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Impact of climate change on the population dynamics of *Ips typographus* in southern Sweden

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Abstract

Mass-propagation of the spruce bark beetle, *Ips typographus,* following windfalls and drought is a serious threat to mature spruce forests. Climate change will affect the population dynamics of *I. typographus* directly as the swarming activity and development rate are mainly controlled by temperature, and indirectly via changes in availability of brood trees. Today, *I. typographus* is in general univoltine in southern Sweden. In Denmark, however, the weather conditions usually support the production of a second generation. By modelling the temperature dependent population dynamics, we have evaluated the effect of regional climate change scenarios for the period of 2070–2099 on *I. typographus* in southern Sweden. Our results indicate that temperature increase will have a step-wise effect on the population dynamics. Earlier spring swarming and a faster development from egg to mature bark beetle increase the probability of a second swarming period during summer. A second swarming will be customary with an annual mean temperature increase of 2–3 °C. The thermal requirement for development of a second generation may, however, not be fulfilled every year with an annual mean temperature increase less than 5–6 °C. Winter is fatal for immature bark beetles, and the larger the temperature increase, the higher the probability that the second generation will complete development and survive hibernation. The temperature regime during autumn will therefore have a decisive impact on the size of the swarming population next spring.

Keywords: Bark beetles; Brood development; Climate change; Forest damage; Impact modelling; *Ips typographus*; Population dynamics; Risk assessment; Temperature

1. Introduction

The general conclusion from assessments made by the intergovernmental panel on climate change (IPCC) is that both the mean temperature and the frequency of extreme weather events such as heat spell, dry spell, storms and flooding, could increase (Cubasch et al., 2001). The development of insects is strongly affected by temperature (Zaslavski, 1988), and abiotic stress, as caused by extreme weather events, affects the interplay between vegetation susceptibility and insect performance. Consequently, climate change has the potential to alter the frequency and intensity of pest outbreaks, both in agricultural (Strand, 2000; Bommarco, 2001) and forest ecosystems (Ayres and Lombardero, 2000;

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Volney and Fleming, 2000). Assessments of the risk of insect outbreaks and damage in response to climate change are required in order to develop pest management strategies (Strand, 2000). Process-based model descriptions of the temperature regulated population dynamics of insects are prerequisites for these kinds of assessments.

In forest ecosystems, insects are often the primary disturbance agents (Logan et al., 2003), and in coniferous forests, bark beetles (Coleoptera, Scolytidae) are the most destructive pests. Impact studies of the effect of climate change on outbreak ranges (e.g. Williams and Liebhold, 2002; Carroll et al., 2003) and infestation risks (Gan, 2004) have been carried out for North American species (*Dendroctonus* sp.), but so far, however, no model studies have projected the impact of climate change on European bark beetles.

In Europe, mass-propagation of the spruce bark beetle, *Ips typographus* L., following windfalls and drought is a serious threat to mature spruce forests. Newly windthrown spruce trees are suitable as brood trees for *I. typographus*, and could thereby cause a significant increase of the bark beetle population. In turn, the risk of lethal bark beetle attacks on living spruce trees increases with population size. Moreover, the resistance of conifers to bark beetle attack is strongly affected by tree vigour (Waring and Pitman, 1983), and especially drought stress is a major factor increasing the susceptibility of spruce to attacks by *I. typographus* (Økland and Christiansen, 2001). This makes *I. typographus* rank among the major insect pests of European forests (Christiansen and Bakke, 1988). Schelhaas et al. (2003) estimate that in Europe, 8% of the total forest damage between 1850 and 2000 was caused by bark beetles, mainly *I. typographus*. In the forests of Sweden, 43% of the standing volume is Norway spruce, i.e. 1279 million cubic meters (Loman, 2005), and forest owners consider *I. typographus* as one of the major threats to forest production (Blennow and Sallnäs, 2002).

The activity and voltinism of *I. typographus* depend of latitude and elevation. In the Nordic countries, one generation of *I. typographus* is normally produced per year (Annila, 1969; Bakke, 1983) with the exception of Denmark where the climate generally allows the establishment of a second generation (Harding and Ravn, 1985). Two generations per year are common in Central Europe, except at higher elevations (Wermelinger and Seifert, 1999). There are thus reasons to believe that in southern Sweden the population dynamics of *I. typographus* will be sensitive to temperature increase, and that this is one of the regions were a change in population dynamics due to climate change will be first observed. Temperature sum requirements and thermal thresholds affect the activity and development of *I. typographus* throughout the year and can be used for modelling the effect of weather on the development of *I. typographus* (Netherer and Pennerstorfer, 2001).

With the aim to assess the potential effect of a temperature increase on the population dynamics of *I. typographus* in southern Sweden, a model for the temperature dependent swarming activity and developmental time of *I. typographus* was developed. The model simulates timing of spring swarming, timing of completed development of the first generation, timing of summer swarming, and potential degree of development for the second generation. For model evaluation, estimated timing of bark beetle activity during spring and summer was compared with observations from the forest Grib Skov in Denmark. Two sites in southern Sweden were chosen for projecting the impact of climate change on *I. typographus*. The results are discussed in relation to the impact of climate change on availability of brood trees.

2. Material and methods

2.1. Climate data

Two sites in southern Sweden with meteorological stations, Ljungbyhed (56°05′N 13°14′E) and Växjö (56°5′N, 14°5′E) were chosen for projecting the impact of climate change on the population dynamics of *I. typographus*. The potential impact of climate change was evaluated by using output data from the Hadley Centre regional climate model HadRM3H. Daily maximum and mean temperature data from three standard scenarios of greenhouse gas concentration were used: the common period for the period of 1961–1990, and the scenarios A2 and B2 for the period of 2070–2099 (Nakicenovic and Swart, 2000). The common period is based on observed greenhouse gas concentrations; the scenarios A2 and B2 both assume elevated emission of greenhouse gases, scenario A2 assuming a higher future emission than scenario B2 based on storylines of population growth, globalisation, environmental protection, economical growth and technological development. Temperature data from regional climate models represent estimated averages for areas of approximately 50×50 km, and model uncertainties as well as local variations in the topography can cause deviations compared to observed climate. Temperature data for the common period were