considered a harmful and generalist invasive species that cause different problems in the productive sector by damaging the bark of numerous trees and bushes species (Pedreira et al., 2017; Zarco et al., 2018; Guichón et al., 2020). According to our previous studies, it is known that this squirrel species affects forest tree species by causing external wounds, in a transversal and longitudinal way

Figure 1. Kind of debarking due to the action of *Callosciurus erythraeus* in species of commercial interest: (a) "typical longitudinal" in *Populus deltoides,* (b) "scratch" in *Pinus elliottii,* and (c) "patches" in *P. deltoides.*

on stem and branches, and destroying live tissues (Pedreira et al., 2017; Zarco et al., 2018). For example, in commercial species of Argentina such as *Eucalyptus dunnii, Populus deltoides* and *Pinus elliottii,* damage may cause deformations in the growth of the stem or breakage, leading to critical wood volume losses in adult plantations that are next to be cut, which affects the profitability of plantations (Pedreira et al., 2020; Pedreira, 2021). Although these previous results show a loss in the volume of the wood, there are no systematic studies aiming to evaluate the impact on the quality of wood caused by this invasive species in Argentina. We proposed, then, to characterize the damage in pieces and planks of wood, recording the presence of internal symptoms in response to that damage, and to evaluate its effect on the commercial quality of the wood of three important forest species in Argentina: *E. dunnii*, *P. deltoides* and *P. elliottii*.

Material and methods

Field work was done between October of 2016 and December of 2017 in a forest plantation called Liebres Fue (34º36'12.1''S 59º11'32.1''W), located in Luján District, Province of Buenos Aires, Argentina. Trees of the commercial species eucalyptus (*Eucalyptus dunnii* Maiden), poplar (*Populus deltoides* Bartham & Mar.) and pine (*Pinus elliottii* Engelm), of different ages (6 and 16 years old; 6 and 13 years old, and 8 and 18 years old, respectively) with and without (control samples) debarking signs, were evaluated. The samples area reached approximately 10 hectares.

To characterize the damage, we analyzed stem cross sections of the samples to evaluate the affected tissues. In addition, we evaluated the internal defects caused by debarking in pieces and planks of the samples. To achieve this, a total of 74 trees of the three species (*E. dunnii*, N=19; P. *deltoides*, N=27; *P. elliottii,* N=28), and four control samples per species, were randomly cut. We identified the kind of debarking following a previous study (Pedreira et al., 2020) that describes three shapes of longitudinal wounds: "typical longitudinal", "patches", and "scratch" (Fig. 1).

Stem cross sections (transversal cutting)

To evaluate the affected tissue, we cut 50% of the stem samples (N=31 with damage; N=6 control) in transversal sections of 50 mm of thickness that were sanded and observed with a stereo microscope (4x). In the samples with damage, we detected scars, cankers, exudates, the presence of compression wood, and differences in the thickness of the growth of the rings. Total circumference of the transversal cuts was recorded with a measuring tape, and the wounds diameter was measured with a digital caliber. We determined the depth of the wounds as the damaged diameter proportion, and the percentage of girdling as the damaged circumference proportion.

Pieces and planks (longitudinal radial cutting of pieces)

To evaluate internal defects on wood, the other 50% (N=31 with damage; N=6 control) of the stem samples were cut in pieces 1.20 m long. First, we measured the circumference, diameter and length of the pieces with a

Table 1 . Classification for quality of sawn wood by visual observation. Based on Shield & Mastrandrea (2007) and adapted from NHLA (1998)

Allowable defects	Wood quality grades			
	1 Premium	2 Select	3 Standard	4 Utility
Crack	Not allowed	<1 mm de wide ancho, <250 mm length	<2 mm wide, <250 mm length	<2 mm wide, unlimited length
Crack with abnormal color	Not allowed	<1 mm de wide ancho, <250 mm length	<2 mm wide, <250 mm length	<2 mm wide, unlimited length
Crack with resin/kino	Not allowed	<2 mm wide, individual max length 250 mm, grouped total length 1/2 of total length	<5 mm wide, max length 1 m, grouped total length unlimited	<10 mm wide, unlimited individual and total length
Crack with bark included	Not allowed	<1 mm wide, <250 mm length	<2 mm wide, <250 mm length	<2 mm wide, unlimited length

measuring tape and a caliber. The morphometric variables of the external wounds (length and width) were measured, and the intensity of the damage (percentage of the external surface damaged) was obtained by adding all the external wounds area measured per piece, and by visual classification (between 1 and 6 according to Pedreira et al., 2017).

Then, planks were obtained by longitudinal radial cuttings of the pieces; bark with exposed wounds was kept in each plank (Chavesta, 2006). The following internal measures obtained by direct observation or with a magnifying glass were recorded:

— Type of defect: 1, crack (separation or local ruptures); 2, crack with abnormal pigmentation; 3, crack with resin or kino; 4, crack with bark included (Shield & Mastrandrea, 2007). Only internal defects present in samples with external wounds caused by squirrels were considered (that is the reason why the bark with wounds were kept when preparing the sample). The dimensions (length and width) of each defect were measured.

— Length and width of the planks were measured in order to determine the percentage and relative surface of the damage.

Data analysis

A descriptive statistical analysis of the affected tissues was made on the transversal cuttings (xylem and bark) for each variable and affected species. The Kruskal-Wallis test statistic (H) was used to analyze the differences in girdling, in the depth of the wounds, and around the internal affected area of the planks according to the kind of debarking. The shapes of the external wounds by type of present defect were described. Also, a Spearman correlation analysis was made to observe the association between the internal affected area in each plank (shown as the sum of the areas of all the defects), the damaged external area (shown as the sum of every external damaged area) and the intensity of the damage determined globally as well as by species.

According to the presence and size of the defects found, the planks were classified in four basic quality grades according to the Shield & Mastrandrea (2007) classification (1: best quality, 4: worst quality) (Table 1), taking into account only defects associated with external damages caused by the squirrels, discarding those defects that were not (e.g. knots, insects galleries, star-cracks on the edge of the pieces caused by an accelerated dehydration of the material, etc.), following the standard sawn wood classification methodology (NHLA, 1998).

Analysis of χ^2 was made to compare the visual classification of the quality by species and the proportion of types of defects provoked by the different kinds of debarking for the entirety of the pieces and by species. The SSPS 24 (IBM, 2016) software was used.

Results

Internal characterization of the stem cross sections

The damage produced by the squirrels affected all stem tissues, including the xylem, in 100% of the samples (N=31) of *P. elliottii*, *E. dunnii* and *P. deltoides*. The average percentage of girdling was higher than 20%, being *E. dunnii* the species with higher values (almost twice than pines and poplars). The depth of the wounds oscillated between 3.64% and 35.09% with significant higher values for *E. dunnii*. Patch type wounds were the less deep (minimum: 3.64%, mean=9.15%, SD=5.8) and, the scratch type wounds were the deeper (maximum: 35.09%, mean=24.57%, SD=9.08), without significant differences between species (Table 2).

Figure 2. Damage on tree species caused by *Callosciurus erythraeus* (District of Luján, Buenos Aires, Argentina). Ram's horn wounds in *Eucalyptus dunnii*: cross section of stem (a) and detail of surface damage (b). Ribbed cracks wounds in *Pinus elliottii:* cross section of stem (c) and detail of surface damage (d). The growth of compression wood is shown in square brackets.

Some of the samples with presence of cankers or incomplete cicatrization (N=11) showed decomposed wood and abnormal pigmentation, with partial disappearance or deformation of the growth rings. None of the control samples (N=6) had affected internal tissues nor abnormalities.

Internally, stem cross sections of the three species showed diverse responses of the tree to the damage. Ram's horn wounds appeared with the typical rolled bark in the margins of the wounds (Fig. 2a). Also, ribbed cracks were observed with bark included (Fig. 2c). Furthermore, in some of the *P. elliottii* samples (Fig. 2c), we observed compression wood growth in response to the damage (eccentric growth rings that seemed to have an abnormal late wood proportion in wider portions).

Internal characterization of the pieces and planks

All the evaluated pieces with external damage (N=31) showed internal defect, corresponding to one of the four types described in the methodology (Fig. 3).

The distribution of the types of defects in the evaluated species was heterogeneous (χ^2=81.01, p<0.001, N=152). The simple crack was the predominant defect in poplar and eucalyptus; meanwhile, the crack with resin or kino defect was predominant in pines and absent in poplar (Fig. 4a).

There were also significant differences in the distribution of internal defects types, according to the kind of debarking (χ^2=24.68, p<0.001, N=152) (Fig. 4b). The wounds

Table 2. Damage to commercial tree species caused by *Callosciurus erythraeus* (District of Luján, Buenos Aires). Morphometric variables in stem cross sections (% girdling and % average depth of wounds). Mean and, in parentheses, standard deviation. Different letters indicate significant differences between species in the columns (p<0.05).

Species	N	Girdling (%)	Depth (%)
Populus deltoides	10	23.92 (2.98)^b	17.93 (9.86)^a
Eucalyptus dunnii	6	42.44 (28.88)^a	22.05 (8.07)^a
Pinus elliottii	15	22.24 (18.92)^b	13.92 (7.44)^a

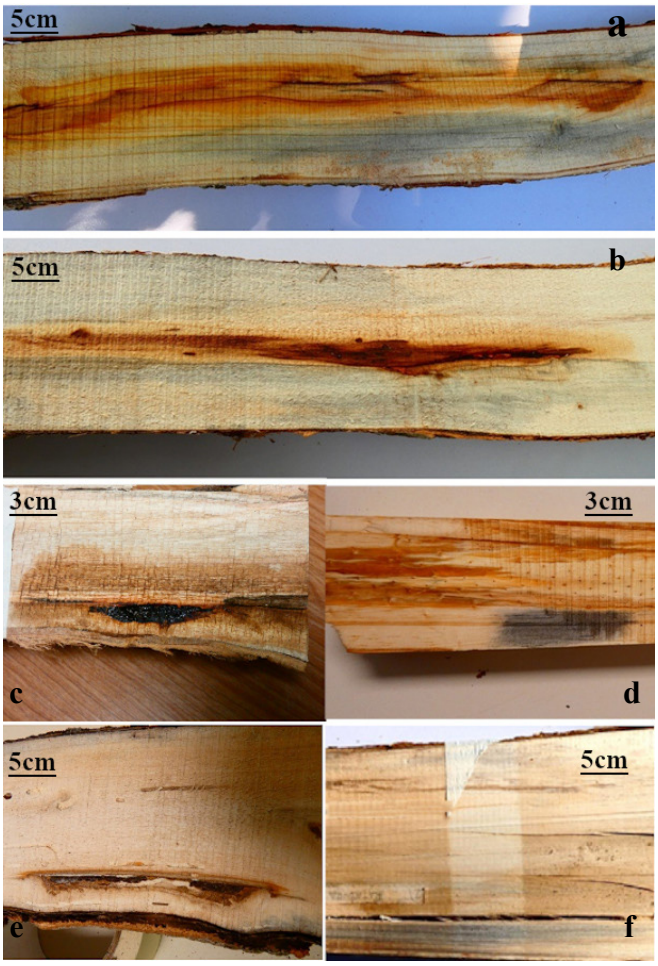

Figure 3. Internal wood defects (radial section) caused by *Callosciurus erythraeus* in three species (District of Luján, Buenos Aires, Argentina). Crack with abnormal coloration in *Pinus elliottti* (a) and in *Populus deltoides* (b); crack with kino in *Eucalyptus dunnii* (c); crack with resin in *P. elliottii* (d); crack with bark included in *P. deltoides* (e), and crack in *P. deltoides* (f).

with typical longitudinal and scratch shapes showed the four types of defects in the pieces, unlike the patch ones, which did not manifest any crack type defect in the wood with resin or kino. On the other hand, the patch and typical longitudinal wounds showed a higher proportion of cracks, both with or without bark included. Regardless of the kind of debarking, the predominant defect in the pieces was the simple crack (52.6%; N=80) and the second most common was the crack with bark included (up to 23.7%, N=36). Cracks with resin and cracks with abnormal pigmentation were detected in a lower percentage (15.1%, N=23 and up to 8.6%, N=13, respectively).

Regarding the morphometric variables of the wounds measured in all the pieces (N=31), the ones that showed typical longitudinal shapes were those with higher external damaged surface (mean=12.83%, SD=11.65, N=25). Patch type wounds had lower values of damaged surface (mean=2.75%, SD=2.60, N=16), and scratch type wounds intermediate values (mean=6.26%, SD=3.60. N=6). Significant differences were only found between patch and typical longitudinal shape wounds ($H=16.80$, $p<0.0002$, N=47).

More than one type of wound was found in the pieces of the sampled trees. Table 3 shows the average percentage of the internal affected area of the planks of every evaluated piece. Even though there was a great variability, when the relation between the kind of debarking and the internal affected area was evaluated, typical longitudinal shape and scratch wounds showed a higher internal defective area, different from the patch wounds ($H=10.16$, $p<0.006$, N=47). As expected, none of the samples without squirrel damage (N=6) presented internal defects in the wood (Fig. 5a).

The correlation between the internal affected area and the damaged by squirrels external area showed a slight but significant positive association ($R=0.532$, $p<0.001$; N=31). The correlation between the internal affected area and the intensity of the damage determined by visual classification showed similar results ($R=0.34$, $p<0.032$, N=31). The correlation between the internal affected area and the damaged by squirrels external area was analyzed by species; significant association was found in poplars ($R=0.725$, $p<0.001$, N=13) and eucalyptus ($R=0.718$, $p<0.001$, N=9) and not in pines ($R=0.183$, $p > 0.318$, N=9). Same results were found when this analysis was done taking into account the internal affected area and the intensity of the damage recorded by a visual classification (poplar $R=0.791$, $p<0.001$, N=13; eucalyptus $R=0.756$, $p<0.001$; N=9; pine $R=0.32$, $p>0.197$; N=9).

Quality grades of the planks

According to the rules of visual classification of sawn woods, none of the evaluated planks with damage (N=31) presented the highest quality, grade 1 (Premium), whereas 40% of the planks were classified as grade 4 (Utility); 48% as grade 3 (Standard) and only 10% as grade 2 (Select). Only the samples without squirrel damage (control samples, N=6) obtained the highest quality (grade 1, Premium) (Fig. 5).

There were no significant differences in the distribution of the quality grades by tree species (N=31) ($\chi^2=4.13$, $p>0.389$). Regarding the pine (N=9), all the pieces were grade 3 (Standard) or 4 (Utility), like most of the pieces of other species. Only 10% (N=3) of the pieces were quality grade 2 (Select) (eucalyptus, N=2 and poplar, N=1) (Fig. 6).

Discussion

Affected tissues in stem cross sections

The results allowed to describe the symptoms inside the wood, related to the damages caused by Pallas´s squirrels

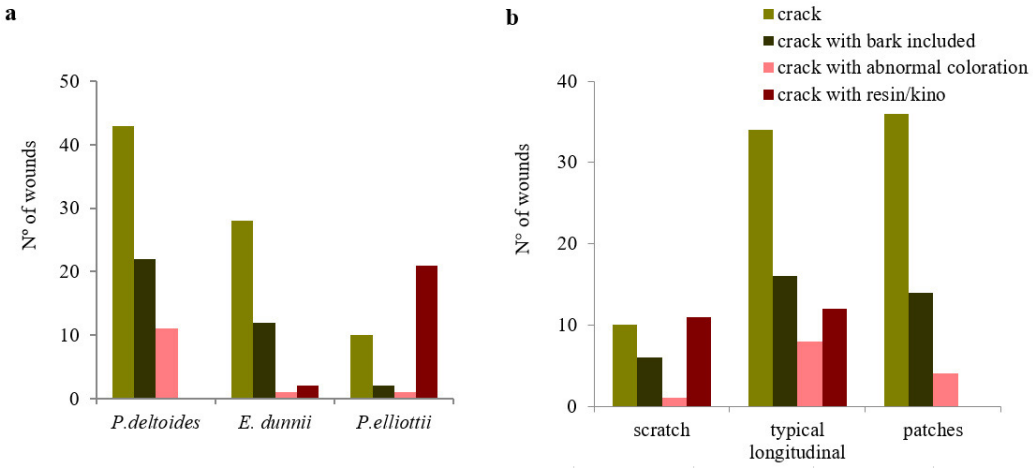

Figure 4. Internal wood defects (radial section) caused by *Callosciurus erythraeus* in three species. (a) Distribution of types of defects in all planks by species (*Populus deltoides* N=13 planks, *Eucalyptus dunnii* N=9 planks and *Pinus elliottii* N=9 planks). (b) Distribution of types of defects according to the kind of debarking (N=31).

when they debark the stems of the trees. In the entirety of the samples with damage, the meristematic tissue that produced wood (cambium), the phloem and the xylem were affected. The damage in the cambium interrupts the growth of the rings in the sector of the wound and causes stem deformation (Spavento & Keil, 2008). This kind of damages (previously described for gray and red squirrels: Sullivan et al., 1993; Rayden, 2002) was observed, although specific quantifications of the number or thickness of the rings were not recorded. However, the record of these damages caused by Pallas´s squirrel, *Callosciurus erythraeus*, is a novel report.

The debarking made by the squirrels has multiple causes (Chang, 1976; Lin & Yo, 1981), and it is associated mostly with the nest building and with feeding. Chang (1976) found 80-100% of cambium of *Cryptomeria japonica* in the stomach content of *C. erythraeus*, in a period of summer shortage of resources in their origin area. Kuo (1982) observed that the squirrels kept returning to debark the same wound until they have reached the cambium. So far, no systematic studies have been made in Argentina about the debarking behavior of *C. erythraeus*; nevertheless, by direct observation it was evidenced that the squirrels remove the bark for the construction of nests and they feed on sap (Zarco et al., 2018; Guichón et al., 2020). Also, remains of bark from several plant species were found in the microhistological analysis of their feces (Zarco et al., 2018).

The proportion of the circumference of the cambium that is eliminated in the different organs of the trees is an important thing to consider given that if it gets to 50% or more of the stem circumference, it can compromise survival and growth parameters or result in death of the trees (Sullivan et al., 1993; Mayle et al., 2009; Richter & Priend, 2015). Regarding the three species studied, *E. dunnii* suffered more than 40% of stem girdling. This fact could severely diminish its growth and increase its susceptibility to pests' attacks, as Priestley (2004) showed for *E. camaldulensis*.

The shape of the wounds has an impact on the percentage of girdling of the trees. In the *E. dunnii* plantations, trees had mainly "typical longitudinal" wounds and a higher percentage of girdling. The presence of "scratch" type damage in *P. elliottii* and "patch" type in *P. deltoides* causes a lower girdling percentage, though is appropriate to point out that the "scratch" wounds are deeper.

The wounds caused by the debarking of the squirrels can be a way in for insects and diseases (Zhu et al., 1990; Mori et al., 2015). In Taiwan, Kuo (1982) described that most of the wounds that were caused by *C. erythraeus* in *C. japonica* and *Cunninghamia lanceolata* did not heal, and after one or two years, secondary infections were observed, related with the decomposition and stain of the wood. This agrees with what we found in this study, given that the wounds left the wood exposed to the external environment and microorganisms could have originated the

Table 3. Internal affected area of evaluated planks (average percentage) related to the kind of debarking by *Callosciurus erythraeus*.

Kind of debarking/ wood piece	Internal affected area, %		
	x̄	SD	N
Patches	1.24 **	1.28	16
Typical longitudinal	5.13 ns	4.85	25
Scratch	7.16 ns	8.58	6

**: $p \leq 0.01$. ns: not significant.

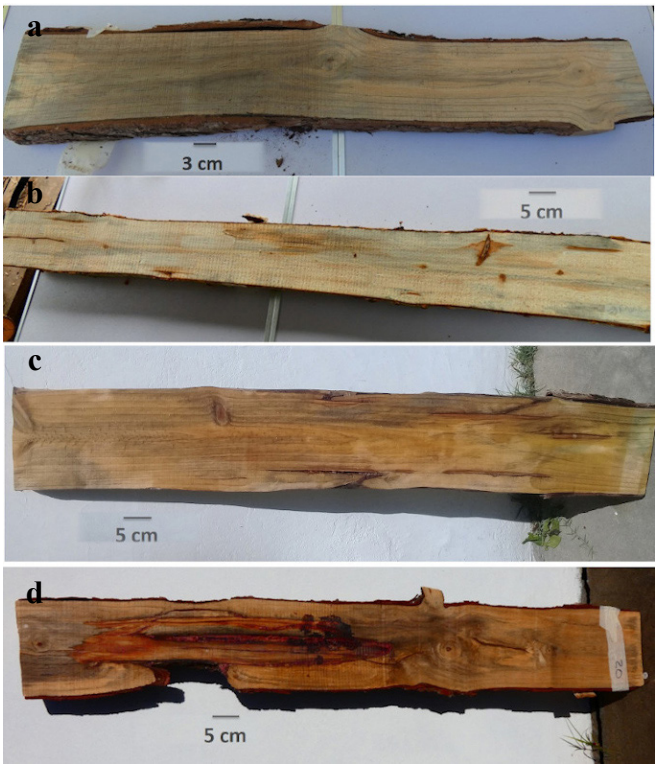

Figure 5. Internal wood damage caused by *Callosciurus erythraeus* (District of Luján, Buenos Aires, Argentina). Quality grades of sawn wood: Premium quality (grade 1), *Pinus elliottii,* without damage (control) (a); Select quality (grade 2), *Populus deltoides* (b); Standard quality (grade 3), *P. elliottii* (c); Utility quality (grade 4), *P. elliottii* (d).

abnormal internal pigmentations and rottenness observed in the analyzed cross sections.

Rayden (2002) mentioned the existence of ram's horn like wounds in trees debarked by the gray squirrel (*S. carolinensis*) as a factor that can affect the value of the wood to commercialize. In this study we also found that the damages originated by *C. erythraeus* caused unfavorable scarring response in some samples (ribbed cracks and ram`s horn), leaving open cracks that make the trees more susceptible to biotic and abiotic factors. These unfavorable scarring responses found in the studied trees in response to the damage, may cause a loss in its value in the wood market at the commercialization time (Mattheck & Breloer, 1994; Martínez & Díaz, 2016).

Compression wood growth is a kind of response that was observed in conifers as a compensation mechanism for the damage caused by squirrels, being unfavorable due to the excessive longitudinal contraction that causes deformation and tearing of the wood (Sullivan et al., 1993). Due to its lower density, the compression wood causes multiple drawbacks for its usage and, from the perspective of a standing tree, it also causes that the specimen may be more prone to failing (Mattheck & Breloer, 1994; Martínez & Díaz, 2016). Here, were report for the first time this kind of compensation mechanism in samples of transversal cutting of *P. elliottii* due to the damages caused by the Pallas´s squirrel. We did not detect this kind of compensatory growth (called tension growth) in *E. dunnii* and *P. deltoides*, as it is difficult to observe it in Angiosperms by direct observation, due to their low differentiation of growth rings.

The results of the present study show that the mechanical damage that this invasive mammal does on the conductor tissues and the support of the trees, is a serious issue as it may have negative impact in the survival and growth of the trees, with unfavorable consequences for the wood commercialization.

Defects found in the pieces and planks

Quality of the wood was determining according to the presence and size of the defects found in the planks, allowing us to discuss how this affects the pulp and solid timber industry.

Four internal defects caused by the wounds of *C. erythraeus* in the radial section of the wood were identified. One of them was the crack with resin or kino, which is similar to a piece of wood with holes, meaning a loss of section that can diminish the wood resistance. This defect can also cause technological problems as different tools that are used may impregnate with resin or kino and also because it makes more difficult the glue or varnish of the wood (Vignote Peña et al., 2013). Also, defects like simple cracks, with pigmentation and/or with bark included in the planks were identified. These defects determine a loss of the resistance of the wood and of the aesthetic value for carpentry (Vignote Peña et al., 2013).

Torelli et al. (1994) explained that the response mechanism of trees generally depends on the intensity and profundity of the wounds, where the more intense and/or deeper wounds cause a higher exposition and posterior dehydration, aeration, depigmentation and decomposition of the tissues and the exudates of the exposed tissues. In this study, the intensity of the damage was correlated positively with the internal affected area, being significant for poplar and eucalyptus but not for pines. In this way, the pine bark features may offer better protection towards the external damage; further studies including a higher number of samples are necessary to deepen this aspect. The external wounds caused by squirrels affected the wood internally with diverse kinds of defects. Planks with patches, with less external damage exhibited less internal defect proportion in the wood. In the other hand, planks with typical longitudinal wounds (higher intensity of damage) and scratch wounds (higher deep), had a higher proportion impact in the internal section. The fact that the same results were obtained when we evaluated the association of the internal affected area and the external damage intensity, calculated as the sum the area of the external wounds measured in each piece and through a visual classification, gives the opportunity

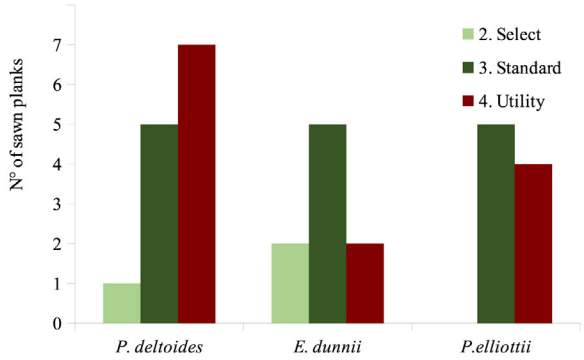

Figure 6. Quality grades of sawn wood by species (*Populus deltoides, Eucalyptus dunnii,* and *Pinus elliottii*) due to internal wood damage caused by *Callosciurus erythraeus* (District of Luján, Buenos Aires, Argentina).

to use the visual classification to infer the possible total internal area with defects on the field.

As mentioned above, defects on the wood as a response from the tree to biological agents are an obstacle for the industrial and commercial use, and it is used for classifying the wood quality of the pieces (Pasanisi, 2006). In this study, all the pieces with damage from the three commercial species evaluated had a worse quality in comparison with the pieces without squirrel damage (control). Having a worst quality of wood will affect the number of resulting planks that may be used, with economical losses for the timber industry.

The studied Angiosperms (*E. dunnii* and *P. deltoides*) exhibited external damages of patch or typical longitudinal type. These damages resulted in simple cracks o depigmentation in the poplar, meanwhile in the eucalyptus cracks with kino, or with bark included were observed. These mechanisms of response were also described for other biotic agents, including other squirrel species, both in Angiosperms (Torelli et al., 1994; Vacek et al., 2020) and Gymnosperms (Sullivan et al., 1993).

Depigmentation defects were observed in poplar plantations. These defects on the wood were previously described in poplar, associated with the synthesis of secondary metabolites as a response to the wounds caused by biotic agents (González et al., 2020). While these responses have a great adaptive importance to the trees, the extension of depigmentation, the exudates presence and the decomposition associated to the wounds are something to worry about because of the negative impact that they produce in the quality of the wood, causing an increase of the costs due to the higher difficulty to carry out the posterior industrialization processes.

In the other hand, wounds of typical longitudinal and scratch type, which were internally associated with cracks with resin, were recorded in *P. elliottii*. Sullivan et al. (1993) found compression growth and changes in the concentrations of the resin of wounded trees of *P. contorta*. Something similar happens with eucalyptus trees that suffered traumatisms, in this case the presence of gum kino resin can cause negative effects in the sawmill and in the pulp industry (Vignote Peña et al., 2013). Complementary chemical analyses would be necessary to determine the concentration of these substances in the damaged wood and estimate the losses in the industrialization processes.

Conclusions

This study is the first work aiming to describe the damage on the quality of wood of the commercial forest species in Argentina *P. elliottii*, *E, dunnii* and *P. deltoides*, due to bark stripping caused by Pallas´s squirrel. The debarking caused by this invasive squirrel species generates wounds in the trees that lead to the appearance of different responses of the trees to recover their morphological and physiological characteristics. These responses are transferred internally to the wood causing abnormalities, which in turn, determines the quality of the wood and its importance for the forest industry.

By doing a global interpretation of the results, the eucalyptus and poplar species showed similar behavior, showing patch and longitudinal types of wounds with a higher proportion of cracks, cracks with pigmentation and cracks with bark included. In the case of pine, cracks with resin defects predominated while being accompanied by low intensity scratched damage as well as poor wood quality. In some eucalyptus pieces with patch or longitudinal damage, instead, the quality decreased less, and simple cracks or with bark included were showed.

The damages caused by debarking in the three commercial species analyzed disqualify the quality of the sawn wood. In addition, there is a positive association between the dimensions of external and internal damage. The different variants of external longitudinal wounds ("typical longitudinal", "scratch" or "patches") affect the internal quality of the wood to a greater or lesser extent. Future studies that include other tree forest species and other kind of analyses will allow a greater predictive power of the internal damage trough the external observation of a wound found in a tree. These will contribute to a quick and good decision-making for the management of this invasive squirrel.

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