Are trees on islands more exposed to lightning-strokes than trees at mainland?

Contents

1. Abstract
All vegetation is subject to different kinds of disturbances. Before human intervention, lightning strikes were the principal natural cause of ignition in conifer dominated European forests (Gromtsev 2002; Granström 2001).

Spatial variation in strokes can provide valuable information about fire regimes in the past, but is not very well investigated. It has been claimed that ignition occurs more often on islands in lakes, than in corresponding habitat in mainland. The isolation and/or elevation would thus contribute to the high susceptibility to lightning strikes on islands. There may also be a difference in the attraction of lightning by different tree species.

In this study, approximately 200 ha forest were investigated for lightning scars in trees on islands in the lake Allgunnen, and on adjacent mainland. To discover potential differences in scars distribution between the areas, the scars were classified into three categories according to the degree of certainty of lightning being the cause of the scar, "confident", "likely" and "uncertain lightning scars". More scars were found on islands (37.9/100ha) than in mainland (25.6/100ha). Scots pine (*Pinus sylvestris*) was incomparably the most frequently damaged species accordingly to tree species distribution in the investigated areas, being struck relatively more than other species. The findings suggest that there may be a difference in lightning strikes in trees on islands in lake Allgunnen compared to trees in corresponding mainland areas. And there may, as well, exist preferences in lightning-scars distribution on different tree species.

Keywords: lightning strikes, lightning scars, islands, Pinus sylvestris, Quercus robur, Betula sp.

2. Introduction
All vegetation is subject to different kinds of disturbances. One significant evolutionary force that has contributed to shaping the boreal forests is fire (Bergeron et al. 2004; Bond & Keeley 2005; Podur et al. 2003; Drevera et al. 2006). During millions of years, fire-affected habitats have evolved in Fennoscandia, with species adapted to, or more or less dependent on certain fire cycles (Podur 2003). From early Holocene, human activity (e.g. slash and burn agriculture, grazing improvement, tar and charcoal production or logging) caused either increased or decreased fire frequencies. The fire intensity and interval (cycles) may differ greatly depending on the topography and vegetation (Wotton & Flannigan 2001). Climate warming might also modify fire frequency (Lynch et al. 2004). These changes in forest dynamics may affect biodiversity and ecosystem function (Granström 2001; Bond et al. 2004). And today we can see that many fire dependant species are threatened (Niklasson & Drakenberg 2001). Although most conservationists and forest managers nowadays consider

fire as an important disturbance agent, we still need more knowledge about how fire regimes have varied in the past (Bergeron et al. 2004).

Before human intervention, lightning was the only natural cause of ignition in conifer dominated European forests (Gromtsev 2002; Granström 2001). And today, lightning ignition is still an important cause of fire, in natural as well as in managed forests (Granström 1993). Lightning is an electrical discharge between a cloud and the earth or between the clouds at different levels (Minko 1966). Regarding ignition probability, the predominant theory is that polarities of the current do influence ignition probability of a stroke. High amplitude positive cloud-to-ground lightning strikes would increase the probability of ignition (Hiedler et al. 2005; Wotton & Martell 2005). Larjavaara et al. (2005a) found that negative strokes are just as likely to ignite fires as positive ones. They also found that an increasing number of strokes per flash decreases the ignition probability of a stroke and intense and long-lasting thunderstorms ignite only few fires per stroke. Most lightning currents that hit a tree flow at the surface of the trunk making a sharp scar in the bark. But in some cases they may enter the trunk causing a complete destruction of the tree (Hiedler et al. 2005). Species dominance and stand age may influence the probability of ignition (Tanskanen et al. 2005) as well as weather conditions at the time (Wotton & Martell 2005). It may be possible that many lightning-ignited forest fires remain undetected if they die out soon after ignition or remain small. Or the total number of lightning-ignited forests may be underestimated due to the fact that only a portion of all fires may be reported to the authorities (Podur et al., 2003; Larjavaara 2005b). Any tree species is likely to be struck by lightning (Plummer 1912 in Latham & Williams 2001 in Pouder et al. 2003).

The spatial variation in strokes is not very well investigated but could provide valuable information about fire regimes in the past. A study in the Blue Mountains (U.S.A) by Diaz-Avalos et al. (2001) found that the number of lightning strikes increases with elevation. But the probability of ignition decreases with increasing elevation and slope. This may be due to precipitation and temperature. In Sweden lightning ignition is most frequent in the southeastern part (Granström 1993). Larvarjaa et al. (2005b) imply in their investigation that lightning-ignited forest fires are more prominent in the south of Finland compared to the north. Bergeron (1991) found that ignition occurred more often on islands with xeric habitat than on corresponding habitat in mainland. He suggested that isolated and elevated islands are more likely to be struck by lightning.

This study will examine whether there is a difference in lightning strikes in trees on islands in lake Allgunnen compared to trees in mainland areas. The hypothesis is that scars from lightning strikes would be more abundant on islands than in the mainland. The investigation will also reveal if there is any difference in numbers of scars in different tree species.

3. Materials and methods

The studied areas are located in Högsby and Nybro kommun, in the southeast part of Sweden. Approximately 200 ha forest were investigated, 82 ha of islands in the lake Allgunnen and 118 ha of the surrounding mainland. Detailed definitions of areas are clarified in Table 1. Most of the investigated areas, the islands, western lakeshore of Allgunnen and Stora Skärsgöl are parts of a network for valuable nature in the EU, Natura 2000 (N56°59´58´´ E16°1´32´´). The islands, western lakeshore of Allgunnen, eastern part of Mjösjögöl, Svartegöl/Gräsgölen and Eskilstjärn are also Nature Reserves (Naturvårdsverket 2007). The investigations were conducted during the summer and autumn of 2006. The area belongs to the boreonemoral zone and the forest includes both conifers and deciduous species. The bedrock consists of granite covered by moraine and boulder formations are numerous. The region is characterised by comparatively dry summers (Wastenson et al. red. 1990).

Islands and mainland areas were investigated by walking along a more or less straight line through the landscape. Trees within 15 m width, on both sides from the walking line, were searched visually while walking. Every 30 m, or whenever the topography and vegetation allowed a suitable view backwards, a stop was made to inspect the passed trees from behind. The coordinates for trees with suspected lightning scars were noted with Garmin GPS 60 navigator. A careful inspection and description of the injury, stands etc. was done. A digital photo (Sony Cyber-shot 5.1 Megapixels) was also taken on the majority of suspected scars for later analysis. Traces of fire (fire-scars, charcoal) were also noted. The basal area of trees was noted using a relascope in the beginning. At a later stage basal areas were estimated. For every found scar not adjacent to another scared tree, an estimation was done (appr. 50).

Table 1. Definitions

Mainland	In the vicinity of Allgunnen.
Islands	Islands, not larger than 25 ha, in Allgunnen.

All found scars were defined according to the level of certainty of lightning being the only cause of damage (Table 2). Then the scars were classified in to three categories (Table 3). Examples of scars are given in Appendix I (fig 1-3).

Table 2. Definitions of lightning scars

Definitions	Lightning scars
For all scars the requirement was that it must be straight, and follow the grain of the tree (Freier 1977).	
One or more straight scars with sharp and "clean", parallel edges in the bark and phloem, following the grain. Sapwood may be visible even after several years. Each scar more than 1 m in length. Top of the scar starts at least 3 m from ground.	Confident, clear lightning scar in accordance with literature
One or more straight overgrowing scars. Shape of edges not visible. Each scar less than 1 m in length and top scar may start less than 3 m from ground.	Very likely a lightning scar
Scars may not show clear and sharp edges or they may not be parallel all the way. Each scar less than 1 m in length and top scar may start less than 3 m from ground.	Uncertain but possibly caused by lightning

Table 3. Classification of lightning scars

Class 1	**Class** 2	**Class** 3
Confident, clear lightning scar in accordance with literature	Confident, clear lightning scar in accordance with literature	Confident, clear lightning scar in accordance with literature
	Very likely a lightning scar	Very likely a lightning scar
		Uncertain but possibly caused by lightning

4. Results

4.1 Total number of found scars

When comparing strikes per tree species, with tree species distribution in the studied transects, it was found that pines were more often hit by lightning than other tree species (fig. 4).

Over all the 200 ha that were searched, 62 scars were found in four species, *Pinus sylvestris, Quercus robur, Betula sp* and *Populus tremula* (denoted as "other species") (Table 4).

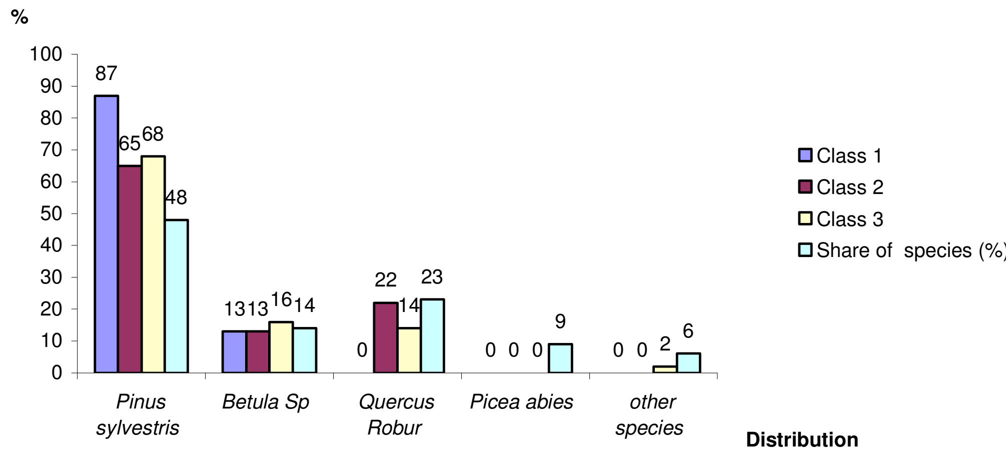

Figure 4. All found scars distribution on classes and species.

Table 4. Numbers of found scars and numbers per 100 ha in total

Species	**class 1**		**class 2**		**class 3**	
	Nr found	**Nr/100ha**	**Nr found**	**Nr/100ha**	**Nr found**	**Nr/100ha**
Pinus sylvestris	20	10	24	12	42	21
Picea abies	0	0	0	0	0	0
Quercus robur	0	0	8	4	9	4,5
Betula sp	3	1,5	5	2,5	10	5
other species	0	0	0	0	1	0,5
	23	**11,5**	**37**	**18,5**	**62**	**31**

4.2 Found scars distribution on islands and mainland

4.2.1 Islands

In total 37,9 scars/100 ha were found at islands. Of this, 15,9 scars/100 ha were classified as class 1. All class 1 scars were found in pine. All scars found in oak, except one, were categorized into the class 2. The only scar in aspen was found on an island ("other species", App. II, fig. 5), class 3 (table 5). The proportion of scars in relation to total species distribution was the highest in pine, class 1 which comprised 41 % of all species at islands. Also in class 2, scars found in pine, constituted a high proportion compared to the species´ total distribution. The same was apparent for scars found in oak (fig. 6).

Compared to the mainland, islands held more oaks relative to other species but also showed a high portion of scars.

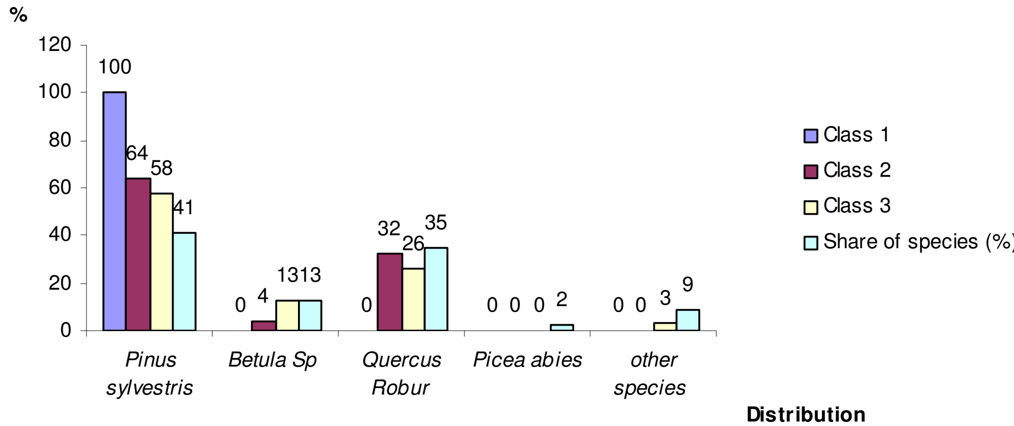

Figure 6. Scar distribution on classes and species at islands.

Table 5. Numbers of found scars and numbers per 100 ha at islands.

Species	**class 1**		**class 2**		**class 3**	
	Nr found	**Nr/100ha**	**Nr found**	**Nr/100ha**	**Nr found**	**Nr/100ha**
Pinus sylvestris	13	15,9	14	17	18	22
Picea abies	0	0	0	0	0	0
Quercus robur	0	0	7	8,5	8	9,8
Betula sp	0	0	1	1,2	4	4,9
other species	0	0	0	0	1	1,2
	13	**15,9**	**22**	**26,7**	**31**	**37,9**

4.2.2 Mainland area

In total 25,9 scars/100 ha were found in the mainland. Of this, 8,4 scars/100 ha were classified as class 1. As before, most scars were found in pine, all classes (Table 6). In class 1, 70 % of all scars were found in pine although pine constitutes only 55 % of all species distribution. Birch represented 30 % of all found scars in class 1. The total share of birch was 16 % (fig. 7).

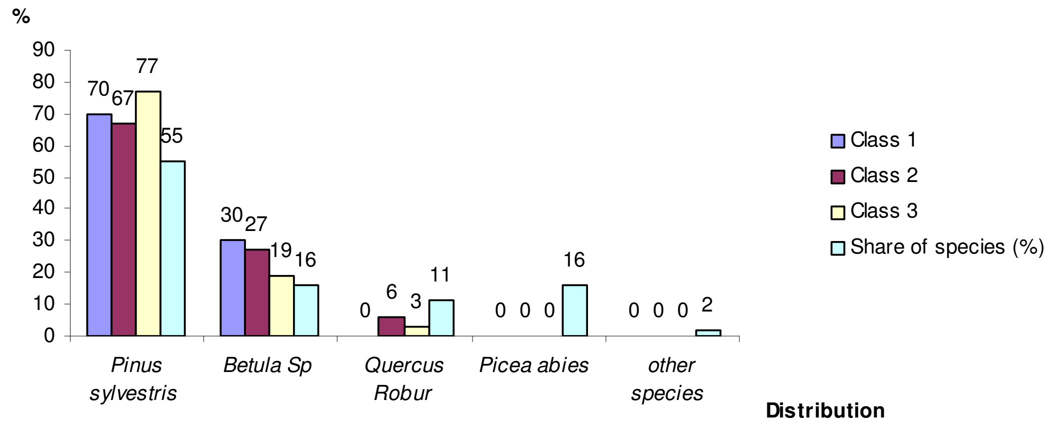

Figure 7. Scar distribution on classes and species in mainland areas.

Table 6.Numbers of found scars and numbers per 100 ha in mainland areas.

Species	**class 1**		**class 2**		**class 3**	
	Nr found	**Nr/100ha**	**Nr found**	**Nr/100ha**	**Nr found**	**Nr/100ha**
Pinus sylvestris	7	5,9	10	8,5	24	20
Picea abies	0	0	0	0	0	0
Quercus robur	0	0	1	0,8	1	0,8
Betula sp	3	2,5	4	3,4	6	5,1
other species	0	0	0	0	0	0
	10	**8,4**	**15**	**12,7**	**31**	**25,9**

4.3 Traces of ground fires

Among 62 found scars, one trace of ground fire was found that could be connected with high certainty to lightning ignition (App. II, fig. 8). The 2 ha pine stand was situated on a ridge and was estimated to approximately 80 year-old. No recent forestry related measurements had been taken in this area, although it bordered a clear-felled area in the east. The particular fire site (appr. 0.5 ha) was delimited by a wetland to the west. The fire may have occurred around five years ago. About 4-8 pine trees with visible trace of fire were found in the slope.

5. Discussion

Most scars were found at islands (37.9/100ha) compared to the mainland (25.9/100ha). According to the distribution of tree species in the investigated areas, Scots pine was incomparably the most frequently damaged species. Thus, there seems to be differences in both topography and species in relation to lightning strikes.

5.1 Scars on islands vs mainland

Irrespective of class, more scars were found on islands. While 25.5 scars/100 ha were found in mainland areas, islands presented 37.7 scars/100 ha. The differences are considerable and the findings are corresponding to the suggestion of Bergeron (1991) that islands are more susceptible to lightning strikes. He also observed that ignition occurred more often on islands than in similar habitats in mainland. The higher frequency of found scars at islands may thus be due to the higher elevation than surrounding water. Trees may act like capturing channels for lightning. After a negative, or positive recharge in the cloud, a conductor transports the charge closer to the ground and creates a discharge around protruding objects, e.g. trees. The ability of the capturing channels is affected by shape and, to some extent ground leading capacity of the protruding object. (Scuka & Högberg 2007). As Allgunnen is a large lake and the distance from islands to the mainland is comparably far, trees on islands in the lake must be considered as clearly ”protruding objects” and thereby possibly better at attracting lightning from clouds dispersed over the lake.

A further investigation could clarify any connection between scars and tree height. Although rather unlikely, a tree ring dating of the scars could reveal if the scars are visible for different times in these two landscape types.

5.2 Scars distribution on different species

In total, 62 scars were found distributed on 200 ha. Scars were found in only four tree species, *Pinus sylvestris, Quercus robur, Betula sp and Populus tremula*. Plummers (1912 in Latham & Williams 2001 in Pouder et al. 2003) mentioned that any tree species is likely to be struck by lightning. Despite that, most scars in this study were found in one species, *P. sylvestris*. At islands, all class 1 scars were found in pine. And the proportion of scars in relation to total species distribution (41%) was also the highest in pine at islands. Oaks on islands also showed slightly more scars than in the mainland. The appearance of scars found in oaks demonstrated a similar pattern, overgrown, less than 1 m and top-scar sometimes less than 3 m from ground. According to this, almost all scars in oaks were categorized in class 2. Only one scar was found in aspen (island, class 3, denoted as “other species”). No scars were found in Picea abies, although its total distribution corresponds to that of birch in mainland. According to Hiedler et al. (2005) most lightning currents flow at the surface of the trunk. And it may be possible that the different water-content inside the trunk or the humidity on the bark-surface influence species preference.

Further knowledge is needed concerning the possibility that species may possess different reaction to lightning strikes, according to their specific physiology.

One trace of ground fire was found in 200 ha of investigated areas (mainland). The lightning scar and the later fire may have occurred around five years ago. No obvious traces from forestry or human activity were found. It could therefore be connected to lightning with high certainty.

5.3 General discussion, possible sources of errors

The Allgunnen study may contain sources of error that affect the figures. First, one may not exclude the possibility that the differences found on islands vs mainland may derive from local forestry practice.

More scars were found on islands than in mainland. According to diameters and soil fertility in mainland stands, one can assume that stand ages are just about 100 years and the area may thus have been subject to 1-3 thinnings. According to preliminary datings in other areas, lightning scars are only visible for approximately 40 years (M Niklasson, pers comm). Trees with scars may also deliberately have been chosen during thinnings. This would have contributed to less found scars in mainland areas. However, stands were deliberately selected as to have the least possible human influence in the recent past although this was not always possible to achieve.

Difficulties in reaching the islands, or later insignificant economic interests, may have resulted in moderate impact by forestry. Trees that would normally have been cut down by thinnings have been left. This may have enhanced the results towards more scars on islands. On the other hand, one can assume that, timber was a valuable resource, even on islands, and cold winters, would provide good opportunities for getting timber from the islands. Furthermore, the age structure of the island stands (pers obs), with a high proportion of trees less than 40 years in addition to some older individuals, >150 years, reveals that the islands had been subject to thinnings and forestry in the past. Most of the visited islands had also been used for grazing, and therefore, presumably, regularly cleared from shadowing trees.

These 200 ha investigated areas are to be considered as comparably small and cover only a short period of time. A thorough survey, covering larger areas, a longer period, and combined with detailed dating of the scars, would provide even more valuable information regarding former disturbance regimes in this region.

Besides the fact that most scars were found in pine, birches showed greatly more scars in mainland areas than on islands, but still not more than its relative share of all the species. The most intricate question is whether the scars seen in birch, is a consequence of lightning at all. Scars in birch have seldom been verified associated with trace of fire. Among scars in pine one can, now and then, find traces in the surrounding that confirm the cause of fire. In this study, covering 200 ha, one scar and charcoal in pine with fire-trace on ground were found. In addition, lightning scars in pine, can obviously, show a wide range in appearance (App. II, fig 9). From just a sharp scar to an explosion where the tree is totally blasted away (Heidler et al. 2005). This is in contrast to the very uniform scars usually found in birch. One explanation may be that frost-scars could be easily confused with lightning scars. Further investigations that help to clarify specific characteristic of lightning strikes and the effect of frost in different species are needed.

Errors may also derive from e.g. undetected scars, or misjudged scars. Nevertheless, the study gives a first insight into the preference of lightning strikes in a hemi-boreal landscape.

6. Conclusion

This investigation showed that more lightning scars were found in trees at islands (37.9/100 ha) than in mainland (25.9/100 ha). Pine was incomparably the most frequently damaged species according to tree species distribution in the investigated areas. This suggests that there may be differences in lightning strikes in trees on islands in lake Allgunnen compared to trees in corresponding mainland areas. And there may as well be preferences in lightning-scars distribution on different tree species.

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Appendix I.

Figure 1. Class 1. Straight scars with sharp and “clean”, parallel edges in the bark and phloem, following the grain. Confident scars in accordance with literature.

Figure 2. Class 2. Straight, but overgrowing scars. Shape of edges not visible. These are considered as very likely lightning scars.

Figure 3. Class 3. Scars not showing clear and sharp edges or not being parallel all the way, were defined as uncertain, but possibly lightning scars.

Appendix II

Figure 5. The only scar found in aspen (class 3).

Figure 8. Class 1 scar, connected with high certainty to a fire.

Figure 9. Possibly a lightning with a burst (class 1).