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Historical experience (1850–1950 and 1961–2014) of insect species responsible for forest damage in Sweden: Influence of climate and land management changes

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ABSTRACT

The ongoing climate change can influence the dynamic of insect populations and therefore the Insect species Responsible for Forest Damage ("insects-RFD" hereafter). The present study aims at identifying the most occurring insects-RFD in Sweden, and exploring the relationships between insects-RFD and climate and land management changes. The recorded insect attacks based on historical reports, literature and databases, were collected for North, Central and South of Sweden, and for two periods at yearly time scales: 1850–1950 and 1961–2014. A series of analyses has been carried out based on this dataset: 1-Estimation of the occurrence of each insects-RFD over years to assess which insect species have caused the major forest damage, 2-Ratios of broadleaved versus conifer host trees to estimate the main types of damaged forests, and 3-Canonical correspondence analyses to evaluate how much climate (winter and summer temperature, winter and summer precipitation, and storms) and land management (land areas for wood production, standing volume for all trees and standing volume for deciduous trees) changes have affected insects-RFD. The results reveal that the most occurring insects-RFD differ between the North and South of Sweden, and between 1850–1950 and 1961–2014. The most occurring insects-RFD since 1850 were *Ips typographus*, *Neodiprion sertifer*, *Tortrix viridana*, *Hylobius abietis* and *Tomicus piniperda*. The occurrences of insects-RFD have been higher in the South of Sweden since at least 1850 than in other regions. The North of Sweden have been mostly affected by insects-RFD between 1911 and 1950. Canonical correspondence analyses show that the spread of insects-RFD might be related to environmental conditions. More particularly, the insects-RFD variation explained are increasing between 1902–1950 and 1961–2007 in all Sweden for temperature (winter and summer) and in Central and South of Sweden for storm damage. However, the evolution of landscape management would participate in influencing insects-RFD, in particular from 1961, when changes in forest management (e.g. increase in land areas for wood production) have been developed, as well as the way to report insect forest damages. This long-term perspective of how changes in climate and land management have influenced insects-RFD is of great interest for further discussion about climate adaptation strategies in forestry and ecosystem services.

1. Introduction

Insects are an important component of ecosystems as a source of food for a large variety of animals, through their roles in the biogeochemical cycle (e.g. soil formation processes affecting water and soil nutrient contents, and decomposition of organic matter) and in the life cycle of other organisms (e.g. as pollinators of flowering plants) (Meyer, 2007). Insects are normal components of a healthy ecosystem. However, some species are considered as harmful and threatening (Stolte, 1997), and are classified as pests (i.e. a sudden and hazardous increase in the abundance of a particular species).

Insect defoliators feed on the foliage of their host trees, affecting photosynthesis mechanisms (e.g. Douce et al., 2002; Glavendekić and Medarević, 2010; North Carolina Forest Service, 2013). Bark beetles bore into the bark of their host trees to feed and/or reproduce, destroying the phloem. Other insects harm their host trees by piercing the surface of soft plant tissues and feeding on nutrient-rich sap, which might cause the starvation of the hosts by depleting it of the carbohydrates produced by photosynthesis. Moreover, the piercing/sucking insects can carry fungal pathogens and contami-

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nate the hosts, increasing the vulnerability of trees. Other insects attack seedlings and small twigs, shoots and buds, weakening the young host trees to face further insect attacks and diseases (e.g. Douce et al., 2002; North Carolina Forest Service, 2013). Insect attacks might therefore influence negatively the resilience of forests to face the ongoing climate change (Flower and Gonzalez-Meler, 2015). The economic consequences of insect damage correspond not only to the market value of forest production losses, but also to the cost expended on prevention and control of insect attacks.

The ongoing climate change would significantly influence the development of most insect species, as they are highly dependent on climate conditions (Andrew et al., 2013; Björkman et al., 2011; Nooten et al., 2014). Temperature has direct and indirect effects on insect populations. The direct effects are the adjustment of developmental rates, reproduction and mortality of insect populations. The indirect effects correspond to the abundance, distribution and physiology of host trees, as well as influences on higher levels of the food chain (Liebhold and Bentz, 2011; Wermelinger, 2004). Climate changes can have different consequences, leading either to larger and more frequent insect attacks or to the reduction of recurring attacks (Liebhold and Bentz, 2011). Investigation of the interactions between environmental conditions and insect damage is therefore necessary for taking appropriate control measures to prevent the spread of harmful insect species.

Forestry represents an important sector of the national economy of Sweden (Barklund, 2009). Sweden is covered by approximately 70% of forests, with 28 million hectares (Swedish Forest Agency, 2014a) and a total standing volume of productive forest land of 42% for Norway spruce, 39% for Scots pine and 12% for birch (Swedish National Forest Inventory, 2013; Swedish Forest Agency, 2014b). Different countermeasures to prevent insect attacks have been conducted, for examples the use of chemical pesticides within forestry between 1967 and 1971 and the salvage and sanitary cutting of stormfelled and insect attacked trees (e.g. Christiansen, 1970; Ehnström et al., 1974; Harding et al., 1998). Considering the potential economic, as well as ecosystem service impacts of insect damage in Sweden for the next decades, researches on how climate and land management changes have interacted with insect attacks in the recent past and still interact today are necessary for mitigation plans.

The present study focuses on historical (1850–1950 and 1961–2014) forest insect damage in Sweden. The aims are to: (1) create a dataset of recorded insect attacks based on historical reports, literature and databases, (2) identify the most occurring Insect species Responsible for Forest Damage ("insects-RFD" hereafter) and the types of attacked host trees, and (3) explore the relationships between insects-RFD and changes in climate conditions (summer and winter temperatures, summer and winter precipitation, and storms) and land management (land areas for wood production, standing volume for all trees and standing volume for deciduous trees) using statistical analyses.

2. Material and methods

2.1. Study area

The forest ecosystems of Sweden are influenced by the latitudinal gradient. South of Sweden (Götaland, 55°N–58.7°N) belongs to the nemoral and boreo-nemoral vegetation zone with a natural mixture of broadleaved and coniferous forest (Ahti et al., 1968). Due to management choices, Norway spruce is the dominating tree species at ~50% of the standing volume (Loman, 2004). Central Sweden (Svealand, 58.7°N–63.5°N) and North Sweden (Norrland, 63.5°N–68.3°N) belong to the southern boreal and boreal vegetation zone, respectively (Ahti et al., 1968). Here the forest is dominated by Norway spruce and Scots pine in roughly equal proportions (Loman, 2004). Along the Scandinavian mountain range, large areas of birch forests are established. Overall, the "typical" forest is dominated by Scots pine and Norway spruce (Swedish Forest Agency, 2014b); most of them have been planted for wood production and have high values for Swedish economy and society.

The climate in Sweden is influenced by the northerly location. The South gets an average of precipitation per year between 700 and 1200 mm and the mountains of the northern areas get up to 2000 mm (data from Swedish Meteorological and Hydrological Institute, SMHI). Snowfall mainly occurs from December to March in the South, from November to April in the Centre, and from October to May in the North. The averages of July temperatures are 8–16 °C according to SMHI. February is usually the coldest month, with average temperatures varying between −14 and 0 °C according to SMHI.

In order to take into account the North-South variation in climate conditions and vegetation of Sweden, our study area has been divided into three large regions, North, Central and South of Sweden. These regions correspond to the respective lands of Sweden (Fig. 1), Norrland covering ca. 58 percent of the Swedish territory, Svealand (ca. 20%), and Götaland (ca. 22%).

2.2. Compilation of historical data

Data compilation (Appendix A) is based on historical reports, literature and databases, including

- two compilations of insects-RFD in Sweden for the periods 1741–1945 (Lekander, 1950) and 1946–1950 (Lekander, 1954), at yearly time scale. These data are based on forestry and entomological literatures, insect reports from Domain Authority, Forestry Board annual reports, Forest Research Institute written communications, Swedish Forest Service reports, foresters' annual reports and the State Forestry Research Institute incoming reports, inquiries and samples. For the relevance of the present study our synthesis starts at 1850, because there is little information before 1850 due to low monitoring of insect attacks at that time.
- a series of papers that correspond to five year published reports and surveys of insects-RFD in Sweden. These data all together cover the period 1961–1990 at yearly time scale (Austarå et al., 1983; Christiansen,1970; Ehnström et al., 1974, 1998; Harding et al., 1998; Löyttyniemi et al., 1979).
- the database Skogsskada (http://www.slu.se/sv/centrumbildningar-och-projekt/skogsskada/), which reports yearly insects-RFD in Sweden from an online and open access database. These data correspond to public reports of forest insect damage between 1991 and 2014, at yearly time scale.

The data sources, i.e. the two compilations of insects-RFD for the periods 1850–1945 and 1946–1950, the five year reports of insects-RFD (period 1961–1990), and the database Skogsskada (period 1991–2014) differ in terms of strategy for monitoring, data collection and reporting. In general, the data from the first period (1850–1950) includes more detailed information than the second period (1961–2014). The periods 1850–1950 and 1961–2014 have therefore been studied separately. Based on visual comparison of number of recorded insect attacks (see Tudoran, 2015), higher number of attacks are reported from 1900, when the first forestry act (1903) was implemented (Royal Swedish Academy of Agriculture and Forestry, 2009). It is therefore suspected that more intense monitoring of insect attacks have been done from that time. We therefore divide the period 1850–1950 into two sub-