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A 400-year history of fires on lake islands in south-east Sweden

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Abstract. Island-lake ecosystems are suitable for testing scale dependence in forests disturbance theories thanks to differences in the potential for fire spread on islands and the mainland. We investigated past fire regime on the mainland and on islands in a large lake in south-east Sweden. We used dendrochronological methods to reconstruct fire disturbances on 18 small islands (0.04–24.1 ha) and in 43 sites in the surrounding 75-km^2 landscape over the last 400 years. In the past, fires were frequent on both islands and mainland but not synchronised on an annual scale. Significant temporal changes occurred around the middle of the 18th century. Before 1750, fires were less frequent on islands than on the mainland (median fire return interval 58 *v.* 25 years respectively). However, an inversion of this pattern was observed during 1750–1860: islands showed even shorter fire intervals than mainland locations, suggesting additional and likely human-related source of ignitions (median fire return interval 15 *v.* 29 years respectively). A substantial decrease in fire activity in both islands and mainland was apparent in 1860–1890. We suggest that the present fire regime (the last 100 years) on the small islands is largely natural as fire suppression is not present there. The dynamic nature of the fire regime on islands still requires further studies: islands may, at times, attract lightning, humans with fire, or both.

Additional keywords: dendrochronology, disturbance regime, disturbance theory, Fennoscandia, forest fire, land-use history, lightning ignition, Scots pine.

Introduction

Lake islands can be viewed as miniature ecosystems where theories concerning biogeography (Drake *et al.* 2002), ecological functioning, biological diversity, and their relation to disturbance and stability can be tested empirically (Wardle *et al.* 1997; Wardle *et al.* 2003). A fundamental property of an island is its size, influencing the probabilities for species to migrate to this island and for certain ecological processes to occur. An example of such a process is lightning strike occurrence and, associated with it, natural fire activity. The probability of a lightning strike hitting an island is a function of the island area. As fire spread to a distant island from the surrounding landscape (another island or the mainland) is uncommon (Bergeron 1991; Dansereau and Bergeron 1993), lightning strikes are the main source of ignitions in these ecosystems under natural conditions. Given that lightning strikes are the only sources of ignitions and that variation in local weather or fuels among islands or between islands and the mainland is insignificant (see, however, Drobyshev *et al.* 2010), the properties of the fire regime (e.g. fire frequency and fire occurrence) should therefore be closely related to the corresponding island sizes. Ultimately, lower probability for fire initiation on an island should result in longer fire return intervals compared with mainland locations. In the real world, variation in fuel and weather conditions (Podur *et al.* 2003; Drobyshev *et al.* 2010), lightning-strike densities (Drobyshev *et al.* 2010), and possibly human impact are factors that may alter the theoretically expected pattern.

In contrast to other ecological concepts, studies of disturbance regimes in the boreal zone have rarely taken advantage of island (or island-like) *v.* mainland comparisons (see though Bergeron 1991; Wardle *et al.* 2003; Drobyshev *et al.* 2008). Such comparative studies can be of value for understanding natural disturbance regimes, especially in areas with a long history of forest management and active fire suppression on mainland locations. By quantifying fire occurrence on islands of different sizes and over different historical periods, it should be possible to evaluate the role of natural (climatic) *v.* human-related courses of past fires (Niklasson and Granström 2000; Drobyshev *et al.* 2004). In the case of no direct human activities on the island ecosystems and with available information on past disturbance histories (e.g. through dendrochronological reconstructions), island fire histories could thus potentially serve as valuable proxies of climatic forcing on

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fire regimes (Bergeron 1991). Finally, linking island fire regimes with species' biology may help explain mechanisms of species survival and population maintenance in a larger geographical context (Diotte and Bergeron 1989; Bergeron and Brisson 1990).

In the boreal and hemi-boreal regions, the density of lightning strikes varies considerably. In Sweden, average frequencies of lightning strikes are between 0.02 and 0.43 strikes km^{-2} $year^{-1}$ (Sonnadara *et al.* 2006). In the Canadian province of Québec, a region with an otherwise similar range of climatic conditions and vegetation cover, the corresponding values are 0.5 to 1.3 strikes km^{-2} $year^{-1}$ (Morissette and Gauthier 2008). Lightning leads to ignition only in a small portion of all discharges reaching the ground. In the Nordic countries and in western Siberia, the forest vegetation is ignited 0.01–0.3 times per 100 km^2 $year^{-1}$ (Granström 1993; Larjavaara *et al.* 2005). Depending on the fire policy implemented within a particular region, successful ignitions either go out with rain, stop in natural fire breaks, or get suppressed actively. Fire suppression policies have often been designed with the idea of prevention or minimising the economic damage due to wildfires (Handmer and Proudley 2008; Crowley *et al.* 2009). In this context, island ecosystems, especially when located in remote areas, may have experienced the lowest impact of modern fire suppression, even in the most recent times. This fact further warrants the interest in island disturbance regimes.

To the best of our knowledge, comparative analyses of fire history in island–mainland systems are currently missing in the Eurasian temperate zone. To get a better insight into such systems, we chose an area in the hemi-boreal zone of south-east Sweden with a long fire history documented in the sediment records and with a naturally high level of lightning-caused fires (Lindbladh *et al.* 2003). In this study, we focussed on fire return intervals (FRI, time between fire events within a site) dendrochronologically reconstructed on islands of a relatively large (3130 ha) lake and the surrounding mainland. Calculation of FRI does not require reconstruction of past fire sizes and, as a result, FRI cannot be used to evaluate the overall fire impact on the studied landscape. By deliberately selecting FRI as the main statistic of interest, we avoided a discussion of fire cycles in this paper owing to the difficulty of defining a reasonable spatial unit ('the study area') for islands. Our main objectives were to reconstruct FRI on the islands, analyse its temporal variation over 400 years, and compare it with intervals reconstructed on nearby mainland locations. Humans have been actively using forest resources in this part of Scandinavia since the early middle ages (Frödin 1952; Goldammer *et al.* 1997) and the time period covered by the current study partly coincided with use of slash-and-burn agriculture and pastoral activities. It was therefore of interest to discuss changes in fire regimes based on available evidence of historical land-use patterns in the study area.

We addressed four partly competing hypotheses concerning the past fire regime:

(1) Changes in fire regime are consistent with the historical record of forest use and onset of different forest-use patterns in Fennoscandia.
(2) Fire intervals on islands should generally be longer, as compared with the mainland. This effect should arise owing to fires on islands being a product of fire ignition frequency solely, whereas on the mainland, it is a product of both ignition frequency within a study area and probability of fire spread from the area surrounding the study area.
(3) Island size should positively correlate with fire frequency owing to increasing lightning ignition probability with a larger surface.
(4) Spread of fire from mainland to islands or between the islands should be unlikely. This would result in the empirically observed frequency of such events (a fire recorded on an island and the mainland or at neighbouring islands in the same year) not being different from the statistical expectation of such events, based on the assumption of an independent (at an annual scale) nature of fire histories at these two landscape elements.

Material and methods

The study area

The study area lies in the Högsby and Nybro communities, in the south-eastern part of Sweden (Fig. 1). Allgunnen Lake (57°01′N, 16°01′E, elevation 85 m) is a medium-sized lake (3130 ha) located in the hemi-boreal zone, in a region with a slightly warmer and drier summer climate than most of southern Sweden. Annual precipitation is 550 mm, of which 31% falls during the summer months (June through August, SMHI 2003). In typical winters, ice covers the lake from early December to early April and snow covers the ground from mid-December to early April (Brandt *et al.* 1999). The mean January temperature is −2°C and the mean July temperature is 18°C (Raab and Vedin 1995). The landscape is largely flat or slightly undulating with only minor altitudinal differences. The lowest point is 71 m above sea level (ASL); the highest point is ~105 m ASL. Wetlands are rather rare and cover less than 10% of the area. The bedrock consists of Småland–Värmland granites covered by moraine rich in boulders. This parent material has resulted in coarse-textured, dry and predominantly infertile soils in the whole region (Fredén 2002).

The two principal conifers, Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*), strongly dominate the region. Scots pine is present in the studied landscape with 74% of the estimated total tree basal area (Anonymous 2008). Pine is often the only tree species on dry and rocky sites as well as on rain-fed high bogs. Under mesic conditions, Norway spruce intermixes with pine, although spruce dominance is only observed on fertile and more fine-grained soils. At the landscape scale, Norway spruce accounts for only 10% of the estimated basal area. Of the deciduous trees, birches (*Betula pubescens* and *B. pendula*) are most common, especially in young forests originating after clearcuts or fires. On wet soils and along watercourses, birches and black alder (*Alnus glutinosa*) commonly dominate. The abundance of aspen (*Populus tremula*), which is strongly connected to disturbances like fire or clear-cutting, is low. The pedunculate oak (*Quercus robur*) is common as undergrowth in most pine stands but rarely forms monotypic mature stands. Large and mature oaks are scattered in pine forests and grow in proximity of the few farmsteads in the area. On the islands, vegetation is very similar to mainland sites, with pine as the

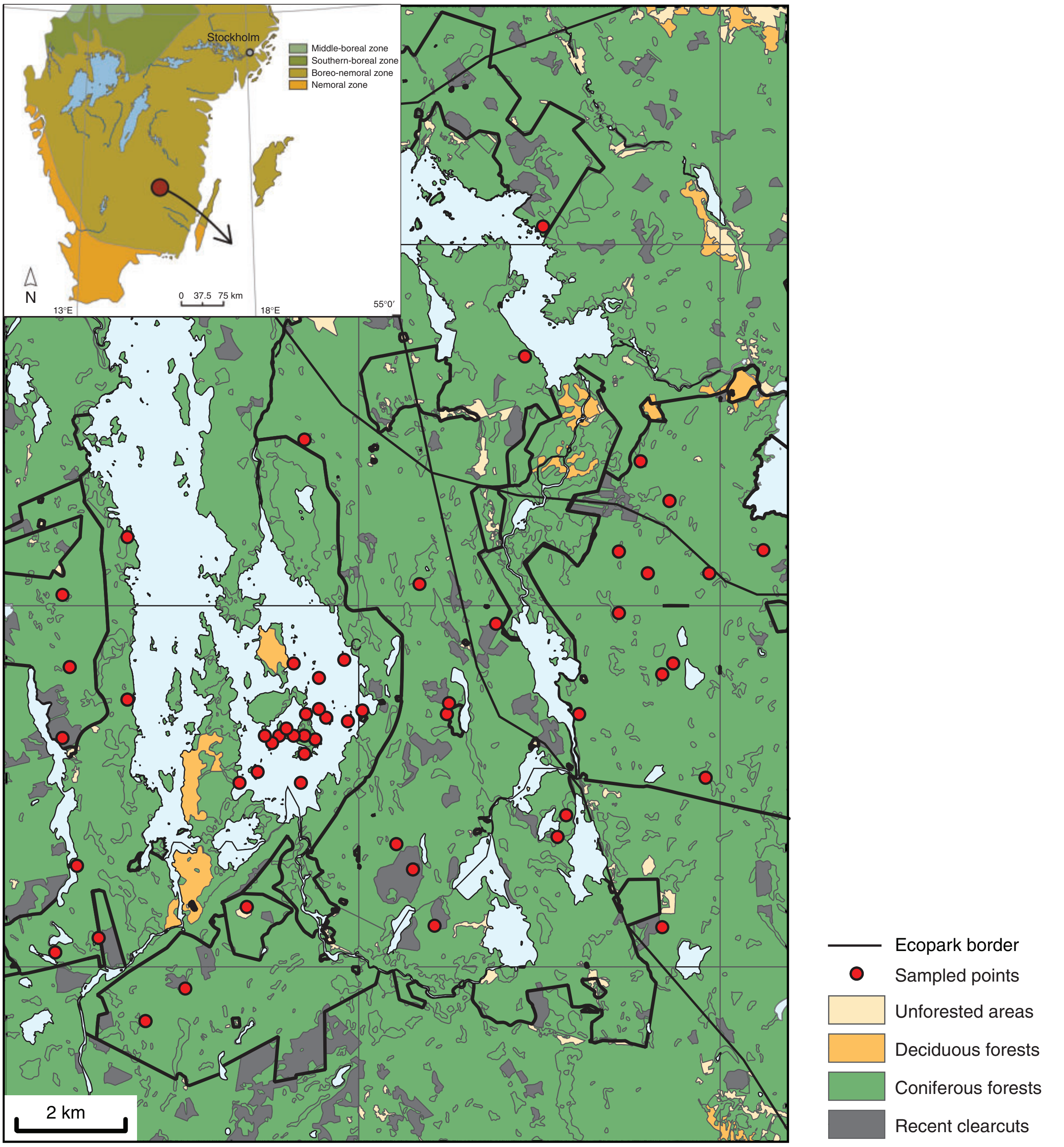

Fig. 1. Location of the study area in the Allgunnen nature reserve and Hornsö ecopark in south-eastern Sweden. A colour version of this figure is available from the journal online.

dominant tree and Norway spruce being present at a very low abundance.

The islands are mostly flat, with an elevation of a few metres, rarely up to ~20 m above the lake surface. The total number of islands is 129; average, mode, minimum and maximum sizes of the islands are 0.95, 0.01, 0.01 and 24.05 ha respectively. The sampled islands were located, on average, 455 m from the mainland (s.d. = 295 m). The minimum and maximum distances to the mainland were 73 and 850 m respectively.

The majority of the study area is included in the Sveaskog Hornsö ecological park, where only restricted forest operations are allowed. Most of the lake islands have been under strict protection since the year 2000 (Länsstyrelsen i Kalmar län 2005).

Field sampling

The fire regime was reconstructed by using fire scars from living trees, snags and stumps. Wood material was collected by cutting cross-sections or partial cross-sections from fire-scarred trees with a chainsaw (Arno and Sneck 1977). Fire-scarred material was originally searched for through a complete inventory of the land area surrounding Lake Allgunnen within Sveaskog Hornsö ecological park and on 25 islands, mostly located within the ecological park borders. On the mainland, an area of 0.5-ha was searched per site. On each of the islands, we searched for the presence of living fire-scared trees or deadwood with preserved fire scars. As the amount of usable material was generally very limited (see below), the whole island area was searched to ensure reconstruction of the most complete fire record. No such fire-scarred material was present on seven of the visited islands. Islands with usable material present ($n = 18$) had an average size of 5.15 ha and a mode of size distribution of 0.27 ha. In total, 54 sites were sampled and analysed: 36 sites on the mainland and 18 islands. We collected a total of 290 wood samples. The sampling effort was similar on islands and the mainland in terms of the samples collected, with an average of 4.2 and 6 samples per point on islands and on the mainland respectively. For islands, the number of samples was 0.16 ha^{-1}, whereas on the mainland at 0.03 ha^{-1}.

To estimate variation in lightning strike density between locations, we estimated the density of trees hit by lightning in forested areas with similar age of dominating canopy cohorts around Lake Allgunnen and on its islands. A total of 82 ha of the islands and 118 ha of the mainland were inventoried. Found scars were classified into three categories reflecting the certainty of identification of the scar as a lightning scar: a clear and confident lightning scar as described in the literature (Freier 1977), stretching over more than 1 m in length and with the scar top located at least 3 m above the ground (class 1); likely lightning scar with overgrown edges (class 2); scars without clear edges smaller than 1 m in length and with their top less than 3 m above the ground (class 3). See further details of the sampling protocol in Ahlander (2007).

Dendrochronological and statistical methods

Samples were sanded and dated under a binocular microscope with standard crossdating techniques (Douglas 1941; Stokes and Smiley 1968). To aid in fire dating, we developed a 500-year-long pointer year chronology for Scots pine and used known dates of major fires in the area as additional pointers. Major pointer years for successful crossdating were: 1969 (narrow ring), 1940 (narrow), 1868 (narrow), 1779 (wide, dark), 1750 (wide, dark), 1679 (narrow), 1598 (wide).

Preliminary analysis showed that the number of fires detected on the site was dependent on the time span covered by the samples from that site. To adjust for this effect while constructing the fire accumulation curve, we weighted the total number of fires recorded in a year by the proportion of *active* sites during that year. Active sites were sites with a fire chronology covering the fire year in question. An active site could be a site recording fire or a site with no fire recorded, thus providing information about the absence or occurrence of a past fire event. This procedure was independently performed on island and mainland datasets.

To study the temporal dynamics of survivorship functions, three periods were subjectively identified: 1550–1750, 1751–1860 and 1861–2003. The period definition was not based on a statistical test, but on a visual identification of the main shifts in the fire regime, as revealed by the dynamics of the cumulative proportion of fires (Fig. 2). We adopted a conservative approach and identified the onset of the most pronounced changes only to meet the requirements of statistical analyses with respect to the number of fires in each group.

It has been shown that the distribution of FRIs (the average number of years between successive fires) for a single stand often may be represented by the Weibull distribution (Grissino-Mayer 1999). We tested the FRIs for goodness-of-fit with respect to the Weibull distribution using the Hollander–Proschan test, utilising both uncensored and censored observations (Dodson 1994). In the context of our analyses, uncensored intervals were those between two fires dated in a stand; censored intervals were intervals between the date of a fire event and a non-fire date (e.g. the first year covered by the fire chronology of that stand or the year of sampling). Differences in FRIs between both periods and areas were checked with Gehan's Wilcoxon and the Cox–Mantel tests. Gehan's Wilcoxon test is specifically adapted for situations where there is a mixture of complete and censored observations (Gehan 1965). The Cox–Mantel test is

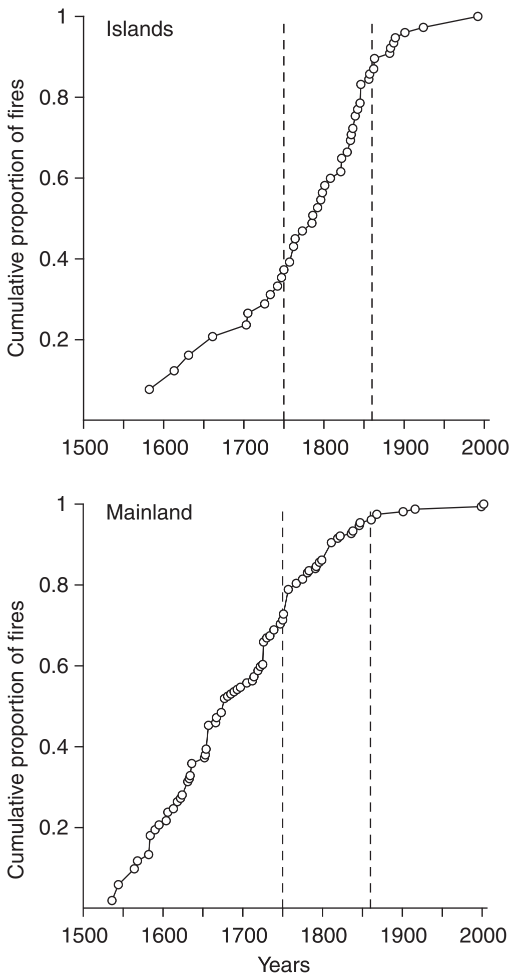

Fig. 2. Cumulative number of fires recorded on islands and the mainland. Data are adjusted for the number of sites covering different parts of the period studied (see *Methods* for the details of this procedure).

more powerful than other alternatives for comparison of survivorship functions drawn from populations that follow Weibull or exponential distributions (Lee *et al.* 1975).

To assess a survivorship function, describing the probability for a site to escape fire during a given time interval, we used the Kaplan–Meier estimator (Kaplan and Meier 1958):

$$S(t) = \prod_{j=1}^{t} [(n-j)/(n-j+1)]^{\delta_{(j)}}$$

where $S(t)$ is the survival function estimated, n is the total number of observations, Π is the geometric sum across all cases less than or equal to t; and j is a constant that is either 1 if the jth case is uncensored (complete), and 0 if it is censored (incomplete).

Results

In total, 40 fires were observed on the islands over 1613–1992, and 82 fires were observed on the mainland over 1536–1999 (Table 1). Approximately 10% of the samples with fire scars collected on the islands could not be crossdated. The tree ring record went back to 1468 on the mainland and to 1450 on island sites, in both cases reconstructed from deadwood material. The minimum age of the oldest living tree was at least 357 years, its centre being hollow.

Except for the most recent period (1860–2003), fire intervals were distributed according to the Weibull distribution on both the islands and the mainland (Table 2). Over time, the fire regime on the mainland and islands was largely similar, with frequent fires until the late 1800s and after that almost no fires on either the mainland or islands (Fig. 2).

Assuming a random spatial nature for these events, the probability of having a fire year on both an island and the mainland would thus be 0.021 annually, which would translate into eight fires over 379 years (time period commonly covered by two datasets). This value did not significantly differ from the empirical value obtained in this study (9 years, Table 1).

The median FRI was more than twice longer on the islands than on the mainland during the period before 1750 (Fig. 3, Table 2). An island had ~67% probability of escaping fire after 100 years, whereas the probability was only 20% for a site on the mainland. The opposite pattern was observed in the period that followed (1750–1860) with fires being more frequent on islands than on the mainland. The shape of the fire hazard function suggested that the probability of a 100-year-long fire-free period was only 25% on islands and 54% on the mainland. The most recent period (after 1860) was characterised by heavily reduced fire activity in both locations, with >85% probability for a site of not catching fire over the 160 last years (Fig. 3, Table 3).

The effect of island size on the fire hazard was significant at 0.042 (Gehan's Wilcoxon test, test statistic = 1.726) or at 0.084 (Cox–Mantel test, 2.030), with larger islands (>1 ha) having a higher fire hazard than the smaller ones (<1 ha) (Fig. 4). A similar pattern was confirmed in the log-linear analysis of the total number of fires *v.* island size (Fig. 5). Island size explained 46% of the variation in the number of fires (Fig. 5). Overall, fire frequency on islands was more than one order of magnitude higher than values theoretically expected from empirical data on lightning ignition frequencies in this part of Sweden (Granström 1993; Fig. 5).

Lightning scars were over 100% more frequent on the islands than the mainland (Table 4), the effect being consistent across all scar classes.

Table 1. Characteristics of island and mainland fire history in Hornsö area

Variable	Islands	Mainland
No. of dated fire events	40	82
Length of fire chronologies	1613–1992	1536–1999
No. of unique fires	38	62^{A}, 20^{B}
No. of years with fires on more than one island	2	–
No. of years with fires on both the mainland and islands		9 (8^{C})

[A]'One-point' fires.
[B]Fires recorded on two or more points (sites).
[C]Theoretically predicted value, based on assumption of random distribution of fire years within the period studied.

Discussion

Temporal changes in fire regime

Large changes in fire regime occurred on islands and the mainland of Lake Allgunnen over the last 400 years and were generally consistent with the history of fire use and suppression

Table 2. Statistical properties of the fire interval distributions on the islands and the mainland
Median, minimum and maximum values of the distributions are calculated on the complete (non-censured) intervals only (n_c); 'H-P' refers to *P* value obtained by the Hollander–Proschan test. Graphical results of the analysis are presented in Fig. 3

Periods	Islands					Mainland				
	n_c	Median (minimum, maximum)	H-P test	Scale parameter	Shape parameter	n_c	Median (minimum, maximum)	H-P test	Scale parameter	Shape parameter
<1750	4	58 (44, 120)	0.645	156.742	2.011	67	25 (0, 90)	0.962	64.573	1.272
1750–1860	20	15 (1, 86)	0.951	68.120	0.929	22	29 (6, 89)	0.979	175.800	0.911
1861–2003	2	–	<0.01	2556.4	0.690	1	–	–	–	–

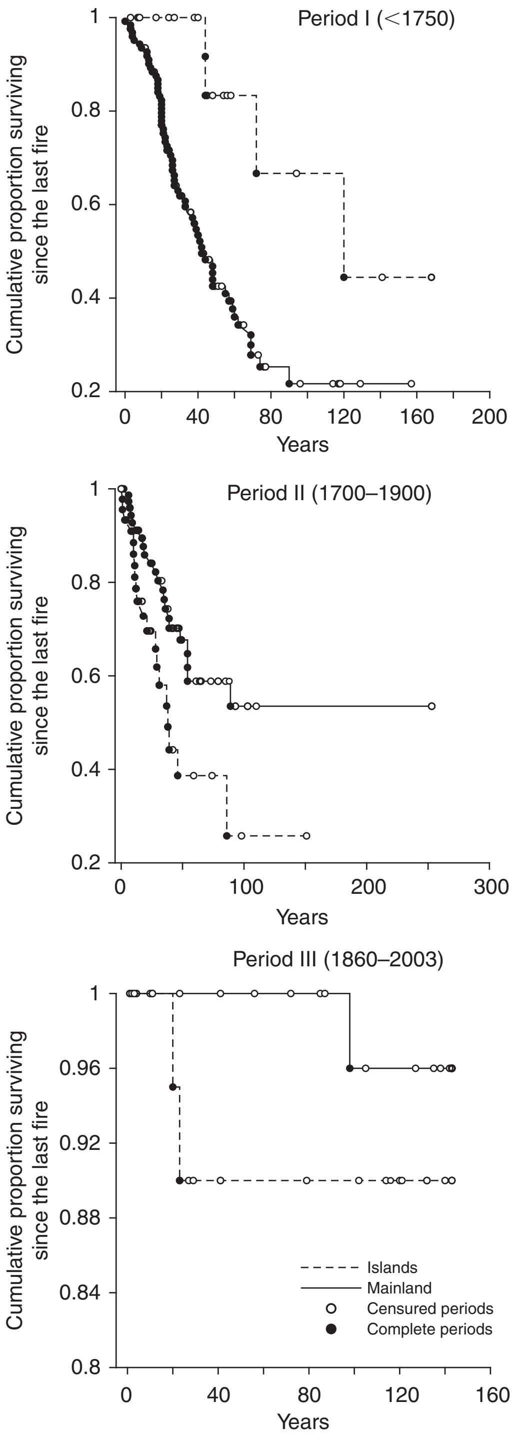

Fig. 3. Island–mainland comparison of survivorship functions (time since fire) for three time periods. Statistical details of analyses are presented in Table 3.

in Scandinavia (Granström and Niklasson 2008). The most dramatic shift in the area took place around the end of the 19th century: before 1860, fires were common on both islands and the mainland, whereas after ca. 1860, fire occurrence decreased strongly and synchronously on both landscape elements. The general decline in fires is consistent with decline in forest fire activity during the 1800s, found in many other Fennoscandian fire history studies (Kohh 1975; Zackrisson 1977; Engelmark *et al.* 1994; Niklasson and Granström 2000; Wallenius *et al.* 2002; Groven and Niklasson 2005). Although no firm evidence of the underlying causes for this change has been presented, it is thought to be mainly a result of active fire suppression rather than a result of climate change (Granström and Niklasson 2008).

Significant temporal changes in the fire regime also occurred around the middle of the 18th century. Before 1750, fires were less frequent on islands than on the mainland, as suggested by our original hypothesis. However, an inversion of this pattern was observed during 1750–1860: islands showed more frequent fires than mainland locations, suggesting an additional source of ignitions. We speculate that the observed pattern might be due to more intensive use of the islands by the local population, resulting in an increase in the number of intentional and non-intentional ignitions. Fire used to improve pastures on the islands was likely an important source of intentional ignitions during that period. We have not found any written documentation of past land use on the studied islands. However, geographical names of single islands in our studied lake often referred to cattle, probably indicating grazing of cows, goats and horses. From the literature, grazing is a well-known land use on islands generally in the past (Frödin 1952) and we believe fires, both intentional and unintentional, may have improved grazing conditions through re-initiating vegetation succession and promoting more palatable plant species and growth forms. Burning for improving grazing is documented for various areas in Fennoscandia in the past (Dahlström 2008). Burning isolated islands could be done without any risk of fire going out of control. The pattern found is consistent with a large increase in the southern Swedish population during the same period (Palm 2000).

Climatic explanation of the main shifts in historical fire activity around Lake Allgunnen is therefore less likely. Humans were likely behind the major decline in fire activity during the 1800s and a change in relative abundance of fires during 1750–1860. As to the latter period, it appears unlikely that climatic variation caused a rapid increase in fire ignitions within one part of the landscape but not within another. Therefore, we believe that the observed pattern might be due to more intensive use of the islands by the local population. The role of humans and historic climatic variability might have been different in other temperate regions. For example, Bergeron (1991) reported a similar shift from frequent fires to rare fires on islands in a comparable lake-island system in eastern Canada at the end of the 1950s and attributed it to a change towards a wetter summer climate.

Fire intervals and effect of island size on ignition frequency

In accordance with the proposed hypothesis, we observed a strong and positive relationship between island size and the number of ignitions (reconstructed fires) on the islands (Fig. 5). However, ignition frequency on the islands was consistently

Table 3. Island–mainland comparisons of survivorship functions (time since fire) for three time periods
See graphic presentation of results on Figs 3 and 4

Time periods	Cox–Mantel test		Gehan's Wilcoxon test	
	Test statistic	*P*	Test statistic	*P*
Temporal comparisons				
<1750	2.933	0.003	3.197	0.001
1750–1860	2.550	0.011	2.413	0.016
1900–2003	1.085	0.278	1.256	0.209
Island size comparison				
Small *v.* large islands	1.727	0.084	2.031	0.042

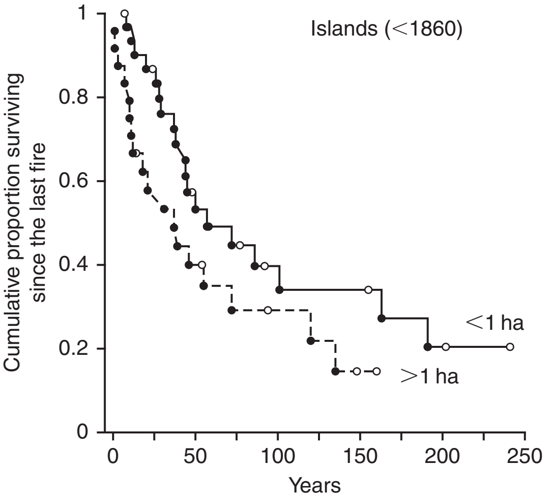

Fig. 4. Effect of island size on the fire hazard before year 1860. Filled dots and solid lines refer to mainland locations; empty dots and dashed lines refer to island locations.

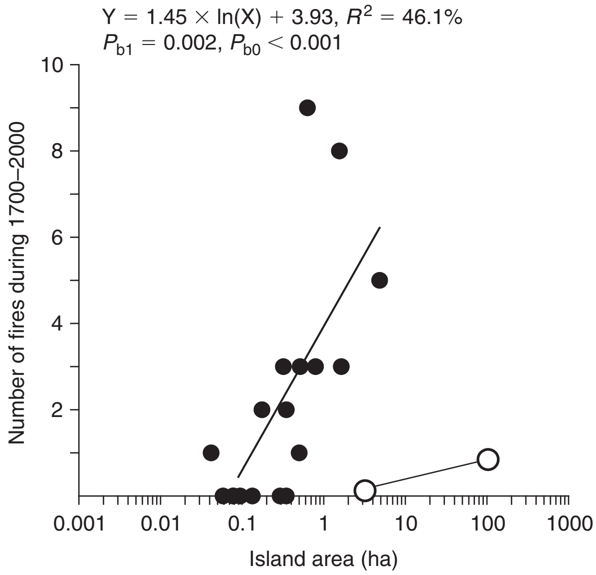

Fig. 5. Relationship between island area and the number of fires detected on the islands (full dots) and theoretically expected numbers based on fire ignition frequency data (empty dots) (Granström 1993). R^2 and significance of regression coefficients are given for the island data. Two *P* values are for b1 and b0 coefficients in regression equation respectively.

Table 4. Lightning scars on the trees on islands and on the mainland
Scar density (ha^{-1}) and its absolute number (in parentheses) are given for each case. See definition of lightning scar classes in the *Methods* section

Type of scars	Islands	Mainland
Class 1	15.9 (13)	8.4 (10)
Class 2	26.7 (22)	12.7 (15)
Class 3	37.9 (31)	25.9 (31)
Total	80.5 (66)	47.0 (56)

higher than expected, suggesting that both the physical properties of the location and human impact might have been potential ignition-contributing factors.

The 'island effect' (see Drobyshev *et al.* 2010) could partly explain the higher number of ignitions on the islands. This effect is a result of elevational differences between the lake surface and the islands and, in the case of larger islands (>100 ha), also the temperature differences between cold water and rapidly warming land area, resulting in convection columns and, eventually, thunderstorms developing over the island. A recent study of lightning-struck trees on islands and mainland in the same area (Ahlander 2007) showed that the 'island effect' resulted in ~100% more lightning-struck trees on islands compared with the mainland (Table 4, data for scar classes 1 and 2). This effect was present despite the fact that all islands in our study were rather flat and had typically mesic or dry forest types similar to the adjacent mainland. Earlier, Bergeron (1991) suggested the 'island effect' as a cause of higher fires frequencies on islands in a similar lake-island system in eastern Canada. Although he did not quantify this effect in the original paper, a follow-up study has shown that the number of strikes (per area and time) is approximately one order of magnitude higher on islands than on the mainland, at least during early summer (Drobyshev *et al.* 2010).

In the past, islands might also have attracted humans, who used fire for pastoral activities or started them unintentionally during camping or as a result of negligence. The effect of island size might then have been important also in the case of human-related ignitions too; larger islands might have been more attractive for grazing compared to small islands.

An important component of reconstructed fire regime is the absolute number of ignitions estimated for island locations. As an example, a 100-ha island in our study region could be theoretically expected to ignite naturally once every 400 years, and a 1-ha island once every 40 000 years (Granström 1993). Fire numbers on islands thus exceeded the *expected* number (once every ~4th year and 10 000 ha) of fires by more than one order of magnitude (Granström 1993; Fig. 5). This result rejected the assumption about the similar ignition frequency on the islands and on the mainland and suggested a fuel-limited fire regime rather than ignition-limited fire regime. The build-up of fuel, its properties and spatial distribution were likely important in controlling fire regime on the islands. For the smallest islands (considerably less than 1 ha in size), which likely burn over completely during a single fire event, the maximum number of fires per time period should be controlled by the time required for fuel to become flammable after the previous fire, which is estimated to be ~10–20 years in southern Sweden (Schimmel and Granström 1997). It agrees with the observation that during 1750–1860, islands typically burned at intervals shorter than 20 years (Table 2).

Fire spread

Our data also suggested minimal fire spread from the mainland to the islands, which were located, on average, ~500 m apart. Fire years coincided on the mainland and an island on eight occasions but, in one case only, the mainland fire was dated on locations close to the shore, which would suggest a possibility for its spread over water to the neighbouring islands by firebrand. The same negligible probability of fire spread was also observed among the islands.

The number of fires reconstructed on islands increased with island size, which supported our original hypothesis and was in accordance with the results from northern Swedish studies on lake islands (Wardle *et al.* 1997, 2003), where island size strongly influenced fire history. If one assumes no differences in fuel loadings and local weather between islands and the mainland for lake systems as small as our study system (though see Drobyshev *et al.* 2010), an increased number of fires on larger islands should reflect an increased probability of a lightning strike hitting a tree within a larger area. Although our data did show such a pattern, we still think human activity was strongly masking this effect in our study.

Modern fire history on islands – a natural fire regime?

The current (since 1890) fire activity on islands may well represent a close-to-natural fire regime. Although active fire suppression activities are believed to be the cause of fire decline over most of Fennoscandia (Granström and Niklasson 2008), this model can not be fully applied for small, remote islands. The decline in fires in such habitats is much more likely to be a result of a strong decrease in the number of human-related fires and lightning becoming increasingly the dominant source of ignitions. Therefore we think the islands must be considered as a landscape element with the least human-affected fire regimes and, possibly, the most natural fire regime over modern Fennoscandia.

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