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# Holocene fire frequency variability in Vesijako, Strict Nature Reserve, Finland, and its application to conservation and management

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ABSTRACT

Fire disturbance is considered paramount for regeneration and biodiversity in the boreal forest with prescribed burning widely advocated in present day forest management. Palaeoecological knowledge is beneficial in understanding the role of fire as a driver of past vegetation dynamics. We use a sedimentary pollen and charcoal record to reconstruct 5000 years of fire and vegetation history from a small forest hollow (approximate area 12 $m^2$) in the Vesijako Strict Nature Reserve, currently one of the few remaining old-growth forest stands in southern Finland. Results indicate three distinct periods in the environmental history (1) 5000–2000 cal. yrs. BP; semi-natural low frequency (430 year return period), low intensity fires in a diverse mixed stand with little evidence of anthropogenic disturbance and an expanding *Picea abies* (Norway spruce) population (2) 2000–750 cal. yrs. BP; anthropogenic-driven high frequency (180 year return period), high intensity stand-replacing fires in a low diversity stand with evidence of slash and burn cultivation and a decline of *Picea* population, (3) 750 cal. yrs. BP to present day; fire absence through a reduction in human-induced fire or active fire suppression and the expansion of the currently dominant *Picea* forest. The changing fire frequency has had a major influence on the forest composition during the last 5000 years. The loss of floristic diversity is associated with an increase in the human use of fire and without this human interference the previously high biodiversity in the stand may have remained up until the present day. If fire remains absent in Vesijako then it is likely that the *Picea* population will continue to dominate in the stand supporting a negative feedback mechanism that will result in lower frequency, higher intensity fires in the future.

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## 1. Introduction

Fire is a significant disturbance agency in the circumboreal forest and there is evidence of varying fire frequencies from charcoal sediment records extending back to the last glacial maximum (Power et al., 2008). Although humans have been using fire since the early–mid Pleistocene (Bowman et al., 2011), it is only since the mid-late Holocene that anthropogenic intervention has modified boreal Fennoscandian fire regimes from their 'natural' state through slash and burn cultivation (Molinari et al., 2005). Almost two centuries of widespread fire suppression in Fennoscandia (Wallenius, 2011), has impacted forest biodiversity by favouring the expansion of *Picea abies* (Bjune et al., 2009) and endangering fire-dependent species including fungi, insects (Kouki et al., 2012) and higher plants (Risberg and Granström, 2012). Recent attempts have been made to reintroduce burning in designated areas to restore important natural values (Hyvärinen et al., 2009; Vanha-Majamaa et al., 2007). However, fire restoration is faced by many challenges, most notably to determine and subsequently attempt to mimic the 'natural' fire regime.

Ecological history is rarely considered in current forest management and conservation practices. However, long-term palaeoecological data can help explore temporal and spatial anthropogenic ecosystem modification, enabling the support of restoration activity designed to foster biodiversity and vital ecosystem functions (Jackson and Hobbs, 2009; Willis and Birks, 2006).

Study of previous fire regimes, notably fire frequency, size and severity prior to any significant human disturbance can provide information and guidelines for present-day and long term management strategies (Bergeron et al., 2002). Previous fire history studies and estimates of fire frequencies in Fennoscandia have been based on fire scars (Niklasson et al., 2010; Wallenius et al., 2007), charcoal layers (Ohlson et al., 2006; Pitkänen et al., 2002), charcoal particles analysed from lake sediment (Carcaillet et al., 2007; Pitkänen and Huttunen, 1999; Tolonen, 1983) and mires (Tolonen,

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1985), however charcoal records with high spatial resolution from forest hollows have not yet been used to estimate past fire frequencies in Fennoscandia (Bradshaw et al., 2010; Higuera et al., 2005). Dendrochronology gives useful insight into the fire history records of fire scars are limited both spatially and temporally. Spatially, trees have to survive a fire and remain in situ to provide a true record. Temporally, fire scar chronology rarely exceeds 600 years (Wallenius et al., 2007) and are considered somewhat more reliable when reconstructing the fire history for the past 400–500 years (Niklasson et al., 2010). Charcoal in the sedimentary record is much more widely available, but previous work calculating fire frequencies from charcoal records has required sophisticated statistical manipulation to help identify charcoal peaks relating to specific fire events (Carcaillet et al., 2007). This is because charcoal records in sediment usually consist of continuous background levels of charcoal.

Here we use a high resolution pollen and charcoal record from a small forest hollow in Vesijako Strict Nature Reserve, Finland, to determine fire frequencies through the last 5000 years and how they are influenced by both natural and anthropogenic factors. We also explore the effects of changing fire frequency on the forest composition and structure and vegetation diversity in the Vesijako reserve and discuss the importance of our results for forest management and biodiversity conservation.

## 2. Materials and methods

### 2.1. Study area and site

Vesijako (61°N; 25°E) is 1700 ha of relatively uninhabited forest situated in the Padasjoki municipality, southern Finland (Fig. 1). Currently administered by Metsähallitus, Vesijako is a state owned research forest with a long tradition of management for timber production and related ecological research (Heikinheimo, 1915). More recently research in Vesijako has focused on restoration of forest biodiversity through active management, for example selective logging, creating dead wood and prescribed burning (Lilja-Rothsten et al., 2008; Shorohova et al., 2008; Vanha-Majamaa et al., 2007). The forest is located in the southern boreal vegetation zone (Ahti et al., 1968) with an altitude ranging between 100 and 170 m a.s.l. The mean annual temperature is 4.2 °C, with a July mean of 16.6 °C and a February mean temperature of −7.1 °C (Pirinen et al., 2012). The mean annual precipitation is 645 mm/yr and the duration of thermal growing period is 160 days.

Vesijako Strict Nature Reserve (61°21′N; 25°06′E) is 115 ha located within Vesijako forest and was established by Metsähallitus in 1956. In Finland, a Strict Nature Reserve is a national state-owned conservation reserve protected by law in its natural state and undisturbed condition due to its exceptionally high scientific value (Similä and Junninen, 2012). The primary purpose of Vesijako Strict Nature Reserve is to conserve an intact representative of southern Finnish Lakeland forest and to use it for scientific research (Fig. 1). The area is considered to be in a near natural state and represents a small but important woodland key habitat of the boreal zone in Finland (Timonen et al., 2011; Rajala et al., 2012). The sampling site, selected for its small forest hollow characteristics (Overballe-Petersen and Bradshaw, 2011) is a wet hollow of approximately 12 $m^2$ situated within a dense forest stand dominated by *Picea abies* with scattered *Pinus sylvestris*, *Betula* and *Populus tremula* individuals present at the site (Fig. 2).

### 2.2. Field, laboratory and statistical methods

A sediment core comprising of three sections, 126 cm in total length, was extracted from the centre of the small forest hollow in Vesijako in May 2008 using a 50 cm long, 5 cm diameter Russian

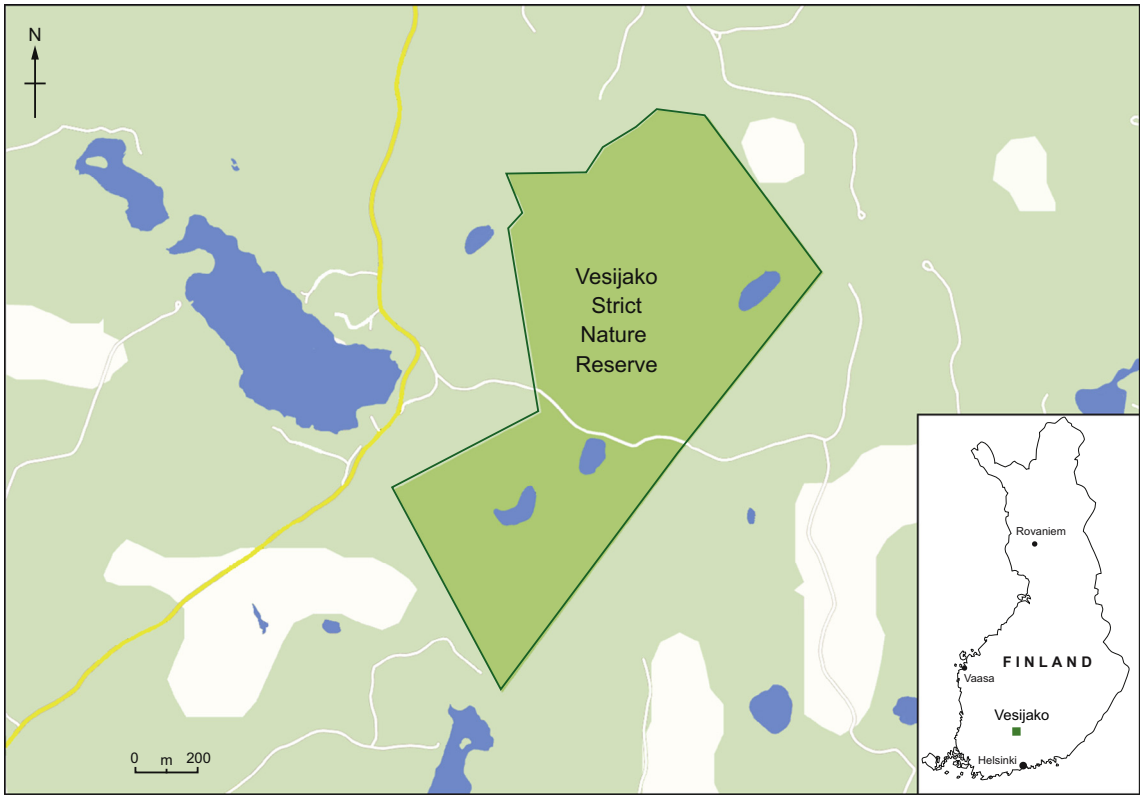


**Fig. 1.** Location map of Vesijako Strict Nature Reserve, Finland.

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