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Institutionen för skogens ekologi och skötsel

Browsing effects on stand development after fire at Tyresta National Park, Southern Sweden

Photo: Anders Granström

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Browsing effects on stand development after fire at Tyresta National Park, Southern Sweden

Betets effekter på beståndsutvecklingen efter brand i Tyresta Nationalpark, södra Sverige

Amanda Eriksson

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SUMMARY

Fire and browsing are two disturbance factors which greatly affect future stand development, yet the two have rarely been studied together in a boreal forest environment. A good opportunity for studying the combined effects of browsing and fire on stand development in a boreal forest environment was provided by the 1999 fire in Tyresta National Park, where an exclosure was set up shortly after the fire. The objective of this study was to examine the influence of browsing on post-fire stand development. For this purpose, the browsing effects on tree seedlings were examined, inside and outside an exclosure (1 ha) in the burned area. The areas inside and outside the exclosure were each divided into a low and a high fertility site. Sample plots were established at each of these sites, and inventoried in 2002 and 2007. Dense seedling populations established after the fire with on average 31,000 *Salix caprea* and 10,000 *Populus tremula* per ha. Results show that species composition and mortality were not directly influenced by browsing, whereas browsing effects on height development and height distribution were great. Eight years after fire, the heights of dominant seedlings of *P. tremula* and *S. caprea* were nearly double in the fenced area compared to the un-fenced area. In order to limit browsing effects on deciduous plants, fencing or browsing refugia should be used.

INTRODUCTION

Fire is the major natural disturbance factor in the boreal forest ecosystem (Engelmark, 1993; Johnson et al., 1998; Thonicke et al., 2001; Suffling et al., 2008) and has great influence over stand development. Fire is considered to encourage colonization by deciduous trees (Linder, 1998), although there are few accounts of this. Increased diversity in the tree layer after fire disturbance should make fire an important tool for forest conservation (Fulé et al., 2004).

Browsing is another disturbance factor which can have great impact on stand development (Cotê et al., 2002). The high density of moose in Scandinavia causes regeneration problems for deciduous trees, such as European aspen (*Populus tremula*) (Edenius and Ericsson, 2007). Browsing alters the structural complexity of forest ecosystems and affects successional development by arresting or retarding height development (Edenius et al., 2002).

The combined effect of fire and browsing has rarely been studied in the boreal forest environment. De Chantal and Granström (2007) analyzed seedling height and browsing history in relation to natural browsing refugia caused by windthrow after fire, and concluded that remnants from the pre-fire stand protect seedlings of palatable species from browsing. Wolff (1978) examined the role of fire in improving moose winter habitat through increased production of woody browse in a mature black-spruce stand and an adjacent burn in Fairbanks, Alaska. He concluded that willow shrubs are able to compensate for loss of biomass from overwinter browsing by increased productivity of browse-damaged stems. Davis (1967) studied the effects of deer browsing on sprouts of chamise brush in the Californian chaparral after fire and concluded that the effects of browsing on chamise brush should be evaluated by the use of exclosures. None of these studies have examined the long term effects of browsing on stand development.

A good opportunity for studying the combined effects of browsing and fire on stand development in a boreal forest environment was provided by the 1999 fire in Tyresta National Park. The burned area was left to develop freely after a high-severity fire consumed a large part of the humus layer. An effective colonization by deciduous trees - *Salix caprea*, *Populus tremula*, and *Betula pendula* - followed. To study the effects of browsing on post-fire establishment and stand development, an exclosure was set up shortly after the fire.

Unmanaged post-fire successions are rare in Scandinavia because felling of fire-damaged trees, soil preparation and subsequent replanting usually take place soon after fire disturbance in productive forests. Tyresta is also unique in that the previous stand was an old-growth forest. In all, this provides a good opportunity for studying post-fire forest stand development influenced by browsing under natural-like conditions.

The objective of this study was to examine the influences of browsing on post-fire stand development, which has important implications for forest conservation and management. What effect does browsing have on species composition and height distribution of seedlings after fire? What relative importance does browsing have for stand development in a post-fire succession, in relation to soil fertility and competition? For this purpose, the browsing effects on tree seedling populations inside and outside a 1 ha exclosure in the burned area in Tyresta National Park, were examined.

MATERIALS AND METHODS

Study area

This study was conducted in Tyresta National Park, in the municipality of Haninge, approximately 20 km southeast of Stockholm, Sweden (Fig. 1).

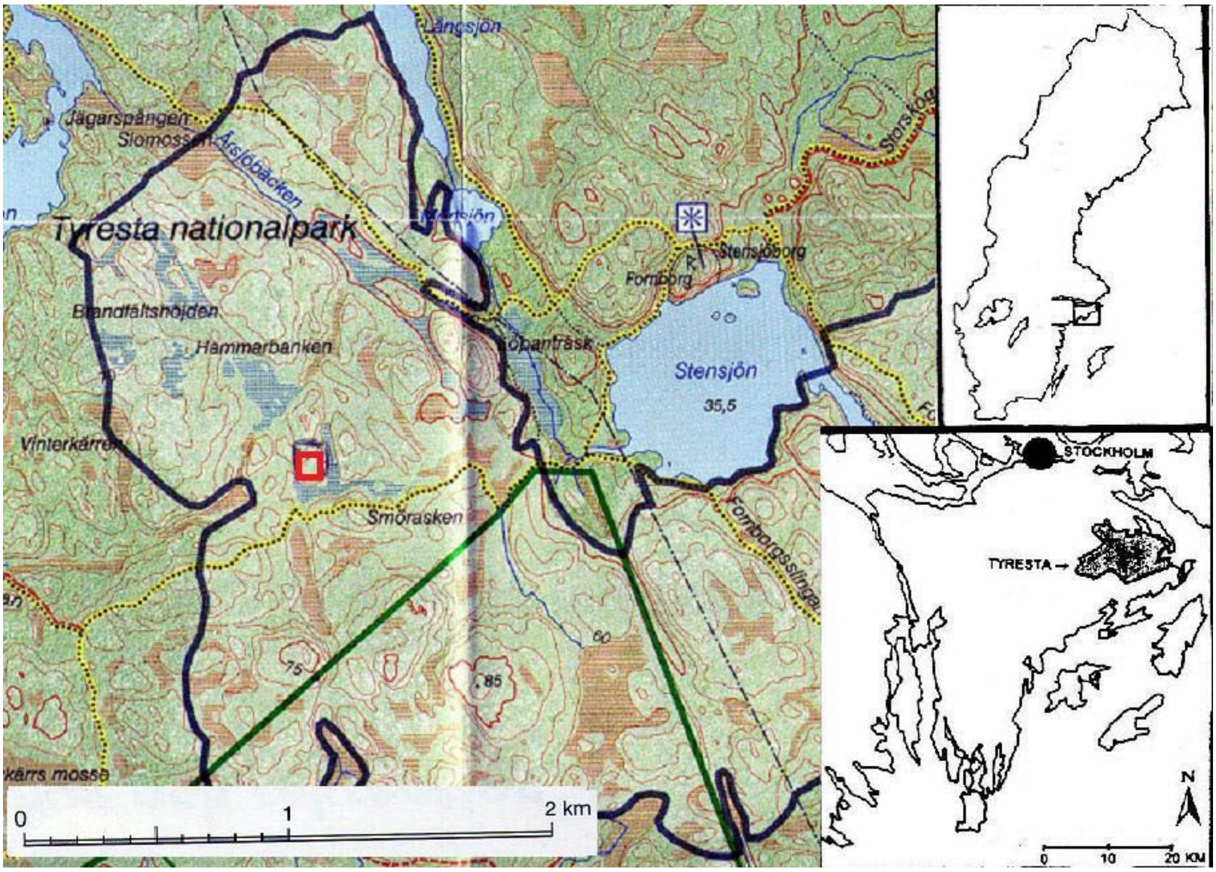

Figure 1. Location of Tyresta National Park and Nature Reserve. Location (red borders) of the exclosure inside the 1999 burn area (black borders). After Stiftelsen Tyrestaskogen (2007) and von Stedingk (1999).

Tyresta National Park is distinguished by a rift-valley landscape, typical for this part of Sweden (Löfgren, 1989). The landscape is characterized by its relatively flat, rocky soil and some larger, partially water-filled rifts, surrounded by steeper terrain. The soil conditions vary between very dry pure lichen-types and moist shrub-types, with some *Rhododendron tomentosum*-mires. Tyresta is one of the largest old-growth forests in southern Sweden.[1] The area is dominated by open pine forests (*Pinus sylvestris*) on the rocky plateaus, and by spruce (*Picea abies*) and mixed-stand forests in the lower rift-valley terrain. Some of the pine stands are up to 350 years old, with tall, coarse trunks, and large amounts of dead wood.

The bedrock in Tyresta consists mainly of gneiss and granite (Engqvist and Fogdestam, 1984). Tyresta's climate is influenced by the area's proximity to Östersjön, which acts as a

[1] With 1970 ha of national park and 2770 ha of nature reserve, Tyresta National Park and Nature Reserve is the largest area of protected non-alpine forest south of Norrbotten (Magnusson, 1993).

buffer for seasonal temperature changes, giving the area somewhat cooler summers and warmer winters than other areas of the same latitude, further inland (Eknert and Haglund, 1984). The average annual precipitation is 550 mm, and the average annual temperature is +5.9 °C.

Fire has been an important disturbance factor in the Tyresta area since 5000 B.C. (von Stedingk, 1999). Before 1650, the fire interval was 30-40 years, but during the last 350 years only a few fire events have been recorded (Niklasson, 2006). Among them was a 1914 fire, in which an area of 150 ha burned.

On Sunday the 1st of August 1999, a fire started in the heart of Tyresta National Park, which lasted for two days (Granström, 2006). The humus layer within the burned area was nearly eliminated, and a large part of the previous forest stand was killed, due mainly to extensive root damage. This root damage led to an increased sensitivity to wind, as well as to drought, and to infections by insects and fungi, which together caused most of the trees still standing after the fire to succumb in storms the following autumn (Fig. 2).

Figure 2. Seedlings of *S. caprea* and *P. tremula* inside the fenced area. The tallest seedlings are about 2 m high and have established under the remains of the previous stand, which was killed by the high-severity fire of 1999. Photo: Anders Granström.

The massive damage to the forest stand was caused chiefly by the following factors: First, the summer of 1999 was one of the driest in the Stockholm region in the 20th century (Granström, 2006). This led to an increased fire depth, which in turn led to a decreased survival of tree roots and ground vegetation. Second, the fire was ignited far from any easily accessible roads, and the wind drove the fire even further away, making it very difficult to suppress. This is why such a large area (450 ha) was affected by the fire.

Methods

This study was conducted within the area affected by the 1999 fire, at a location known as *Smörasken* (Fig.1). At this location, inventories were made in 2002 and 2007 inside and outside an exclosure that was set up in January 2001, one and a half years after the fire.

The exclosure (100 x 100 m) is located 300 m from the edge of the fire area. It consists of wire mesh, nailed to a number of wooden posts of about 3 m in height. The exclosure was designed to keep out moose (*Alces alces*) and roe deer (*Capreolus capreolus*) but not hares (*Lepus europaeus*). The exclosure was inspected regularly and any damages from fallen trees were repaired.

A low-fertility area and a high-fertility area were selected inside and outside the exclosure, based on the number and size of visible rocks on the ground surface. At each of these four sites, ten sample plots of 1 x 1 m were established, based on their representativeness of either high-fertility or low-fertility soil.

In October 2002, the plots in each of the four sites at *Smörasken* were inventoried (a total of 40 plots). In each of these plots, the vascular plant species present were identified, and their cover estimated. Each individual tree seedling was mapped on paper (scale 1:5), and their height measured.

In September 2007, another inventory was made. In each of the 40 plots, all vascular plant species present were identified, and their cover estimated. All individual tree seedlings were counted, and the height of the ten (if present) tallest seedlings per species was measured and the number of bites was counted (Fig. 3). (In plots with less than ten individuals of each species, all individuals present were measured.)

In eight of the plots (two from each site) a complete inventory was made. In these plots, each of the individual tree seedlings were identified (based on their position on the 2002-maps) and their height measured. The data was then compared to data from the same sites collected in 2002, to see how much the individual seedlings had grown in the last five years, and whether the same individuals were still dominant.

Figure 3. Seedlings of *S. caprea* outside the exclosure that have been exposed to repeated browsing (indicated by the red arrows). Photo: Anders Granström.

RESULTS

Seedling density

The most abundant species in all four sites 2002 was *Salix caprea* (about 17,000-43,000 seedlings/ha; Fig. 4). This pattern was stronger on high fertility soil, than on low fertility soil, regardless of fencing. In 2007, *S. caprea* was still the most abundant tree species in all four sites, although densities were greatly reduced (to about 8,000-15,000 seedings/ha).

The second most abundant species in 2002 was *Populus tremula* (Fig. 4). This abundance was greatest on high fertility soil outside the exclosure (about 15,000 seedlings/ha). In the other plots *P. tremula* densities were roughly the same (around 8,000 seedlings/ha). Densities were slightly lower in 2007 (about 5,000-7,000 seedlings/ha). On high fertility soil outside the exclosure, density was reduced by about half (to about 7,000 seedlings/ha).

Betula pendula was found at low densities (100-1,500 seedlings/ha) in all four sites 2002 (Fig. 4). In 2007, *B. pendula* densities had increased slightly (100-1,600 seedlings/ha), except on low fertility soil inside the exclosure, where it remained unchanged.

The densities of *Pinus sylvestris* in 2002 were also extremely low (100-700 seedlings/ha) in three out of the four sites, except on high fertility soil inside the exclosure (Fig. 4). In 2007, *P. sylvestris* maintained low densities on low fertility soil inside the exclosure (200 seedlings/ha) and on high fertility soil outside the exclosure (900 seedlings/ha). On low fertility soil outside the exclosure, *P. sylvestris* has perished, but could instead be found on high fertility soil inside the exclosure.

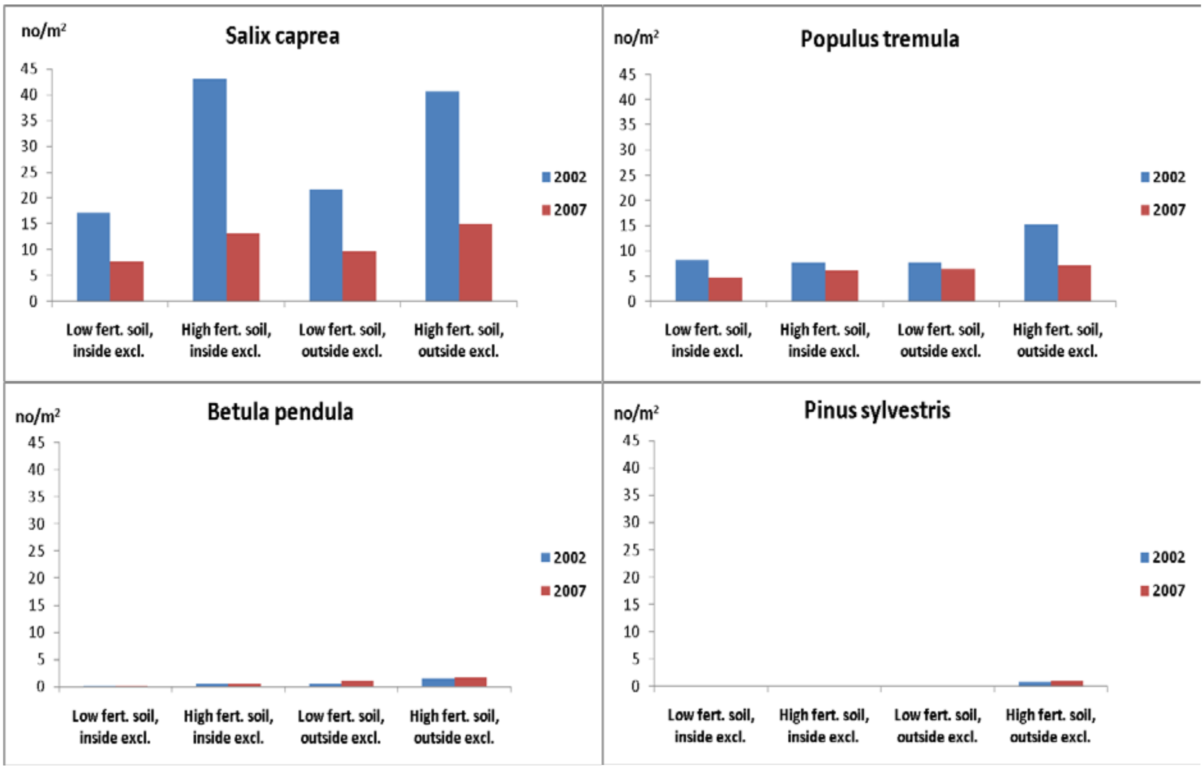

Figure 4. Seedling density 2002 and 2007 on low and high fertility soil, inside and outside the exclosure.

S. caprea mortality was relatively high between 2002 and 2007 (Table 1), especially on high fertility soil, although the difference between high and low fertility soil was not particularly big. For *P. tremula*, mortality was much lower, except on high fertility soil outside the exclosure, where it was over 50%. Mortality was also relatively high on low fertility soil inside the exclosure. For *B. pendula,* density increased everywhere, except on low fertility soil inside the exclosure, where it was unchanged. *P. sylvestris* mortality was 100% on low fertility soil outside the exclosure, and density increased slightly in the other sites.

Table 1. Change in seedling density from 2002 to 2007.

	Inside exclosure						Outside exclosure					
	Low fert. soil			High fert. soil			Low fert. soil			High fert. soil		
Species	**2002**	**2007**	**Δ (%)**	**2002**	**2007**	**Δ (%)**	**2002**	**2007**	**Δ (%)**	**2002**	**2007**	**Δ (%)**
Salix caprea	17.2	7.6	-56	43.1	13.2	-69	21.6	9.7	-55	40.7	15	-63
Populus tremula	8.1	4.8	-41	7.7	6.1	-21	7.6	6.5	-14	15.2	7.1	-53
Betula pendula	0.1	0.1	0	0.5	0.6	+20	0.6	1.1	+83	1.5	1.6	+7
Pinus sylvestris	0.1	0.2	+100	0	0.1	-	0.1	0	-100	0.7	0.9	+29

Seedling height development

There was a great degree of similarity between *S. caprea* and *P. tremula* in height development, both inside and outside the exclosure (Fig. 5). Both species showed a more rapid height development inside the exclosure, regardless of soil fertility, than outside. For both species, the differences in height development between soils of different fertility were greater inside the exclosure than outside.

For *B. pendula*, height development was more rapid on high fertility soil than on low fertility soil, regardless of fencing (Fig. 5). On low fertility soil inside the exclosure, *B. pendula* had perished. For *P. sylvestris*, height development was slow but steady on high fertility soil, regardless of fencing, but quite rapid on low fertility soil inside the exclosure. On low fertility soil outside the exclosure, *P. sylvestris* had perished.

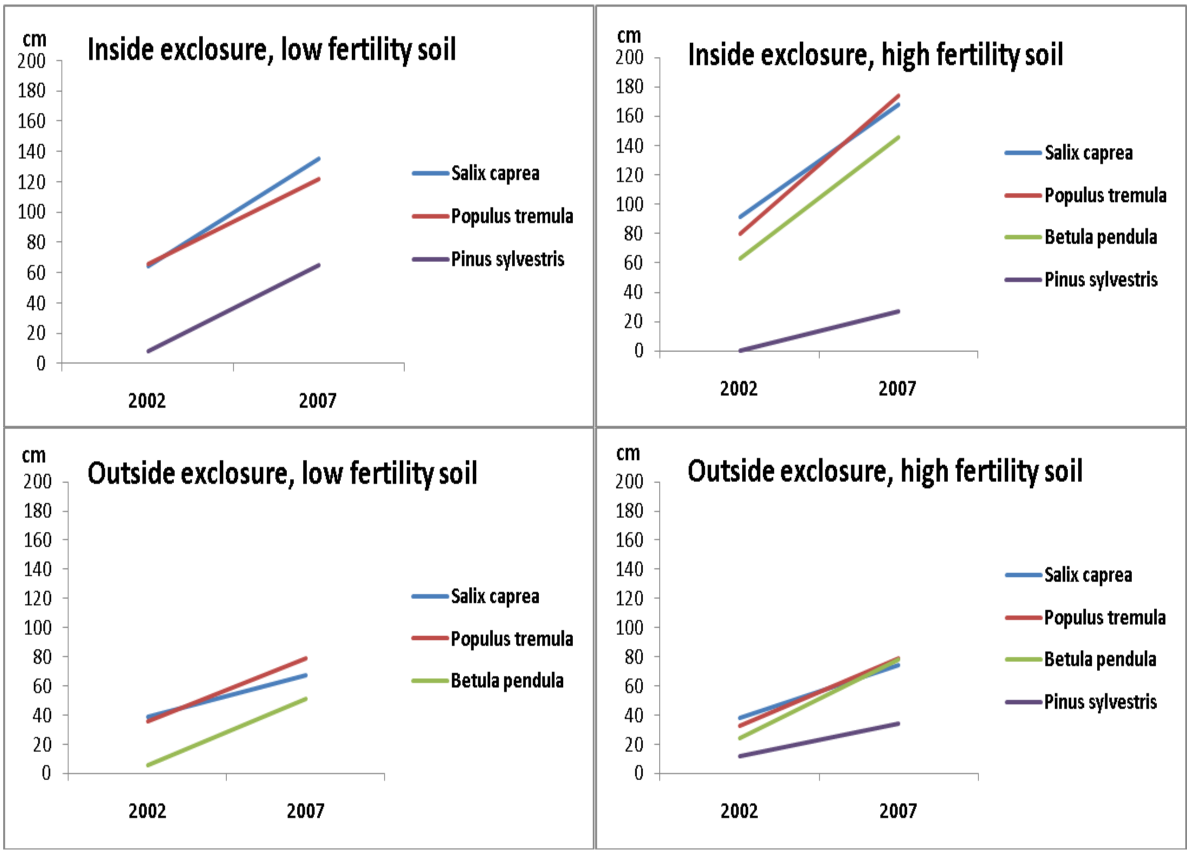

Figure 5. Height development of dominant seedlings from 2002 to 2007 on low and high fertility soil, inside and outside the exclosure.

Seedling height distribution

For *S. caprea* there was a clear difference in seedling height distribution between inside and outside the exclosure, both in 2002 (Fig. 6a) and in 2007 (Fig. 6b). Inside the exclosure, seedlings were generally taller and there was a greater height span, than outside the exsclosure.

P. tremula were also generally taller inside the exclosure, and more spread out over the different height classes, than outside. This was true both in 2002 (Fig. 6a) and in 2007 (Fig. 6b), but especially in 2007.

For both *B. pendula* and *P. sylvestris*, the sample was too small to distinguish any clear pattern.

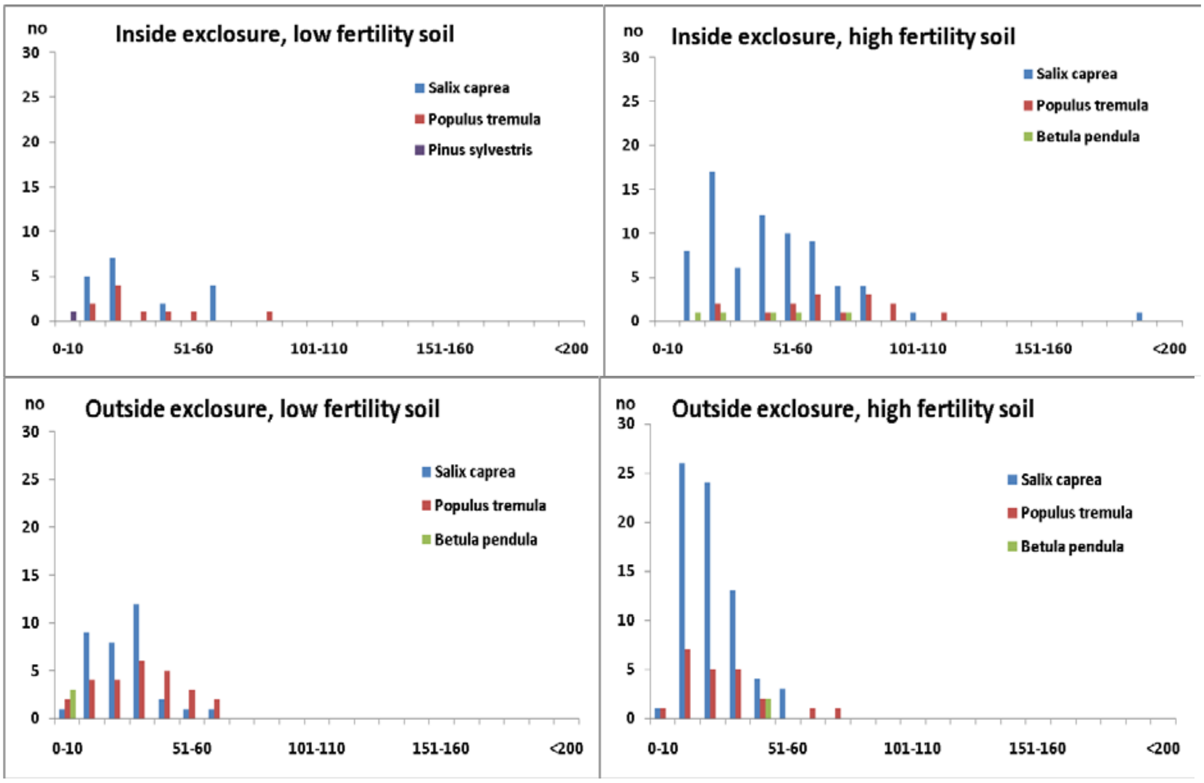

Figure 6a. Seedling height distribution 2002 on low and high fertility soil, inside and outside the exclosure.

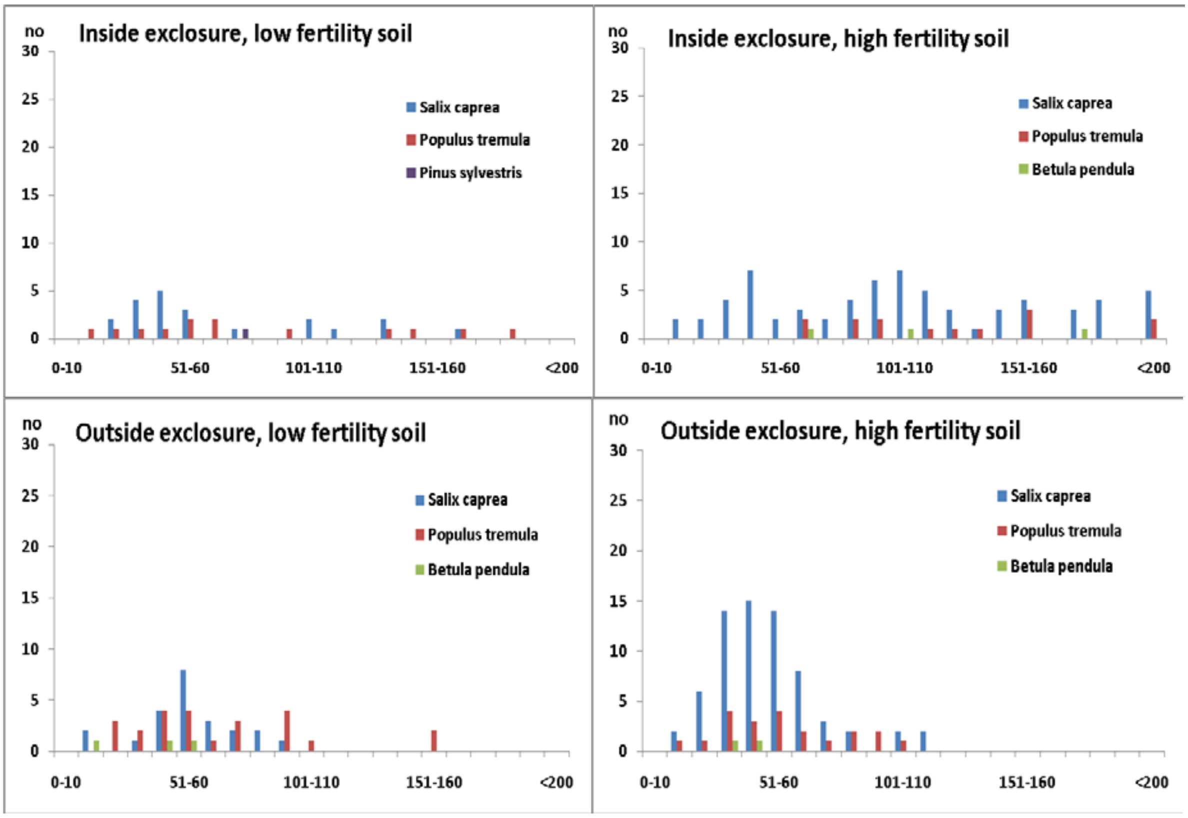

Figure 6b. Seedling height distribution 2007 on low and high fertility soil, inside and outside the exclosure.

Ground cover

The average ground cover in 2002 was quite high for *S. caprea* (about 20-60%; Fig. 7), compared to the other tree species, especially on high fertility soil inside the exclosure. *P. tremula* ground cover was also high (about 15-25%), particularly on high fertility soil outside the exclosure. *B. pendula*, and *P. sylvestris* each covered quite a small percentage of the ground (about 0-2%).

In 2007, *S. caprea* ground cover remained high (about 15-60%; Fig. 7), especially on high fertility soil inside the exclosure. So did the cover of *P. tremula* (about 15-30%). *B. pendula* increased its ground cover in most areas (about 0-10%), whereas *P. sylvestris* maintained very low cover (about 0-5%).

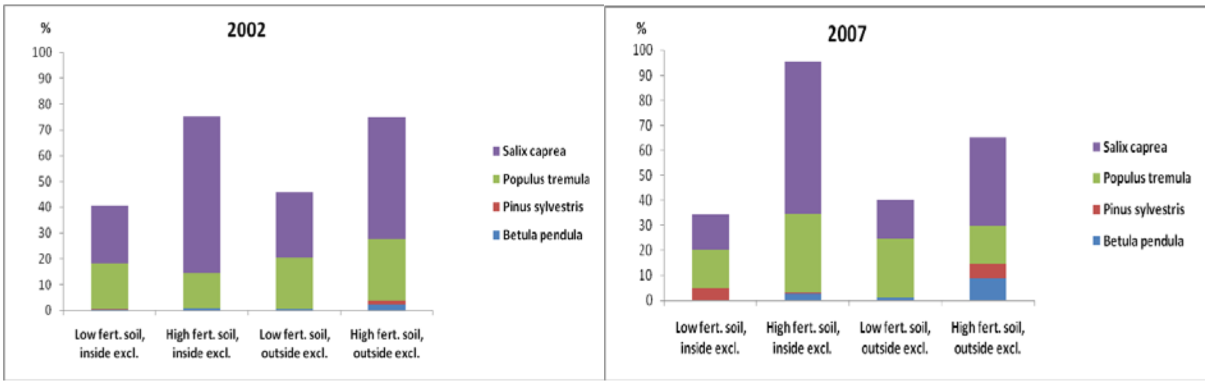

Figure 7. Average ground cover of tree seedlings 2002 and 2007 on low and high fertility soil, inside and outside the exclosure.

Bryophyetes covered most of the ground in 2002 (Table 2), mainly *Polythricum sp.* accompanied by small acrocarp bryophytes (mainly *Ceratodon purpureus*). Vascular plants only covered less than 10 %. *Epilobium angustifolium* was most abundant. Other vascular plants present were *Carex pilulifera*, *Luzula pilosa*, *Seneceo sylvatica*, *Vaccinium myrtillus*, *Vaccinium vitis-idaea*, and *Vicia cracca*.

In 2007, the cover of bryophytes had increased. *Polythricum sp.* now covered most of the ground, whereas the small acrocarp bryophytes had disappeared entirely (Table 2). For vascular plants, *V. vitis-idaea* had increased its cover on low fertility soil inside and outside the exclosure, whereas *E. angustifolium* had receded to small cover percentage in all areas. Small amounts of *Calamagrostis arundinacea*, *Calluna vulgaris*, *C. pilulifera*, *Deschampsia cespitosa*, *Festuca ovina*, *L. pilosa*, *Myrica gale*, *V. myrtillus* and *V. cracca* were also present.

Table 2. Average ground cover of vascular plants and bryophytes 2002 and 2007 on low and high fertility soil, inside and outside exclosure.

	Inside exclosure				**Outside exclosure**			
	Low fert. soil		**High fert. soil**		**Low fert. soil**		**High fert. soil**	
Species	**2002**	**2007**	**2002**	**2007**	**2002**	**2007**	**2002**	**2007**
Calamagrostis arundinacea	-	-	-	0.1	-	-	-	-
Calluna vulgaris	-	-	-	-	-	0.7	-	-
Carex pilulifera	-	-	0.2	0.02	-	-	0.5	-
Deschampsia cespitosa	-	-	-	-	-	0.7	-	-
Epilobium angustifolium	3.9	-	9.1	1.8	0.9	0.4	3.2	0.2
Festuca ovina	-	2	-	-	-	-	-	-
Luzula pilosa	-	-	0.4	-	0.1	-	-	1.5
Myrica gale	-	-	-	-	-	-	-	0.6
Seneceo sylvatica	0.1	-	-	-	1.3	-	-	-
Vaccinium myrtillus	-	1.3	0.3	0.3	0.8	3.5	-	0.3
Vaccinium vitis-idaea	-	-	0.7	1	0.5	4.2	-	-
Vicia cracca	0.9	0.5	-	0.1	0.4	-	-	-
Total vascular plants	**4.9**	**3.8**	**10.7**	**3.3**	**4**	**9.5**	**3.7**	**2.6**
Polythricum sp.	36.7	90	69.3	88	51.5	95	75	100
Small acrocarp bryophytes	37.8	-	3	-	20	-	11	-
Total bryophytes	**74.5**	**90**	**72.3**	**88**	**71.5**	**95**	**86**	**100**

Bite frequency

On both low and high fertility soil, *S. caprea* had the highest bite frequency, followed by *P. tremula* (Fig. 8). Browsing in relation to cover (no of bites/percent coverage) was relatively high for *S. caprea* (1.3 bites on low fertility soil and 0.6 on high fertility soil). For *P. tremula*, this relation was also quite high (1.0 bites on low fertility soil and 0.25 on high fertility soil), though not as high as for *S. caprea*. The samples of *B. pendula* and *P. sylvestris* were not large enough for analysis.

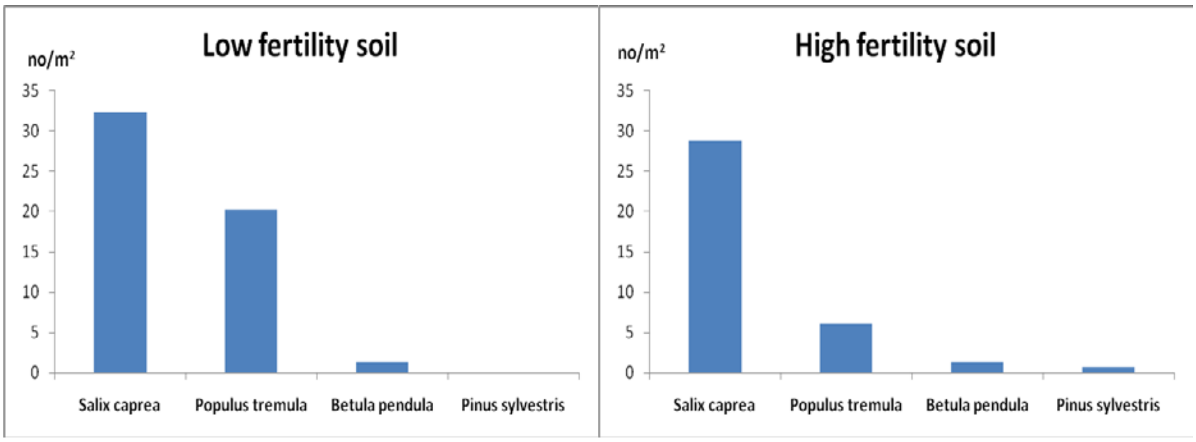

Figure 8. 2007 bite frequency per m^2 on low and high fertility soil outside the exclosure.

DISCUSSION

Post-fire species composition under the influence of browsing

Species composition was not directly influenced by browsing. Browsing-prone species such as *S. caprea* and *P. tremula* (Hörnberg, 2001) were the most abundant in both 2002 and 2007, and densities of both species were very high. *B. pendula* and *P. sylvestris* could only be found at low densities. However, whereas both *S. caprea* and *P. tremula* densities decreased in all sites between 2002 and 2007, *B. pendula* densities either increased or remained unchanged, indicating occasional seedling establishment several years after the fire, in contrast to *S. caprea* and *P. tremula*. Likewise, *P. sylvestris* either increased in density or perished.

Although it is difficult to draw any conclusions about the determinants of either *B. pendula* or *P. sylvestris* densities due to the small size of the available sample, it is clear that *S. caprea* and *P. tremula* densities are not directly influenced by browsing, since densities were similar on soils of the same fertility, regardless of fencing. This was true not only for *S. caprea*, but also for *P. tremula*, which is in accordance with Zakrisson et al. (2007), who also used exclosures to study browsing effects. They found no difference in mortality of *P. tremula* root suckers caused directly by browsing. Hence, the major determinant of *S. caprea* and *P. tremula* densities is competition for light caused by crowding, and this is also likely the cause of the high mortality that has taken place for both species between 2002 and 2007. Nevertheless, data from this study show that both *P. tremula* and *S. caprea* can establish dense and vital seedling populations after fire, and that they survive despite intense browsing pressure.

Post-fire height development and height distribution under the influence of browsing

Height development was strongly influenced by browsing. *S. caprea* showed a much more rapid height development inside the exclosure than outside, regardless of soil fertility. For *P. tremula*, height development was slightly more rapid on low fertility soil inside the exclosure, and much more rapid on high fertility soil inside the exclosure, than on either of the two sites outside, regardless of soil fertility. This would indicate that although browsing is clearly a determining factor for *P. tremula* height development, soil fertility is also of importance, especially in the absence of browsing.

B. pendula height development was probably also influenced by browsing, as the species developed more rapidly inside the exclosure, than on either of the two sites outside the exclosure, regardless of soil fertility. These results is a bit uncertain since the sample size of *B. pendula* was small in general, and in the low fertility control inside the exclosure not present at all, but are overall consistent with Persson et al. (2005), who have shown that height development of *B. pendula* decreases considerably with increased browsing. For *P. sylvestris*, there was a marked difference between high fertility soil and low fertility soil. Again, as the sample is small, and as the corresponding data from outside the exclosure are missing, it is difficult to draw any real conclusions from these observations. There may be a tendency for *P. sylvestris* to do better on low-fertility soil, indicating that it is strongly affected by competition for light from coexisting species. Browsing, however, seems to have much less effect under these circumstances, as the height development curves on high fertility soil are very similar, regardless of fencing.

Size distribution was also strongly influenced by browsing. Seedlings outside the exclosure were generally fewer and fell into lower height classes than inside the exclosure, in both 2002 and 2007. This was true for both *S. caprea* and *P. tremula*. For *B. pendula* and *P. sylvestris*, the sample size was inadequate to draw any conclusions about the size distribution of these species.

Future stand composition

Although *S. caprea* and *P. tremula* are currently the most abundant species in the post-fire area at Tyresta, *B. pendula* densities are still increasing, as are, to some extent, those of *P. sylvestris*. Both *S. caprea* and *P. tremula* seedlings have seen a high rate of growth in the past five years, in spite of high browsing pressure, and will soon reach browsing-free height. It therefore seems very likely that the future stand will be composed of mainly *S. caprea* and *P. tremula*. *B. pendula* heights are on par with the other two deciduous species, and it will most likely also be a part of the future stand, although to a somewhat lesser extent than either *S. caprea* or *P. tremula*. *P. sylvestris* will probably find it increasingly difficult to establish, as the deciduous species reach browsing-free height. However, *P. sylvestris* densities are still increasing, and it is yet too early for any definitive conclusions to be drawn about its role in the future stand. A periodic follow-up will most definitely be necessary to confirm the observations of this study.

Implications for management

The promotion of deciduous species has been put forward as a priority in national forestry management goals (Edenius and Ericsson, 2007). The 1999 fire was stand-replacing. The previous coniferous stand in the heart of the park was completely destroyed and high densities of *S. caprea* and *P. tremula* have since established there. This scenario may have been more common in the past, before fire suppression became widespread (Niklasson, 2006). Before the 17^{th} century, large areas would burn during recurring years of drought (Granström and Niklasson, 2000). The post-fire succession at Tyresta may therefore indicate natural conditions in the past.

For this type of stand-replacing burn to occur, however, a high-severity fire event must take place under conditions of intense drought. Prescribed burns today are seldom carried out in dry conditions for safety reasons, and although several forest certification systems (e.g. FSC and PEFC) prescribe a certain proportion of the regenerating forest area to be burned every year, there are no regulations with regards to the severity of these burns. In order to promote the establishment of deciduous trees in non-productive forests, prescribed burns of varying severity under dry conditions are therefore to be recommended.

Furthermore, the browsing pressure in Scandinavian forests is relatively high (Edenius et al., 2002), and although the Tyresta area has been left to develop freely since the fire, entirely natural conditions cannot be achieved without a management strategy to limit browsing.

Limiting browsing is a useful strategy to promote the rapid establishment of a deciduous post-fire stand. Browsing has in this study proven to have strongly adverse effects on the height development of deciduous species (e.g. *S. caprea*, *P. tremula* and *B. pendula*) in the post-fire area at Tyresta. Because *P. tremula* has been singled out as a priority species in sustainable forest management (Edenius and Ericsson, 2007) some method of limiting browsing may indeed be needed in order to promote the rapid height development of this species.

One method of limiting browsing is the use of exclosures, which is the method used in this study. Even though there were incidences of moose breeching the exclosure after the fence had been broken by falling trees, this method proved very effective in protecting both *S. caprea*, *P. tremula* and *B. pendula* from browsing, and height differences between inside and outside the exclosure were great for all of these species. Similar conclusions are drawn by Edenius and Ericsson (2007), who suggest that fencing should be introduced in areas with high ungulate densities before *P. tremula* ramets reach browsing height. For *P. tremula*, the positive effect of higher soil fertility was also evident inside the exclosure. Månsson et al. (2009) have shown that fertilization increases moose feeding on several species, there among *P. tremula* and different species of *Salix*, so fencing may be especially important to promote the rapid development of *P. tremula* on high-fertility soil. The fence may be removed after seedlings reach browsing-free height.

Another method of limiting browsing and encouraging the rapid development of deciduous species is through the use of browsing refugia. De Chantal and Granström (2007) have shown that dead wood aggregations formed after fire and windthrow act as browsing refugia that protect *P. tremula* and *S. caprea* from browsing through physical and, possibly, visual obstruction. In the Tyresta area, these dead wood aggregations occurred naturally, but it is possible that they might also be constructed manually to serve the same purpose. De Chantal and Granström (2007) predict that stand-replacing fires and long fire-intervals are prerequisites for producing large enough aggregations of dead wood and the large, wide-crowned, thick-branched trees necessary to protect seedlings until they reach browsing-free height. However, the rate of breakdown for dead wood aggregations is currently unknown. Observations from the field indicate that breakdown rates are too high for this method to provide protection until seedlings reach browsing-free height, but more research is needed into the potential use of dead wood aggregations as a management method for limiting browsing. Overall, more research is needed about the management of deciduous species in post-fire areas under the influence of browsing.

CONCLUSIONS

The general impression of the post-fire area at Tyresta National Park is that deciduous species have regenerated quite successfully there, in spite of the high browsing pressure. Densities of *S. caprea* and *P. tremula* were very high in all sites, and linked to soil fertility and competition for light, rather than browsing. Although *B. pendula* densities were generally low, densities did not decrease between 2002 and 2007, indicating that *B. pendula* may indeed become part of the future stand. It is still too early to draw any conclusions about whether *P. sylvestris* will become an important part of the future stand, as the sample is still too small.

Both *S. caprea* and *P. tremula* were heavily browsed, and showed significant retardation in height development and height distribution outside the exclosure. *B. pendula* heights were on par with those of *S. caprea* and *P. tremula,* but were also noticeably influenced by browsing. Browsing plays a very significant role in stand development, and the application of some management method to limit browsing, e.g. fencing or dead wood browsing refugia, will definitely be necessary for a future deciduous stand to develop in a post-fire area like the one at Tyresta National Park.

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