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Clear-cuttings effect in ecological restoration of the Norway spruce stands damaged by red deer (*Cervus elaphus*)

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Abstract

In the recent decades, in Norway spruce forests have been reported ecological imbalances caused by red deer (*Cervus elaphus*) by bark-stripping, with a great impact on stability and productivity of the stand. When the profitability of the Norway spruce stands starts to decrease, due to the wood volume with stem decay, an ecological restoration of this ecosystems is imposed. This study reports a case study from the north of Eastern Carpathians. It presents the results of nine experiments from two of the most affected area from North of Romania by red deer (*Cervus elaphus*), in order to test the success of applying some forestry treatments: the progressive clear-strip cutting (stands more than 10 ha) and the clear cutting on small areas (stand less than 10 ha), with reference to strip width, the direction of the strips, the felling direction, the regeneration process and the cuts return interval. Number of extracted trees·ha^{-1} varied between 1340 and 324 and the removed volume was between 457 m^3·ha^{-1} and 181 m^3·ha^{-1}. The proportion of stem decay volume was important (between 23% and 42%), being related to the stand age. In stands over 50 years, the wood volume with stem decay is less than 30% (23% to 27%), while in those over 35(40) years, it is greater than 33% (34% to 42%). A successful regeneration (natural and artificial), in the time elapsed from the implementation of the previous silvicultural treatments (about 25 years), support the success of the applied ecological restoration. The progressive clear-strip cutting and clear cuttings on small areas, as part of the ecological restoration of the red deer (*Cervus elaphus*) damaged Norway spruce stands, showed good results, and could be considered as a tool for the ecological restoration of these stands.

Keywords: forest management, *Picea abies*, forestry treatments, stem decay

Özet

Son yirmi otuz yıldır, Norveç Ladini ormanlarında kırmızı geyiklerin (Cervus elaphus) kabuk soyma faliyeti sonucu, meşcerelerde büyüme ve dayanıklılıkları konusunda ciddi zararlar olduğu belirtilmiştir. Norveç Ladini ormanlarındaki kârlılık odun hacmi ve gövde çürüklüğü nedeniyle azaldığında, bu ekosistemlerde bir yenileme çalışması yapılması gerekliliği doğmaktadır. Bu çalışma, kuzeydoğu Karpatlar'daki ormanlarda yapılan bir araştırmayı sunmaktadır. Çalışma, Romanya'nın kuzeyinde kırmızı geyiklerin en yoğun zarar yaptığı 9 alandan 2'sinde yürütülmüş ve bazı ormancılık uygulamalarının, bu zararlara karşı elde edebildiği başarıyı sunmaya çalışmak için; kademeli etek şeridi tıraşlama (10 ha'dan büyük alanlarda), tam alanda tıraşlama (10 ha'dan küçük alanlarda) uygulanmış ve şerit genişliği, şerit yönü, devirme yönü, gençleştirme işlemi ve makta süresi faktörleri bağımsız değişken sınıfları olarak uygulanmıştır. Kesilen ve meşcere dışına çıkarılan ağaç sayısı 324 ile 1340 adet/ha ve kabuklu odun hacmi 181 ile 457 m3/ha arasında değişmiştir. Gövde çürüklüğü oranı da (%23 ile 42 arasında) yaşa bağlı olarak, önemli düzeyde yüksek bulunmuştur. Yaşı 50'den yüksek olan meşcerelerde gövde çürüklüğü %30'dan düşük (%23 ve 27), yaşı 35'ten büyük meşcerelerde (40 yaşındaki)

%33'ten büyük (%34 ve 42) olduğu tespit edilmiştir. Bir önceki silviküLtürel işlemin uygulanmasından itibaren yaklaşık 25 yıllık sürenin geçmesinin tamamlanmasının ardından gerçekleştirilen başarılı gençleştirme uygulamasının ekosistemin yenilenmesine iyi bir şekilde hizmet ettiği görülmüştür. Kademeli etek şeridi tıraşlama ve küçük alanlarda tıraşlama kesimi yapılması, kırmızı geyikler tarafından tahrip edilen alanların ıslâhında etkili olduğu tespit edilmiş ve bu tür alanların iyileştirilmesinde başarılı bir uygulama olarak seçilmesi önerilmektedir.

Anahtar kelimeler: Orman yönetimi, Picea abies, ormancılık uygulamaları, gövde çürüklüğü.

Introduction

The future development of forestry needs improvements of the management (Schlaepfer 1987, Hasle et al. 2000) and, among others, attention should be pay on the possible actions of disturbing factors (e.g. wind, snow and deer) in some risk areas (deCalesta and Stout 1997, Akashi, 2009, Hlásny et al. 2011, Niinimäki et al. 2012). This is also the case of Norway spruce stands affected by red deer (*Cervus elaphus*), where in some cases the human intervention is necessary, in order to link the structure of the affected stands with the site potential and the ecosystem functions assigned (Jackson and Hobbs 2009). To promote a sustainable management of these stands, an appropriate framework should be considered (Ballon et al. 2005, Slodicak and Novak 2006, Vospernik, 2006, Kiffner et al. 2008), including key aspects as biodiversity or the multiple ecological and social-economic functions of these forest ecosystems (Kishimoto et al. 2010, Żmihorski and Durska 2010, Gheysen et al. 2011).

In young Norway spruce stands, most of the red deer (*Cervus elaphus*) damaged trees belong to the upper canopy classes and, thus, the mid- and long-term management of these stands is affected (Welch et al. 1987, 1988, Verheyden et al., 2006, Gheysen et al. 2011). Many factors (stand age and composition, damage frequency and wound age and their location in the stand) must be accounted in their management, among which the costs of the wounds produced by red deer (*Cervus elaphus*) in forests (Ward et al. 2004). Past research (Vasiliauskas and Stenlid 1998, Welch and Scott 2001, 2008, Gill et al. 2001) emphasized the prejudices of the timber volume, by a qualitative downgrade of stem decay, as resulted from red deer (*Cervus elaphus*) wounds (Čermák et al. 2004, Čermák and Strejček 2007, Scott et al. 2009, Vasaitis et al. 2012).

In Romania, the red deer population (*Cervus elaphus*) has grown significantly after the Second World War, when large gaps were created in the stands by clear-cutting on large areas or following extensive windfalls (Ichim 1990). As a result, in the Norway spruce forests located in the north of Eastern Carpathians important damages produced by the red deer (*Cervus elaphus*) were recorded. For example, in Suceava County, the affected stands represent about 21.3% of forest area; most affected being the Norway spruce stands between 20 and 80 years old (Vlad and Sidor 2011).

The structure, function and dynamics of natural and artificial systems (Norway spruce stands, in our case) are affected when the systems are subjected to severe stress (damages produced by deer) and that can be considered, besides a major environmental problem, an important opportunity for the ecologist (Cairns, 1987). The practice of ecological restoration has developed rapidly over the past few decades (Higgs 2003; Falk et al. 2006) taking into account the potential impacts of climate change (Harris et al., 2006).

Few studies reported information on the ecological restoration of Norway spruce stands damaged by the red deer (*Cervus elaphus*), and most aimed to the management of deer populations (Schlaepfer 1987, deCalesta and Stout 1997, Ballon et al. 2005). The paper aim is to present results following planning and implementation of the silvicultural treatments (clear-cutting) in Norway spruce stands damaged by the red deer (*Cervus elaphus*), as a part of the ecological restoration process, in an area with higher damages.

Material and method

Study area

The studied area is located in two forest districts from the northern part of the Romanian Eastern Carpathians, including many damaged Norway spruce stands (Vlad and Sidor 2011). Based on previous available statistics related to a higher intensity and frequency of damages produced by the red deer (*Cervus elaphus*), the forest districts Tomnatic (47º40'54" N; 25º27'16" E) and Pojorâta (47º26'09" N; 25º23'49" E) were selected for the case study (Figure 1).

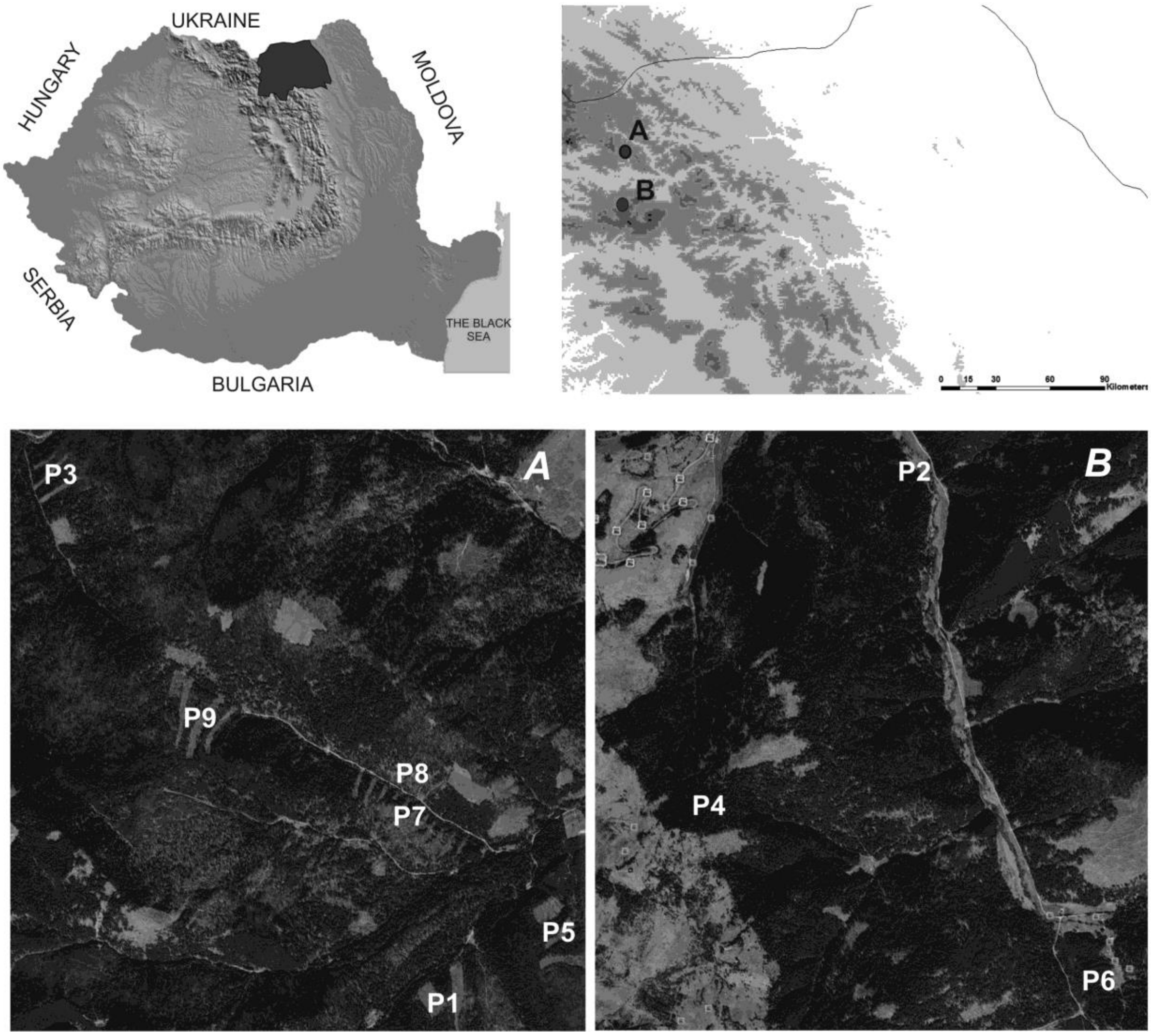

Figure 1. Study area (A – Tomnatic Forest District; B – Pojorâta Forest District; P1-P9 – experimental plots).

The stands subject to the ecological restoration (six from Tomnatic forest district and three from the Pojorâta forest district) were pure of Norway spruce, aged between 35 and 65 years and located between 500 m and 910 m, on moderate slopes (from 15º to 20º), mainly on northern aspect (Table 1).

Table 1. Basic characteristics of the stands subjected to the ecological restoration.

Stand	Coordinate	Forest district	Altitude (m)	Slope (^{0})	Aspect	Age (years)	Surface (ha)
P1	47º40'11" N 25º27'36" E	Tomnatic	860	15	N	35	20,0
P2	47º28'00" N 25º23'04" E	Pojorâta	550	15	N	35	1,8
P3	47º42'18" N 25º25'21" E	Tomnatic	870	17	N	40	8,7
P4	47º26'33" N 25º21'55" E	Pojorâta	600	15	N	55	5,4
P5	47º40'30" N 25º28'18" E	Tomnatic	850	16	N	55	25,3
P6	47º25'48" N 25º24'17" E	Pojorâta	500	15	NV	55	5,8
P7	47º40'57" N 25º27'28" E	Tomnatic	800	20	NE	55	20,0
P8	47º41'06" N 25º27'26" E	Tomnatic	840	20	SV	60	11,7
P9	47º41'20" N 25º26'10" E	Tomnatic	910	16	NE	65	22,3

Applied silvicultural treatments

The above stands were part of a larger forest restoration, based on different clear cuttings: progressive clear-strip cuttings and clear cuttings in small areas (up to 3.0 ha). The proposed forestry treatments were planned in two steps, and considering also the restrictions generated by the cuts location. These were projected and implemented in the field considering the different stands behaviors, e.g. the structural and qualitative stand characteristics, the frequency of damages or the wood volume with stem decay as a result of the wounds produced by the red deer *(Cervus elaphus)*.

The spatial arrangement of the cuttings was designed also to ensure the resistance of the remained stands to wind and an install and protection of seedlings. The width of the strips was 1-1.5 mean height of the stand and varied between 30 m to 40 m, alternating with sections about 75 m-80 m wide. The direction of the strips was established perpendicularly to the dangerous wind (mostly NE-SW).

The return interval in the progressive clear-strip cutting followed the seed production periodicity, the speed of the seedling establishment, the development of the young plants and the common forestry protection restrictions; a five-year interval being used responding to all these requirements. The strips regenerated both naturally and by plantations. In the case of progressive clear-strip cutting, three interventions were used, while for clear cuttings on small areas, two interventions.

Data collection

To assess the stand characteristics, in each stand subject to cuttings were installed a variable number of sample plots, according to the stand area. Mostly, 80% of area was inventoried. Circular sample plots of 300 m^2 were used in stands with ages between 21 and 40 years (36 sample plots), while 500 m^2 for stands with ages between 41 and 80 years (184 sample plots). The heterogeneity of the structural parameters was established to 45%, based on an average coefficient of variation of the frequency of the damage caused by red deer *(Cervus elaphus)*, from older inventories with the same purpose.

In each sample plot was measured the diameter at 2.0 m height for damaged trees, the diameter at 1.30 m height (DBH) for healthy trees, the tree height and the wound age - the last two for 50 random trees chosen from all the diameter categories. The diameter at 2.0 m was preferred based on the past experience; at this height the tree stem being no longer deformed as compared with the deer wounded area.

For the studied area, we considered unnecessary a wound split by its origin, i.e. between cervid, roe deer (*Capreolus capreolus*) and red deer (*Cervus elaphus*), as the wounds height clearly suggested an origin of the red deer (*Cervus elaphus*). Age of wound was determined with Pressler drill samples taken from the wound area, measured in the field with Haglof Core Reader (Haglof, Sweden).

Data analysis

The assessment of wood volume with stem decay was based on collected data (the 2.0 m height diameter for the trees damaged by the deer, the DBH for the healthy trees, the heights and the wound age corresponding to the 50 trees, from each diameter class), as follows. First, the diameter measured at the 2.0 m height was scaled to DBH using the available regression model developed for area (Vlad 2007a) and then, for each damaged tree, the height of the stem decay was derived and the volume of the tree trunk corresponding to the stem decay height was calculated using the equation of the volume settlement along the trunk (Giurgiu and Drăghiciu 2004). Finally, the wood volume with stem decay, the healthy volume, the total volume of the stand and the percentage of the wood volume with stem decay (as ratio between the wood volume with stem decay and the total volume of the stand) were also derived. The volumes (healthy volume and volume with stem decay) before and after the first intervention were assessed using the DEER software application (Vlad 2007a).

Results

The average values of trees density (from 1356 to 425 individuals·ha^{-1}), DBH (16.7±4.8 cm to 36.4±9.3 cm), the corresponding height (18.5±5.0 m to 28.7±7.3 m), the basal area (22.8 $m^2 \cdot ha^{-1}$ to 46.1 $m^2 \cdot ha^{-1}$) and the volume (211.2 $m^3 \cdot ha^{-1}$ to 595.9 $m^3 \cdot ha^{-1}$) of the stands present values common to the development stage of the stand (Table 2). The density index varied between 0.42 and 0.77 and the frequency of the wounds produced by the red deer *(Cervus elaphus)* ranges between 62% and 98% respectively, while the mean age of the wounds is between 23 and 28 years old.

Norway spruce stand damaged by red deer *(Cervus elaphus)* and subject to the ecological restoration correspond to the "first regeneration urgency", according to the Romanian forest regulation (damage frequency more than 70% - P1, P2, P3, P4, P5, P7 and P9; damage frequency between 60% and 70%, density index less than 0.5 and volume with stem decay more than 25% - P6 and P8) (Table 2).

Table 2. Structural characteristics of the Norway spruce stands at the ecological restoration start.

Stand	Structural characteristics							
	DBH	Height	Density	Density index	Basal area	Volume	Deer damages frequency	Average wound age
	(cm)	(m)	($N \cdot ha^{-1}$)		($m^2 \cdot ha^{-1}$)	($m^3 \cdot ha^{-1}$)	(%)	(years)
P1	16.7	18.5	1356	0.70	22.8	211.2	70	23
P2	24.2	26.5	1153	0.60	44.6	457.4	98	24
P3	24.4	21.7	767	0.58	31.1	291.5	83	25
P4	28.6	28.3	776	0.77	46.1	595.9	70	28
P5	32.9	25.3	420	0.52	41.1	450.8	87	26
P6	33.2	32.0	462	0.46	35.9	506.6	69	26
P7	34.5	24.9	499	0.50	30.9	272.2	70	27
P8	36.2	28.7	431	0.48	30.2	287.7	62	26
P9	36.4	28.1	425	0.42	36.4	389	71	28

Year of the first cuts of the applied progressive clear-strip cuttings and clear cuttings on small areas varied between 1992 (P8) and 2011 (P2, P4 and P6), the last intervention being in the period 2007 (P7) and 2009 (P8). The intensity of the first intervention, defined as ratio between the area of the applied forestry works and the total stand area, ranged between 25% and 36% (when three interventions were applied), 52% and 56% (two intervention) and 100% (one intervention) (Table 3).

Table 3. Stand information related to the applied forestry treatments.

Stand	Structural treatments characteristics												
	ST	Intervention		CF size	PC		Intensity (S)	Extracted					
								Number of trees				Volume	
		First (I)	Last (II)		strip width	strips size		Total		Deer damaged			
								I	II	I	II	I	II
				(ha)	(m)	(ha)	(%)					(m^3)	(m^3)
P1	CF	1997	-	5.5	-		28	7370		5071		1161	
P2	CF	2014	-	1.8	-		100	2076		2034		823	
P3	PC	2001	-	-	35	2.6	30	1236		989		470	
P4	CF	2014	-	3	-		54	2819		1804		1268	
P5	PC	1997	-	-	35	7.1	28	2982		2653		3201	
P6	CF	2014	-	2.9	-		52	940		639		1031	
P7	PC	1997	2007	-	40	6.4	32	2976	4521	2083	3074	1622	3057
P8	PC	1992	2009	-	40	2.7	23	810	1204	454	722	781	1391
P9	PC	1999	-	-	40	6.2	28	2635		1845		2417	

Note: ST - forestry treatment, CF - clear cutting on small area, PC - progressive clear-strip cutting, S – from stand area; I - first intervention; II - last intervention

Number of extracted trees varied between 1,340 trees·ha^{-1} (P1) and 324 trees·ha^{-1} (P6), which correspond to a proportion between 56% (P8) and 98% (P2), close to the initial damage frequency of the stand. Because the frequency of the red deer *(Cervus elaphus)* damages was, mostly, more than 60%, the distribution of the damaged trees, at the beginning of the silvicultural treatments, followed the distribution of the whole stand (Figure 2). In the case of damaged trees, the distribution resulted from the first intervention was different between stands, being influenced by the number of interventions of the forestry treatment (one, two or three) (Figure 3). The extracted volume varied between 457 m^3 · ha^{-1} (P2) and 181 m^3 · ha^{-1} (P3).
The volume with stem decay resulted from the application of the ecological restoration (reported to the extracted total volume), recorded values between 23% (P6 and P7) and 42% (P2). In stands older than 50 years, the wood volume with stem decay was less than 30% (23% to 27%), while in stands aged 35(40) years was greater than 33% (34% to 42%) (Figure 4).

When related the volume with stem decay to some structural (DBH, trees density) and qualitative characteristics (deer damages frequency, average wound age) of the stands, were found positive relationships with the deer damages frequency and number of trees·ha^{-1}, and negative with the DBH and wound age (Figure 5). The narrow allure of the point cloud suggested the higher influence of the damage frequency.

Discussions

Stand deer damages

Among others, the general stability of Norway spruce stands is linked to the health of the trees, which is influenced by root and stem decay (our case). These becomes windfall and windbreaks favorable factors, the of quality and health trees/stands being negatively affected. In these stands, the structural (number of trees·ha^{-1}, basal area, volume, density index) and qualitative characteristics (deer

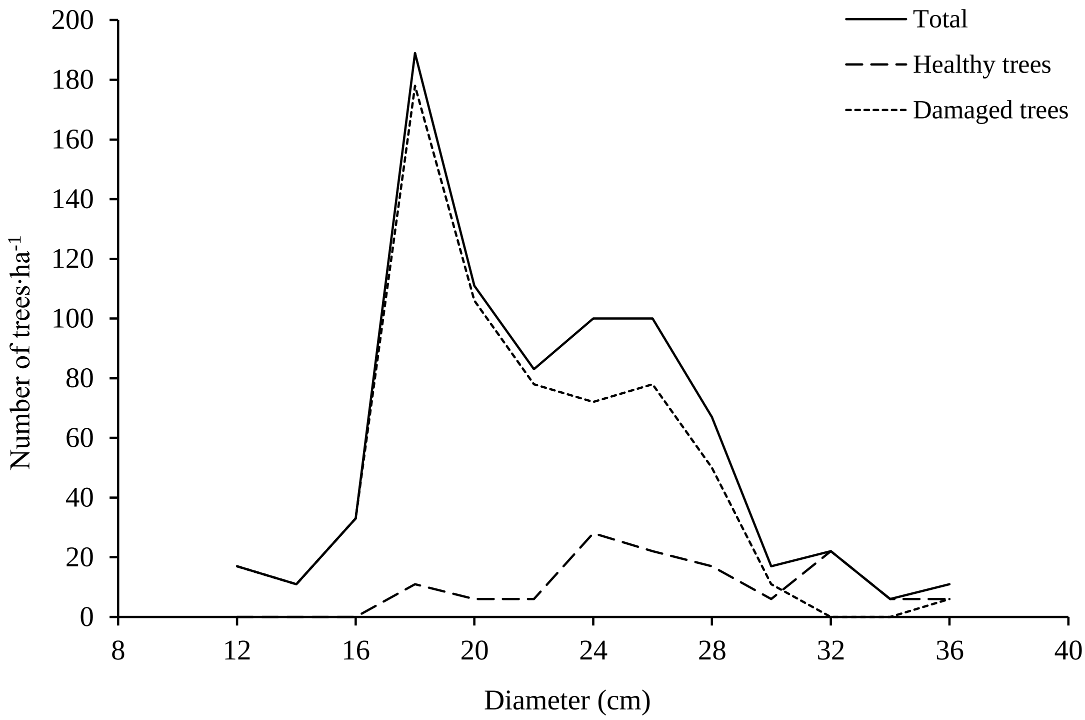

Figure 2. DBH distributions of trees before the first intervention (P3 stand).

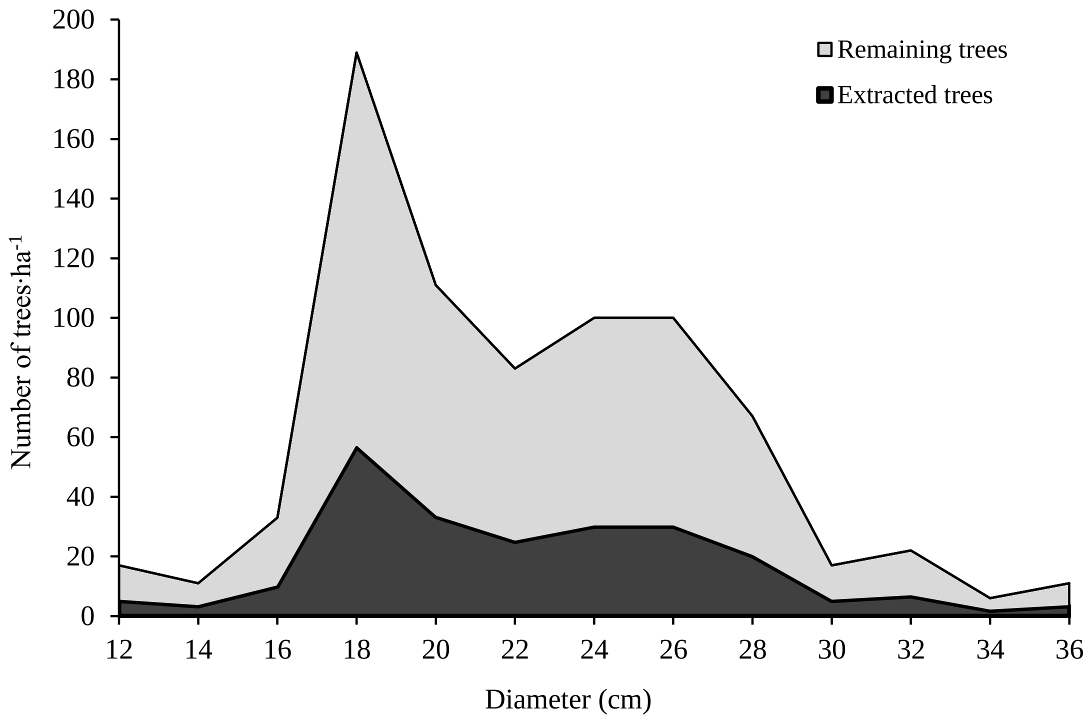

Figure 3. DBH distributions of the remained and extracted trees after the first intervention (P3 stand).

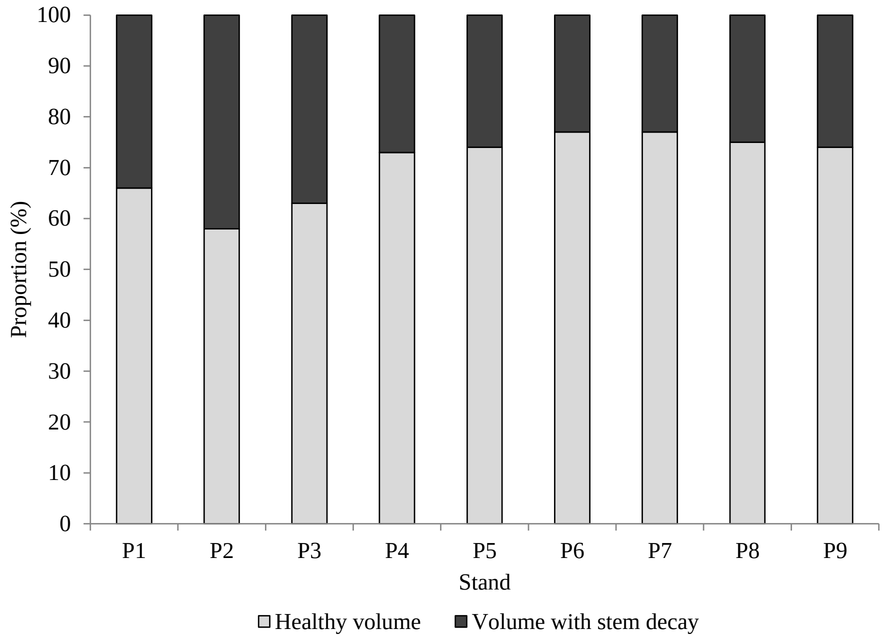

Figure 4. Proportion of stem decay volume in the stands.

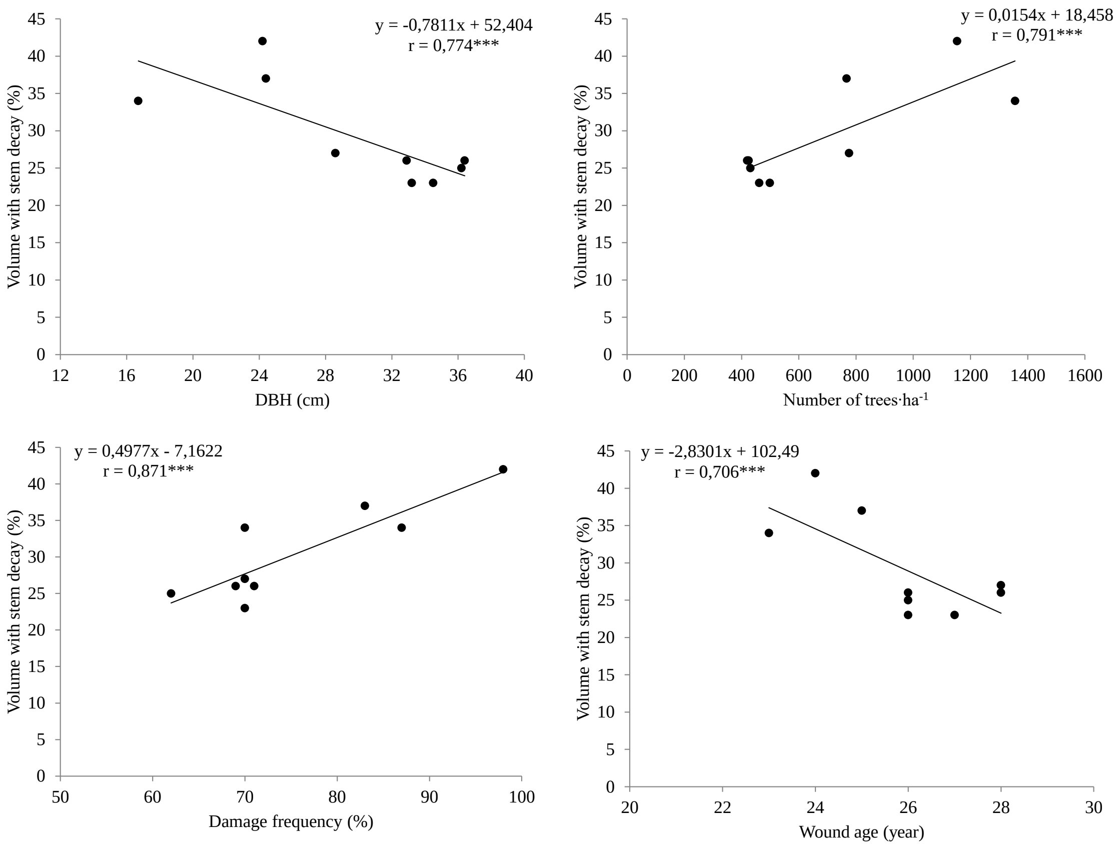

Figure 5. Relationships between the proportions of the stem decay and different stand characteristics.

damage frequency, wood with stem decay) are less than normal, a situation showed by previous research (Vasiliauskas and Stenlid 1998, Čermák and Strejček 2007, Vasaitis 2012).

The damage frequencies in extracted trees was close to the former stand values, suggesting that, at higher percentages of damages, these are uniformly distributed in the stand. We speculate that the lower values of the deer damages in the last cutting indicated that, mainly, the trees damaged by red deer *(Cervus elaphus)* were affected by wind and snow, similar to other results (Čermák et al. 2004).

The application of silvicultural treatments in Norway spruce stands damaged by red deer *(Cervus elaphus)* (progressive clear-strip cutting and clear cutting on small areas) yielded to volumes with significant proportion of stem decay, variable with the stand age (lower in the 50 years stands and higher in young stands of 35-40 years). Previous research on the damage produced by deer by bark-stripping and subsequent rots in the Norway spruce stands pointed on the highest loss (proportion of timber impaired by decay), found in the second age class (stands between 21 years and 40 years), assessed to be at 60% of the total timber volume (Čermák et al. 2004). Similar research reported that the stem decay accounted for 22% to 70% (an average of 42%) of the merchantable stem volume of sample trees (Čermák and Strejček 2007), while within 7 years of deer wounding, the decayed proportion of the stem cross-section at the wound site (stump) was of 3% to 84% (Vasiliauskas and Stenlid 1998).

Practical issues on the ecological restoration of deer damaged stands

According to the ecological criterion the background of the ecological restoration in the Norway spruce stands damaged by red deer *(Cervus elaphus)* account for the fact that the affected stands present reduced biodiversity and stability, impeding their eco-protective and productive functionality (Vlad 2007b). Balancing between different uses of the forestry resource is complicated by the limited capability to predict the impact of different management regimes (Kaien 2006). For example, it could be assumed that the use of bark in some forest areas is related to high moose density, concurring with reduced food availability. Changes in forest management support this conclusion (Randveer and Heikkilä 1996).

In our case study, a two-cut shelterwood system, using two different seed cutting intensities (25% or 40%) of stand basal area and different strip widths (15 m to 45 m wide) was tested as a forestry tool to solve the problems of these stands (Beguin et al. 2009). Narrower strips of 20 m and 40 m wide showed increased seedling density, as reported, e.g. for a successful regeneration; strip widths should be no more than 80 m (Jeglum and Kennington 1993).

The strip clear-cutting system effectively improved the stocking of the former spruce stands and thus should be the preferred method since it would be more cost-efficient (Pothier 2000). Also in our case, a successful regeneration (natural and artificial), in the time elapsed from the implementation of the previous forestry treatments (about 16 years), support the success of the applied ecological restoration (Figure 6).

The moment when the economic efficiency of a stand begins to decrease, it has to be replaced. In the case of deer-damaged Norway spruce ecosystems, it is necessary to measure the effect produced by the damages caused by bark-stripping (the effect of stem decay), from the point of view of specific wood yield and yield capacity (Vlad 2007b). In Sweden, among the most important consequences of the browsing damage were included the insufficient stand regeneration, the volume losses and the timber quality impairment. A balancing analysis between the costs and benefits related to deer density is difficult, since little data about the final losses in timber volume or quality impairment is available (Kaien 2006).

The browsing-induced reduction in timber quality (measured as the proportion of trees with multiple-stems at harvest) is economically important (Ward et al. 2004, Vlad 2007b) and the action of the deer, by bark-stripping on Norway spruce stands, indicated that the most significant losses are found with the superior sorts, i.e. trees for timber, which is the most expensive wood (Welch and Scott 2001, 2008, Čermák and Strejček 2007, Scott et al. 2009, Vasaitis et al. 2012).

Figure 6. Regeneration in P3 stand were applied forestry treatments (clear-cuttings).

Conclusions

As tools to be used in the ecological restoration of the Norway spruce stands affected by red deer *(Cervus elaphus)*, the progressive clear-strip cutting and clear cuttings on small areas seems to be promising, with good results, including also the wind resistance of the stand along the implementation. Open questions or dilemmas for further research remains on the regeneration process, as the main effect of the forestry treatments applied in the deer damaged Norway spruce stands. Moreover, the assessment of the volume (healthy wood volume and wood volume with stem decay) and the forest site productivity should be included in models of forest development, on the mid- and long-term, forecast based on further identified relations between deer population and different variables (e.g. stand density, stand productivity, or stand mixtures).

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