Early warning systems for European spruce bark beetle

What exists and how are they used

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Master's thesis in Forest Science, 30 hp Swedish
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Abstract

The European spruce bark beetle (ESBB)*, Ips typographus*, has killed roughly 34 million cubic meters of Norway spruce (*Picea abies*) in Sweden since the drought in 2018. Outbreaks of this species have led to direct impacts on timber markets, transformations of landscape structures and can alter ecosystem functioning. With increasing summer and winter temperatures in combination with changes in precipitation patterns, the risk of ESBB outbreaks will increase in the future.

Monitoring population developments during endemic and epidemic (outbreak) phases is important for damage and forest management. To reduce and prevent direct and indirect damage caused by ESBB, early detection is necessary. Despite this, there are no current comprehensive monitoring system available in Sweden. Such a system would ideally be incorporated in a framework to forecast risk of damage available in forestry practices.

The aim of this study is divided in two objectives. The first objective is to assess the available tools for early warning used in Swedish forestry practices. The second objective is to understand forest company attitudes towards the available methods and the development of an early warning system. To reach the first aim, a literature study of available monitoring tools and early warning system was used. For the second aim, interviews with forest practitioners from different forest companies in Sweden were conducted.

The results for the first aim showed that ground surveys, pheromone traps, risk maps, remote sensing are common tools to monitor ESBB population, infestations and outbreaks. The literature study also showed that there are no early warning systems for ESBB outbreaks available in Sweden. However, researchers in Austria and Slovenia has developed early warning systems for ESBB outbreaks that are available for forest owners. The results for the second aim of this study showed that forest companies combine different monitoring tools and use their own experiences with ESBB to manage and prevent ESBB related problems. The forest practitioners' attitudes indicate that while the introduction of an early warning system for ESBB outbreaks is perceived positively, there is some scepticism regarding its actual implementation due to certain challenges. This reflects a contradictory stance that require further investigation. However, an explicit early warning system for ESBB infestations could help stakeholders in the forest sector to keep population densities low during endemic periods, save timber value and help forest companies with planning of resources.

Keywords: European spruce bark beetle, monitoring tools, early warning, early warning system, forest management, outbreak, attitudes

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Abbreviations

Abbreviation	Description
AI	Artificial intelligence
ESBB	European Spruce Bark Beetle
GIS	Geographical Information System
SLU	Swedish University of Agricultural Sciences

1. Introduction

The European spruce bark beetle (ESBB), *Ips typographus*, is one of the most important pest insect species when it comes to tree mortality. In Europe, the bark beetle has killed and damaged millions of cubic meters of spruce trees since 2015 (Kautz et al. 2023). In Sweden alone, roughly 34 million cubic meters of Norway spruce (*Picea abies*) have been killed since the drought in 2018 (Swedish Forest Agency 2024c). Outbreaks of this species have led to direct impacts on timber markets, transformations of landscape structures and can hinder ecosystem service functioning, for example carbon sequestration (Hlásny et al. 2021). ESBB outbreaks are strongly associated with abiotic disturbances, such as extreme drought, ice storms or windstorms (Netherer et al. 2022). Large-scale drivers such as climatic variation and landscape structure also affect outbreak dynamics (Seidl et al. 2016). The species colonises weakened trees at endemic densities but can also attack healthy trees adjacent to the weakened tree (de Groot et al. 2018). With increasing summer and winter temperatures in combination with changes in precipitation patterns, the risk of ESBB outbreaks will grow (de Groot & Ogris 2019). Monitoring population development prior to and during outbreak phases is important for outbreak and forest management, since outbreaks of bark beetles often are associated with high economic costs and losses of other values (Waring et al. 2009; Ogris et al. 2019). Early detection of ESBB infestations are important for reducing damage intensity, applying direct management methods to reduce ESBB populations, and saving timber value and other ecological functions (de Groot & Ogris 2022).

Research in Austria and Slovenia has resulted in several models based on ESBB phenology to monitor ESBB and ESBB outbreaks (Baier et al. 2007; de Groot & Ogris 2019; Ogris et al. 2019), and in more recent years forecasting tools has been developed to both monitor and predict ESBB damage or outbreaks (de Groot & Ogris 2019; de Groot & Ogris 2022; BOKU University 2024). These tools are broadly based on data from remote sensing technologies, ESBB ecology, abiotic factors and previous sanitary fellings due to ESBB. A good example used in practice today in Austria is the bark beetle dashboard (BOKU University 2024). In Sweden, available monitoring tools are based on the development and swarming of ESBB, and risk maps based on information about the forest stand composition and ESBB ecology (Langvall 2022; Swedish Forest Agency 2024b). However, to my knowledge, currently no warning systems combine phenology, abiotic factors, remote sensing data and specific data regarding previous damages and sanitation fellings due to the presence of ESBB in Sweden. The study presented here aims to investigate early warning systems for ESBB in the Swedish forest sector, and to address the attitudes towards implementing an early warning system for ESBB in Sweden.

1.1 Problem background

Norway spruce (*Picea abies* (L.) Karst) is the most common tree species in Swedish plantation forests. The species thrives on soils that are nutrient-rich, influenced by lime and with good water supply. The root system is shallow which makes it sensitive to windfelling. Norway spruce is also sensitive to drought and forest fires (Swedish Forest Agency 2024e). Norway spruce grows well under different climatic conditions and are considered a highly productive species, replacing other tree species in production forests across Europe (Seidl et al. 2011). Due to the potential of high productivity under different climatic conditions combined with an increased demand for timber production with shorter rotation periods, Norway spruce has been planted on sites outside of their natural habitats (Jandl 2020). These stands were either former arable lands, which were afforested with spruce in the 1960s and 70s in Sweden, or stands that are generally dry, typical “pine sites”, in order to limit grazing damages caused by ungulates with a preference for pine over spruce (Johansson 2015; Skogforsk 2022).

ESBB are considered a natural disturbance agent important for ecosystem functioning and forest health, promoting forest succession. The species creates habitats, i.e. dead wood or forest gaps, that are necessary for maintaining high forest biodiversity. However, rising temperatures due to climate change have led to an upsurge in beetle populations, resulting in increasing levels of damage associated with droughts, storms, and other climate-related impacts (Hlasny et al. 2021). The upsurge in beetle populations have lead to huge economic, social and ecological losses in the forests of Europe (Morris et al. 2018).

The damage by bark beetles has an impact on social and recreational values of forests. For example, forest with severe bark beetle outbreaks contain high amounts of standing dead wood, increased number of clear cuts and standing dying trees which can affect tourism, general outdoor life and subsequently human well-being. Bark beetle outbreaks can result in a safety concern that requires special management and planning if the outbreak is located near a hiking trail (Arnberger et al. 2018). As a large proportion of the forests in Europe and Sweden are managed for production purposes, many forest owners have economic incentives for the choice of management strategies (Swedish University of Agricultural Science (SLU) 2023; Hlásny 2021). Sanitary fellings and preventive harvesting of larger areas also impact the international wood markets since they might become saturated because of oversupply, resulting in a reduction in profitability of salvaged wood and leading to declining of prices. Outbreaks also have an impact on ecosystems in through affecting nutrient cycles, microclimate and water quality (Hlásny 2021). Increased harvesting due to outbreaks and more dead trees could increase carbon emissions, which have an impact on the climate (Hlásny 2021).

Monitoring population development prior to and during outbreak phases is important for outbreak and forest management. Variable monitoring methods and tools are used including pheromone traps, ground surveys, trap logs and remote sensing technologies (Ogris et al. 2019). However, monitoring ESBB and detecting infested trees early is challenging. For example, pheromone traps are often set up too late and there is a lack of knowledge regarding how long these traps should be monitored (Ogris et al. 2019). Another example is the challenge of separating bark beetle infestations with other forest disturbances when using remote sensing technologies, which are mostly used to map insect infestation and risk areas (Kautz et al. 2023; Senf et al. 2017). Ground survey methods are frequently used in forestry practices to detect ESBB infestations. It involve searching for early signs of bark beetle colonisation in forms of entrance holes, resin flow from entrance holes, the presence of boring dust and the loss of bark scales. Ground surveys are often time-consuming and insufficient for managing mass outbreaks (Kautz et al. 2023).

To reduce and prevent direct and indirect damage caused by ESBB, early detection is necessary (de Groot & Ogris 2022). Early detection allows for integration of appropriate management methods at the right time to reduce ESBB populations and reduce damage intensity (de Groot & Ogris 2022). Several studies argue that there is a need of a warning system that is able to assess the likelihood of an outbreak in time, provide accurate information about the actual developmental process of the bark beetle population and the number of bark beetle generations per year (Ogris et al. 2019; de Groot & Ogris 2022).

1.2 Future challenges regarding tracking and managing ESBB populations

As described above the consequences of ESBB outbreaks go beyond periodic high tree mortality. Observed and anticipated changes in weather patterns will affect the ESBB population dynamics and might even lead to higher overall (endemic) population levels and associated tree mortality. Hence, the need of a comprehensive monitoring system ideally incorporated in a system to forecast risk of damage has increased. Current monitoring methods are based on in depth knowledge of ESBB ecology which is described in the paragraph below prior to descriptions of different monitoring methods.

1.2.1 Ecology of ESBB

The 8-toothed ESBB (*Ips typographus* L.) is an 5-6 mm long, hairy and brown to black insect that belong to the order Coleoptera and the Curculionidae family (Christiansen 2008; Global Biodiversity Information Facility 2023).

Photo: Göran Liljeberg, https://granbarkborre.slu.se/

The beetle is native to Eurasia. Its geographical range is from the Mediterrean region to Scandinavia, and from Western Europe to East Asia (Jeger et al. 2017; Schebeck et al. 2022). It mainly attacks and colonises weakened and/or dying trees of Norway spruce (*Picea abies*) (Wermelinger 2004). However, at epidemic densities the species will also attack healthy trees. The life cycle of ESBB and its ecology have been studied for many years. The beetle hibernates as a fully developed adult. Most of the beetles hibernates in the top soil close to the tree it emerged from, or under the bark of that tree or another standing tree, felled tree or log closeby (Christiansen 2008; Schroeder 2023). According to Weslien et al. (2023) around 40% of ESBB hibernates under the bark in the southern parts of Sweden. This number decreases in the northern parts of Sweden, which has to do with different winter temperatures. For the beetle to be able to survive the colder winters in northern Sweden, it has to hibernate under the ground where a coat of snow isolates them (Weslien et al. 2023).

Growing degree-days are important measures for the life cycle and biology of ESBB. It is the cumulative temperatures that are required for development above a lower threshold. Depending on the degree-days, forecasts can be made for beetle development, initiation of spring flight, emergence of new generations and re-emergance of parental beetles (Anderbrant 1985; Annila 1969). The most commonly used lower development threshold for beetle development is 5°C (Annila 1969). The beetle are able to start flying during early spring when maximum air temperatures exceeds 16.5°C, which in Fennoscandia may occur in May-June (Christiansen 2008; Fritscher & Schroeder 2022). Depending on temperature during summer, up to three generations of ESBB might be produced. However, in the Fennoscandia region, there is often only one new generation of ESBB each year due to the colder temperatures (Christiansen 2008). The day length also determines how large proportion of new-generation beetles that will be reproductive (Fritscher & Schroeder 2022). In Sweden, ESBB require a lower thermal sum in the north where the climate is colder than in the southern parts, which might be explained by the beetles being more dependent on sun-exposed material or local adaptations (Fritscher & Shroeder 2022).

When flying, the beetles are looking for suitable breeding substrate such windfelled trees, newly harvested trees with bark, logging debris or even living trees. The male adults bore into the tree and creates a chamber in the phloem. The species is polygamous. The females can produce around 100 eggs which she places in galleries that are about 6-15 cm long. There may be as many as 500 galleries per square meter bark surface. The larvae feed under the bark on the phloem. Under suitable conditions, female beetles might leave their host tree to construct new galleries and thereby give rise to sister broods (Christiansen 2008).

The beetles are guided by the host trees volatile when searching for breeding material. When the first males have entered the tree, they attract more beetles of both sexes by emitting tree volatiles. They emit aggregation pheromone which results in more beetles that can attack the tree at the same time. If the number of beetles attacking a tree is large enough, it can overcome even a healthy trees defences. To overcome a healthy trees defences, a "mass attack" is needed, which can happen if there is a lot of breeding material that has helped the population grow big enough to exceed a threshold level, i.e. if there are many windfellings or a long period of drought (Christiansen 2008). The ESBB is also strongly associated with other microorganisms, especially different types of fungi. The most important fungal associates come from the family Ophiostomataceae, which are fungi that causes blue stains to the wood (Christiansen 2008).

1.2.2 Forest management strategies to limit ESBB

Current forest management strategies and methods to tackle ESBB involve processing windfellings and top breakages, harvesting risk areas, debarking with harvester, search and remove attacked trees during the swarming period, and search and remove attacked trees during winter when the beetles are hibernating (Swedish Forest Agency 2024a). Removing infested trees during winter (sanitation logging) can have an impact on ESBB populations. However, it requires that the bark should be both frozen (to reduce the risk of bark falling off and beetles thereby being left in the forest) and contain a high number of hibernating beetles. Sanitation logging during winter periods could also negatively affect populations of natural ESBB predators, such as Medetera (Weslien et al. 2024). In some countries, there is also an option to use insecticides, although it is largely restricted. In Sweden, there are no forestry insecticides that are approved (Swedish Forest Agency 2024g).

Preventive management involves stand structure and composition, and according to de Groot et al. (2018), mixed species stands are suggested. After a disturbance event, it is easy to miss the "less damaged" trees when performing sanitary fellings. Sanitary fellings often focus on the broken trees or windfelled trees which leads to a lot of weakened trees missed that are suitable breeding substrate for ESBB (de Groot et al. 2018). Furthermore, the removal of fallen trees and weakened trees should be completed before the second year after a large disturbance to reduce the risk of ESBB outbreaks (de Groot et al. 2018). Seidl et al. (2016) find that with a landscape-scale management approach, managers could focus on the connectivity between host and beetle populations. Long term management could then involve to focus on stand structure and promote a composition of species that increases diversity to be able to balance bark beetle populations and at the same time avoid negative consequences on biodiversity (Seidl et al. 2016).

Negative consequences on biodiversity can eventually arise when short term management involves removing infested trees or other methods that lead to a reduce in bark beetle populations (Seidl et al. 2016).

1.3 Aim and research questions

The ability to manage either forest conditions or the ESBB population has become more urgent, as observations show an increase in ESBB damage over the recent decades. One tool that could be beneficiary is a comprehensive early warning system to predict and mitigate the impact of ESBB outbreaks. Therefore, the aim of the project is to assess the early warning systems used for spruce bark beetle in Sweden. This aim can be divided into two objectives:

1. Understand the scope of monitoring/early warning systems available in Sweden and how they compare to warning systems available in other European countries.
2. Understand forest practitioners' attitude towards the available methods and development of a comprehensive early warning system.

The aim will be reached by providing a literature overview, an overview of early warning in Sweden in comparison to other European countries and we will use interviews for a qualitative assessment of forest practitioners' attitudes towards early warning.

The research questions are:

Early warning systems

1. Which early warning systems are available for forest companies in Sweden?
2. How do they compare to available systems available in Europe, specifically Austria and Slovenia.

Representatives within the forest sector

1. What are the attitudes of Swedish forest companies towards early warning systems?
    a. Why do they or don't use the available systems?
    b. What determines their trust in the early warning?
    c. What type of system would they use?

2. Method

2.1 Literature study

A literature study was employed to assess the available tools and methods for monitoring and managing ESBB populations, infestations and outbreaks.

2.1.1 Literature search strategy

Information about monitoring tools and models were collected from websites of Swedish organisations and were complemented by scientific research. To find relevant studies, specific key words/sentences was selected during the search. These key words/sentences were: "monitoring *Ips typographus*", "early warning systems for *Ips typographus*", "forecasting *Ips typographus* outbreaks", "outbreaks of *Ips typographus*", and "early warning for *Ips typographus*". ESBB ecology and forestry management methods are important for understanding the function and development of monitoring and forecasting ESBB infestations.

Different web browsers were used during the search, including Google scholar, Primo and Web of science.

2.1.2 Data extraction and analysis

The data collected from websites and scientific literature databases were reviewed and categorised which resulted in themes. These themes are presented in the result section as the different monitoring methods and tools, and the existing early warning systems developed in other countries. Information about ecology and management of ESBB is presented in the indroduction, as it is important for the understanding of the results of this study.

2.2 Semi-structured interviews

The second aim of this study is to understand attitudes for an early warning system for ESBB. To understand attitudes for an early warning system for ESBB, a qualitative approach was employed for this study. For this study, interviews with participants from different forest companies in Sweden was performed. A qualitative approach with interviews will provide a deeper understanding of the perspectives of participants directly affected by the subject, which are valuable for future innovations and solutions (Weddle & Oliveira 2024).

2.2.1 Participant selection

The study was conducted in Sweden where the forest companies were chosen purposely to achieve variation in both geographical location, size and structure of the company and clients. Three forest owner associations were selected: Norra skog, Mellanskog and Södra Skogsägarna; and four private owned forest companies: ATA Timber, Holmen Skog, SCA and Stora Enso; and one state-owned forest company: Sveaskog. The selection of different forest companies contributes to diversity and a larger range of forest owners. The location of their head offices are shown in figure 1. However, their operation areas are larger, but this provides a brief overview about their operational scope. The head office of Stora Enso is actually located in Finland (Stora Enso n.d.).

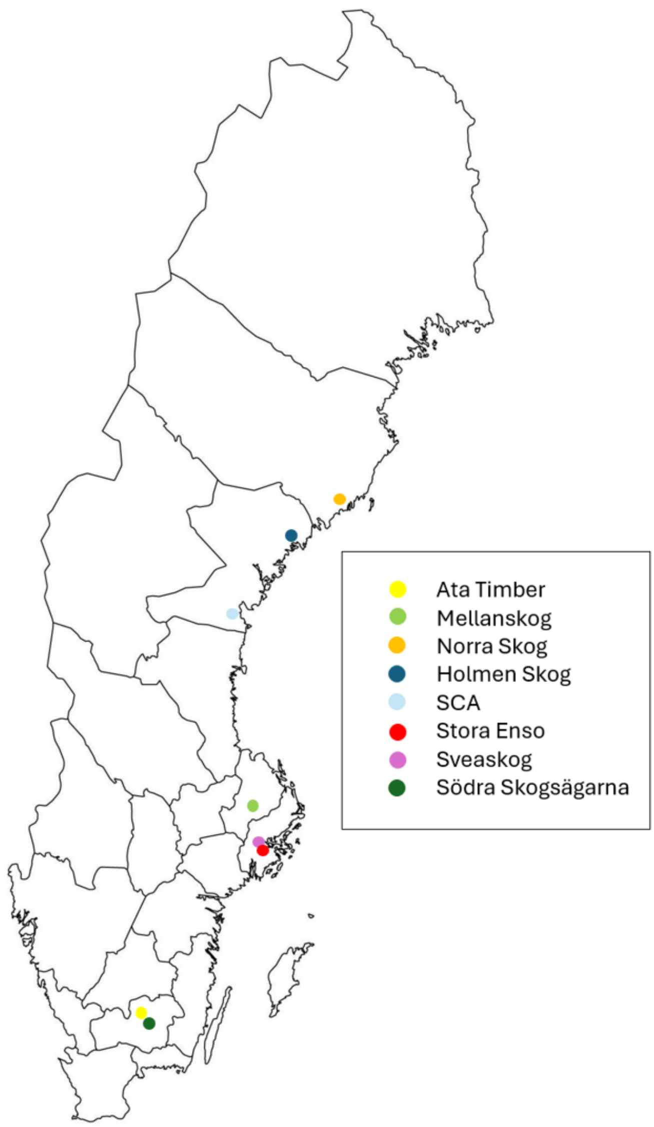

Figure 1. The map shows the locations of the head offices of the forest companies participating in this study

For each company, one interview was conducted with a person that works with ESBB related questions that involves early warning, outbreak monitoring and management. These individuals have a central role in the company regarding forest management and have experience with ESBB outbreaks.

2.2.2 Interview design

Semi-structured interviews were conducted which allowed for flexibility in data collection and ensured rich and informative data (Denzin & Lincoln 2018). Experiences with ESBB monitoring and management, experienced changes in management due to historical ESBB outbreaks and future perspectives were addressed during interviews with the forest companies chosen for this study. The interviews included questions that targeted different themes about current usage of early warning systems, attitudes towards warning systems and the future need of early warning systems (Appendix 1). Questions formulated to respond with simple "yes/no" answers were in general avoided, ensuring more flexibility, open discussions and more rich data.

The interviewees were first contacted through email to ensure that they were willing to participate in the study and meet for an interview. The interviews took place either in person or by a digital video meeting using zoom.

2.2.3 Data analysis

To be able to analyse and process the data, the interviews were recorded and notes where taken during the interview. The time frame during the interviews were approximately one hour. During the analysis process of the data, summaries of each interview where written and specific quotes where marked and later coded into different themes and subthemes. The coding process resulted in two main themes for the results: information use and decision-making on ESBB management, and attitudes towards early warning systems. The subthemes for the first theme were: Monitoring tools; targeted monitoring; management for ESBB and; early warning for ESBB. These subthemes are closely related. For the second theme, the following subthemes were used: credibility; expectations and; challenges. Quotes were chosen and translated from Swedish.

2.2.4 Ethical considerations

Every participant in this study was provided with an information and consent form (Appendix 2) before the interview started. The information and consent form provide information about what the participation entails, including how their data will be collected and used. By signing the form, participants confirm that they understand the provided information and consent to participate in the project.

While companies were explicitly named when direct quotes are presented in the result section, the quotes aim to highlight statements that were reflected by several participants or to illustrate examples to a broader concept. In the discussion, possible variation in attitudes are addressed, but these variations are not meant to be directly linked to specific quotes used in the results.

2.3 Limitations

The literature study focused on studies conducted in Europe to ensure relevance to this study's scope. The literature on early warning systems for ESBB outbreaks in Europe is sparse. When searching for scientific literature, only three web browsers were used. Additional studies from other web browsers may not have been identified. Studies that were not written in English were excluded.

The time frame of this study limited the number of interviews possible to conduct, process and analyse. The time frame allowed for one interview with each forest company chosen for this study. The analysis of the qualitative interviews reflects my interpretation as the author. However, the findings remain rooted in the participants' perspectives and direct statements, ensuring that their voices are authentically represented throughout the study.

3. Results

The first section of the result summarises the findings from the literature study, which answers the first objective. The second objective aims to understand forest practitioners' attitude towards the available methods and the development of a comprehensive early warning system. The second part of the results presents the outcomes of the interviews.

While the literature study provides a theoretical foundation by identifying and summarising available monitoring tools for ESBB management, the interviews give an insight on how these tools are applied or challenged in practice. The interviews provided valuable information about future possibilities and challenges when it comes to ESBB management.

3.1 Literature review of ESBB monitoring tools

The literature review resulted in an overview of ESBB monitoring tools available. The different monitoring tools are presented in the following section and are summarised in table 1. The tools for monitoring ESBB described in the literature study presented below showed that ground surveys, pheromone traps, and a satellite-based program that shows risk index maps are currently available for forest companies in Sweden to use. In Slovenia and Austria, phenology models and early warning systems have been developed that are accessible for forest owners to use (Baier et al. 2007; de Groot & Ogris 2022; BOKU University 2024).

Table 1. Summary of ESBB monitoring tools

Monitoring tool	Type of technology	Function	How it works	Primary users	Sources
Ground surveys	Manual observations	Identifying infested trees	Visual inspection of entrance holes, resin flow, bore dust, peeled bark, loss of needles, changes in needle appearance or/and traces of woodpeckers	Field personnel, forest managers, forest owners	*Skogforsk (2023), The Swedish Forest Agency (2024)*
Pheromone traps	Chemical-based	Monitoring swarming activity and population densities	Emit pheromones to attract and trap beetles	Forest managers, forest owners, researchers	*Weslien (1992), SLU (2020), Langvall (2022)*
Risk maps	GIS-based and remote sensing data	Identifying risk areas for ESBB infestation	Highlight areas with increased vulnerability to bark beetle activity, based on forest health changes	Forest managers, governmental agencies, forest owners	*The Swedish Forest Agency (2024)*
Remote sensing	Satellite programs, drones, aeiral images, hyperspectral sensors, light detection and ranging	Assess forest vitality and detect damage	Detect stress indicators in forest vitality (e.g., discoloration, canopy thinning)	Forest managers, governmental agencies, researchers	*Bozzini et al. (2023), Abdollahnejad et al. (2021)*
Phenology models	Computational models	Predicting swarming periods	Uses climate data and ESBB ecology to estimate development stages.	Researchers, forest managers	*Baier et al. (2007), Ogris et al. (2017), Ogris et al. (2019)*
Early warning systems	Decision-support system	Predicting ESBB emergence, forecast outbreaks	Use computational models (e.g., phenology models) and integrate remote sensing data.	Researchers, forest managers, forest owners	*de Groot & Ogris (2019, 2022), BOKU University (2024)*

3.1.1 Ground surveys

After the drought in 2018 that resulted in mass outbreaks of ESBB in Sweden, the Swedish forest agency started a collaboration project together with a lot of forest companies and other organisations to stop the current outbreak and prevent future outbreaks. The project was called "stoppa borrarna" and was active until the end of 2022. The project helped educate forest owners about ESBB and about forest management regarding ESBB, encouraged inventory of ESBB, and optimised logistics. During this project, companies also started collaborating with monitoring and managing current populations of beetles. Today, this type of work is part of daily forestry practices, with ground surveys conducted on a regular basis (Skogforsk 2023). Many forest companies, as well as the Swedish forest agency, has created guidelines for forest owners and forest workers to search and identify early signs of ESBB presence. These guidelines show what symptoms to look for on the spruce tree at a specific time of the year based on ESBB ecology and are visualised in figure 2 (Skogforsk 2023; Swedish Forest Agency 2024f).

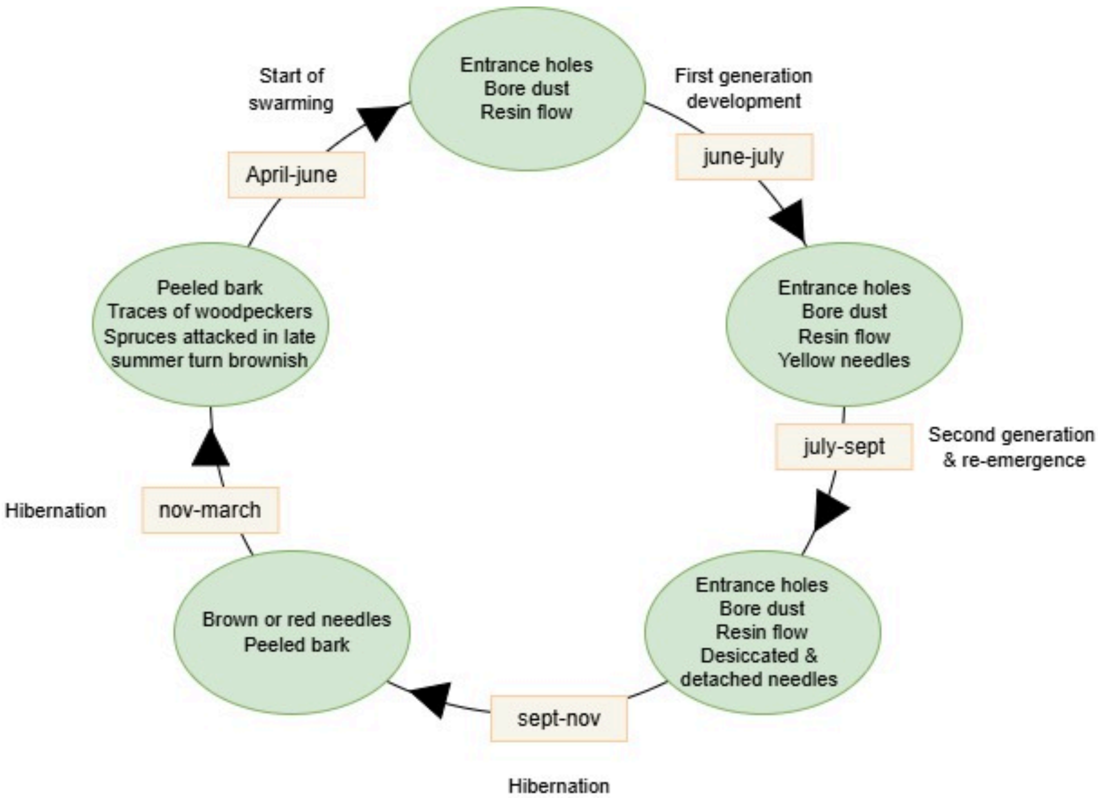

Figure 2. Visual symptoms to identify on ESBB infested trees when performing ground surveys. The figure illustrates what symptoms to look for at a specific month or period based on ESBB ecology

3.1.2 Pheromone trapping

Pheromone traps are often placed on clear-cut areas and near previous ESBB infested areas to attract ESBB. These traps need to be provided with pheromones before the start of swarming in spring (Swedish Forest Agency 2024g).

In Sweden, there is a national wide swarming monitoring where pheromone traps are set up across the country and are emptied every week from the middle of April until the start of September. Based on the start of the swarming that is determined using the pheromone traps combined with local weather data, a forecasting tool has been created. This forecasting tool calculates the timeline for the beetle to start swarming in spring, and when the next generation is developed and ready to swarm (Langvall 2022). The weather data is collected from climate stations that measures air and soil temperatures, humidity, global radiation and precipitation (SLU 2020).

Pheromone traps can also be used as a tool for predicting future population densities by analysing the ratio of catches of first generation beetles to catches in spring (overwintering beetles), which show a correlation with population trends for the following year and can serve as an early warning for future ESBB damages (Faccoli & Stergulc 2006).

Pheromone traps can be used to reduce the ESBB population size. However, the effect on population sizes and tree mortality is limited and there are no pheromone substrates that are allowed in Sweden to be used as a means to control (Weslien 1992; Swedish Forest Agency 2024g).

3.1.3 Risk maps and remote sensing

Remote sensing technologies are often used to collect data using satellites or drones. Satellite programs can provide data with fine spatial and temporal scale (Senf et al. 2017). Satellite data can capture large-scale environmental variables, detecting vegetation health and stress signals (Abdollahnejad et al. 2021). To visualise and analyse data from remote sensing technologies, tools based on geographical information systems (GIS) are often used (Senf et al. 2017). Satellite programs have also been used in studies to predict ESBB outbreaks (Bozzini et al. 2023).

In Sweden, GIS-tools are currently used to help identify where risks of ESBB outbreaks might occur. For example, the Swedish Forest Agency developed together with Metria a map that shows the risk index of a certain area for ESBB outbreaks (Figure 3). This is calculated with risk factors such as timber volume, stand dry lands, clear-cut edges and areas with recorded outbreaks. However, this map shows how attractive a certain area might be for ESBB outbreaks, and does not show the current population of ESBB in certain areas (Metria 2023; Swedish Forest Agency 2024d).

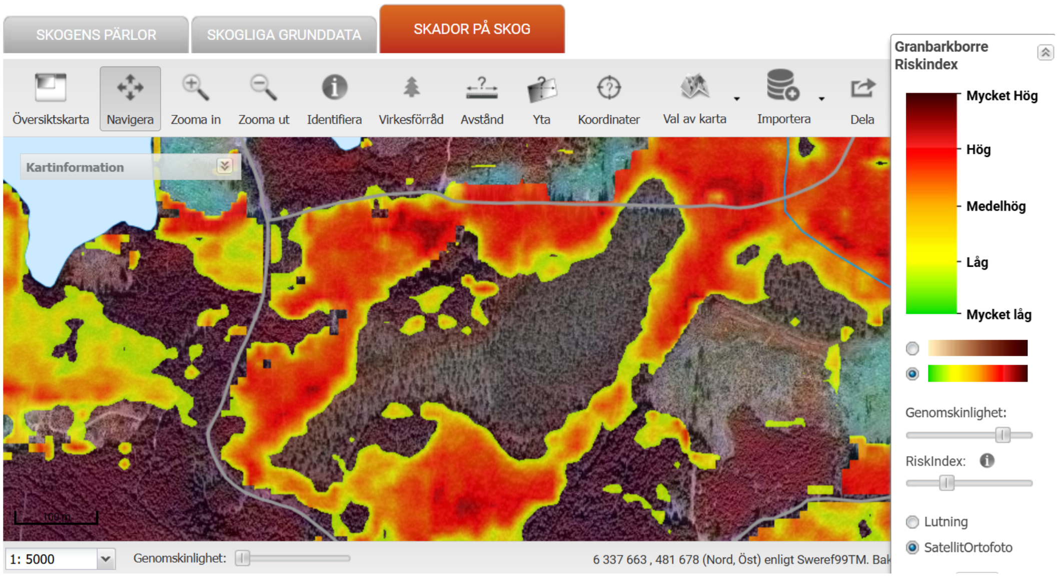

Figure 3. Risk index map by the Swedish Forest Agency. Red areas show high risk of ESBB infestation, yellow areas show medium risk of ESBB infestation, and green areas show low risk. Photo: Swedish Forest Agency [*https://kartor.skogsstyrelsen.se/kartor/?startapp=skador*](https://kartor.skogsstyrelsen.se/kartor/?startapp=skador)

The Swedish Forest Agency have developed a tool for analysing changes in forest vitality, called change analysis (Figure 4). Change analysis is a combination of data from satellites and visualisation of data by GIS. This remote sensing tool can be used to detect ESBB infested areas (Swedish Forest Agency 2024d).

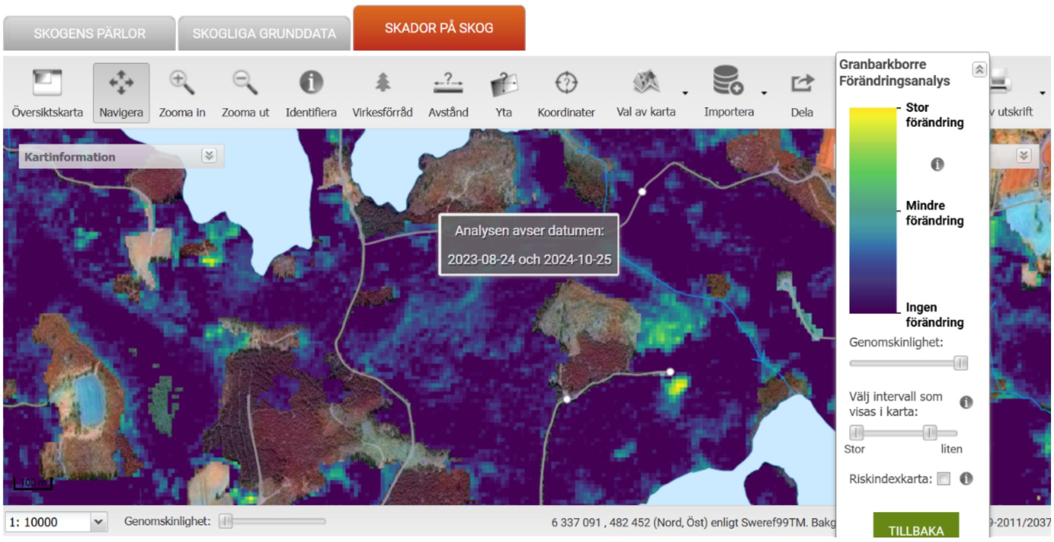

Figure 4. Change analysis tool available at the Swedish Forest Agency. Areas with high changes in forest vitality are yellow, while areas with less change or no change are green to blue. Photo: Swedish Forest Agency [*https://kartor.skogsstyrelsen.se/kartor/?startapp=skador*](https://kartor.skogsstyrelsen.se/kartor/?startapp=skador)

Satellite imagery are used frequently in studies regarding ESBB outbreaks since it makes it possible to cover larger areas, and has proven useful for predicting forest health issues (Senf et al. 2017; Abdollahnejad et al. 2021). However, according to Abdollahnejad et al. (2021), there is a lack of knowledge about analysing ESBB population dynamics via remote sensing. For detecting health status classes, spectral resolution is of high importance (Abdollahnejad et al. 2021).

3.1.4 Phenology modelling

To develop a phenology model for ESBB outbreaks, knowledge about beetle development regarding rate and thermal thresholds are required. A phenology model called PHENIPS was developed in Austria by Baier et al. (2007) that is based on a nonlinear function for calculating effective thermal sums and includes the prediction of swarming in spring, onset of infestation, re-emergence of parent beetles, and the number and emergence time of regular and sister broods. In this study, they used trap trees and pheromone traps to investigate the developmental process. For this model, many parameters were modelled, including topographic parameters (slope, aspect and elevation), solar radiation, air temperature, spring swarming, onset of infestation, bark temperature, and effective thermal sum. For the topographic modelling, a synoptic grid resolution of 300 meters were used. The authors mean that it is challenging to model ESBB since their microclimate is complex to model. Furthermore, the solar radiation might change the bark temperature on sun exposed sites compared to the ambient air temperature. The results of the PHENIPS model could be used to estimate brood development, landscape forecasting, identify vulnerable areas, and study population dynamics of ESBB (Baier et al. 2007). Based on this model, other studies have developed similar models. For example, there has been attempts to implement the model in Slovenia resulting in phenology models called RITY-1 and RITY-2 (Ogris et al. 2017; Ogris et al. 2019).

3.1.5 Forecasting ESBB infestations

A study aimed to develop short-term forecasting models for bark beetle outbreaks was done by de Groot and Ogris (2019) in Slovenia. The study used data from different databases and maps, and was prepared for a grid of 1 x 1 km. The results showed that the amount of sanitary fellings due to ESBB in the previous year is the most important variable. This variable show that there is a temporal density dependent effect that can influence future outbreaks or population dynamics. Since measuring the influence of extreme weather events on ESBB outbreaks is considering challenging and difficult, sanitary fellings are used as a proxy for this impact (de Groot & Ogris 2019). Furthermore, the results of the study showed that the probability of sanitary fellings because of bark beetles increased depending on the amount of Norway spruce, soil base saturation percentage, temperature, amount of sanitary felling in the previous year, number of weakened trees in the previous year and the amount of sanitary felling as a consequence of abiotic factors in the previous year. The study also showed that the probability of sanitary fellings because of bark beetles decreased depending on slope, soil cation exchange and standardise precipitation index.

The same authors have also created a model to predict the amount of sanitary felling of Norway spruce due to ESBB. They found that the best model included the amount of Norway spruce, slope, amount of sanitary felling of spruce in the previous year, amount of sanitary felling because of abiotic factors, standardise precipitation index, temperature, soil depth, soil cation exchange capacity, and soil base saturation percentage (de Groot & Ogris 2022). Other factors also have an impact on bark beetle damage, such as forest structure and species composition, forest management, climate, soil, tree vitality, predisposition to storm, ice and snow damage and phenology. Model input sensitivity, environmental variability or modelling approach can explain some variation of the results in these forecasting models (de Groot & Ogris 2022).

BOKU University and the Austrian Research Centre for Forests are currently involved in a joint project that is called The bark beetle dashboard. The dashboard provides information in several maps with high spatial and temporal resolution which are important for management of ESBB in Austria. The type of information the dashboard provides involve information on the current water supply of forests, the site- and stand-related susceptibility of forests to ESBB infestation and the amount of damaged timber in the past year. The dashboard also shows the daily updated ESBB development status. The development of ESBB shown in the dashboard are based on the ESBB phenology model PHENIPS. Furthermore, the dashboard combines ESBB development and the daily updated drought index that estimate the current water supply of forests to be able to identify times when the dispersal of the ESBB and tree stress coincide. The bark beetle dashboard uses an model called Predisposition Assessment System for estimating the predisposition of forest to ESBB infestation that was adapted to the high-resolution remote sensing data available. The maps have a spatial resolution of 10 meters. Some of the influencing factors that this model takes into account are factors that characterise the susceptibility of the site, for example the possible number of generations of ESBB in recent years. Satellite image data using machine learning algorithms provided maps that show changes of forest structure due to timber utilization, windthrow or ESBB infestation that were used to develop this model for the dashboard. Use of the bark beetle dashboard can help with early detection and sanitation of ESBB infestation, identify hotspots and help with adaptation, decision-support and mitigation strategies (BOKU University 2024).

3.2 Information use and decision-making on ESBB management by Swedish forest companies

All of the participants confirmed in the interviews that their company are actively monitoring the development of ESBB populations and swarming periods. They are monitoring the development of ESBB by using data from pheromone traps, ground surveys and remote sensing. Several companies also use drones to monitor ESBB damage. The data collected from pheromone traps either come from the monitoring network operated by the Swedish Forest Agency or from their own trap network. The pheromone traps detect the start of ESBB swarming, in addition to aiding forest management decision, the trap catches will also increase communications between different actors in the forest supply chain. For example, high trap catches will increase dialogue with transport entrepreneurs to ensure that newly harvested spruce wood is removed from the site quickly, or warn forest owners to keep a closer eye on their forests. This is considered important for the logistics and resources planning and operation in the supply chain, specifically if changes were necessary in order to manage and prevent ESBB outbreaks. ATA Timber expressed the importance in following the development of the pheromone traps *"It is important to act quickly, so having information about swarming periods is crucial"*, which the other participants also echoed as they highlight the importance with timing when it comes to swarming periods and harvesting. However, a lot of pheromone traps have been removed. Södra means that the need for pheromone traps is decreasing as we have more knowledge today about how temperature and other factors affect the population when it comes to, for example, swarming periods, and Mellanskog also adds that pheromone traps does not have a significant effect on the population if used as a method for population control. Furthermore, they will rely on the trap network by the Swedish Forest Agency.

To be able to detect ESBB in time, which most participants refer to as "before the trees go brownish" and "when the beetles are still in the trees", all of the forest companies in this study utilize ground surveys. These ground surveys are performed by employees of the company that visit specific areas and look for bore dust, resin flow and changes in tree vitality. Changes in tree vitality are often observed during drone flights when the needles have shifted colour. Drones can cover larger areas.

New information about potential ESBB attacks often come from direct contact with private forest owners. The three forest owner associations are all describing a close collaboration with their members for information exchange. For example, members receive information about when and where to look for ESBB in their forests, and report back identified areas with damage or infestation symptoms to the forest owner associations. This information exchange is also occurring for several of the other participants as well.

Remote sensing technologies are frequently used for detecting changes in tree vitality. The forest companies in this study were all familiar with the Swedish Forest Agency's tools that can be used for monitoring ESBB. However, some are not using it actively and some have developed their own tool based on satellite data.

3.2.1 Targeted monitoring of ESBB

Areas for ground surveys and drone flights are selected based on stand characteristics, new or previous ESBB presence, and changes in tree vitality shown by remote sensing programs. Some forest companies have a specific application with a GIS tool available where they can mark identified ESBB damages, old or new. This type of planning tool is in some cases also available for forest owners to add information about ESBB presence.

Previous sanitary fellings are often recorded and can be used for selecting areas to perform ground surveys. The exact volume of previous sanitary fellings due to ESBB cannot be confirmed since the entire stand is often harvested when ESBB is detected and the damages are expected to be large. Stora Enso expressed this as *"What we collect is how much we harvest, as well as the drone inventories and change analysis. However, we cannot specify exactly how much bark beetle-damaged timber we have, as we often harvest entire stands."*.

SCA mentioned the use of helicopter flights for different inventory purposes that also could help detect ESBB and select sites for ground surveys. Changes in tree vitality could indicate ESBB attacks and help with selecting relevant sites for ground surveys. The forest companies in this study are using either the change analysis from the Swedish Forest Agency or another remote sensing tool unique to their company. Several participants also mention the involvement of artificial intelligence (AI) to analyse these changes. With AI, the analysing process of identifying ESBB infested areas become more efficient.

Other ways to select areas for ground surveys that were briefly mentioned in some of the interviews was by looking at forestry management plans or stand registers, and thereby identifying older spruce stands, which helps with prioritising of resources.

3.2.2 Management for ESBB

All forest companies in this study are or have been working with "search and remove", where infested trees are detected and removed. Search and remove are both a way of monitoring and managing ESBB since it is a method for keeping the populations of ESBB low and ensure timber quality. However, the forest companies are not removing single trees in a greater extent today since it is not considered resource efficient nor economically motivated to move machines between different locations to harvest single trees. The decision whether to harvest the whole stand or single trees are based on, for example, the extent of damage, how many trees are infested and/or the size of the population of ESBB based on catches in the pheromone traps. Norra Skog expresses this as *"How to respond to damage depends on the extent of the situation. If an entire stand is at risk of failing, the whole stand is harvested rather than just conducting search and remove."*, and Stora Enso exemplifies on what influence decisions *"If the damage is significant enough, we harvest everything. We can't specifically separate how much is damaged by spruce bark beetles. Whether the population is large or not can influence the decisions made."*. These factors are addressing the risk of ESBB spreading.

Processing new windfellings and top breakages are important for managing ESBB. All participants are providing forest owners with information about the importance of detecting windfellings or top breakages during increased risk for ESBB attacks. Information about where to look for new windfellings are part of ESBB preventive management, for example to inspect new edges due to recent clear-cut areas. For employees, use of drones can help identify recently clear-cut areas, which can indicate a location to look for stressed trees or windfellings connected to the area. Several participants mention winter harvest as a complement, mostly if there was not enough time, resources or site related possibilities to manage ESBB damages earlier that year.

All participants highlight the goal of saving timber value. When an ESBB infested area is detected and harvested, the timber should reach the industry as quickly as possible to avoid reduction in wood quality (and to reduce the risk of ESBB spreading). However, historically during ESBB outbreaks, the market became saturated with spruce timber. Today, several companies have different strategies to avoid these outcomes. Sveaskog describes the importance of planning in advance and collaborating with the industry *"We plan ahead for the season to ensure pine quotas are filled on time, allowing focus to shift to spruce. Collaboration with the industry is crucial."*. Other strategies involve mixed assortments and debarking timber to reduce the risk of ESBB if it is not possible to transport it to the industry directly during periods when ESBB are active.

All participants are considering forestry management methods to reduce risk for ESBB. All highlight the importance of site adaptation and planting the right tree species on the right soil. However, Norra Skog means that it is hard to ensure site adaptation in northern conditions where they experience issues with ungulate grazing *"A large moose population and growing populations of ungulates are forcing forest owners to choose something that is not site-adapted."*.

Several participants indicate that we have shorter rotation periods for spruce stands today than earlier, as a precaution to ESBB.

Several participants also experience an increased interest among forest owners to plant exotic tree species such as larch or lodgepole pine.

Other preventive management involve spreading risks, which they refer to as managing and providing mixed forests, fewer thinnings in spruce stands, and informing forest owners about the risks of saving older spruce trees which might require extra surveillance.

Most of the participants have contacts with researchers and have been involved in projects regarding ESBB. Further collaboration with research centres, and knowledge- development and exchange are considered important for future forestry management decisions about ESBB.

3.2.3 Early warning for ESBB

As mentioned above, whole stands are often harvested when ESBB infestation is detected. However, prioritisation and decisions regarding stands for sanitary fellings are often based on data from different monitoring methods. By combining monitoring methods and tools such as monitoring swarming periods, population densities, weather, ground surveys, drone flights, satellite images and direct information from forest owners, with data of previous sanitary fellings and detected infested areas, the forest companies are working with early warning.

Data of previous years sanitary fellings are one way that several of the forest companies in this study uses to estimate how much ESBB infested wood they will harvest. For example, Mellanskog uses fuelwood to make their predictions *"We can extract numbers on previous volumes of fuelwood, and it can often be determined that 90% of it is bark beetle-damaged. Based on that (and swarming statistics), we make a forecast on whether it will increase or decrease".*

Södra explains that a way of getting an overview of ESBB damage is to perform inventories on chosen forest properties across their operating area that are representative of their region when it comes to, for example, tree composition and age structure. These inventories for ESBB are performed during autumn, at least this year "*We (the forest inspector) go over the property and assess the volumes present, while also reviewing whether any damaged forest has been harvested earlier this year. This provides a good overview and allows us to calculate an average across all of Södra's member lands, giving an idea of the volumes and an understanding of where the most significant damage is located*.".

Other examples of how several participants use combined monitoring tools and data are by using the information from pheromone catches and weather, as well as documented data from previous sanitary fellings and use it as preliminary information about what to expect when looking at new satellite imagery. Furthermore, previous ESBB damages are considered one of the best guides for investigating new damages.

Detecting ESBB early is important for all of the participants in this study. They use different monitoring tools, experience and collected data about previous sanitary fellings to make some kinds of predictions. These predictions could involve estimations of how much damages they will have to deal with, where the damages might be located and if the damages will increase or decrease. However, there are no common way in the forest sector to work with early warning and there are no explicit early warning system available with open access. The need of an explicit early warning system is addressed in the section below.

3.3 Attitudes towards early warning systems

As mentioned in the previous section, monitoring and management of ESBB today focus on identifying risk areas, detecting infested areas and remove infested trees in time. The satisfaction of the forest companies in this study with the different tools they are using and combining to monitor ESBB varies. Several participants also mention their attempts with trying new tools. Södra expresses their attempts to finding new solutions to detect ESBB early *"Over the years, we have participated in numerous projects involving satellite data, drone data, and drone flights to capture scent molecules, you name it, but so far, we have not found anything that works in practice, and by that, I mean with early detection. What does work is moving on the ground, looking for bore dust and entry holes, and so on, but it is not particularly efficient when trying to cover large areas."*

Often several methods are used to create an overview of the current situation, for example, ground surveys are complemented by drones, which are complemented by satellite images, and so on. Sveaskog mentions that they experience that the support wanted from these tools in general comes too late in relation to when they need to take necessary management actions *"We have worked extensively with various planning tools to identify damage and changes through remote sensing. My experience is that field staff feel the assistance arrives too late, so they don't feel it has been as helpful as they had hoped."*.

In general, all participants experience a need for an early warning system for ESBB. However, the attitudes and expectations regarding an explicit early warning system for ESBB varied across the participants. This variation will be addressed in this section.

3.3.1 Credibility

According to the participants, the early warning system needs to be easily navigated. This is considered extra important if private forest owners should have access to the system. Several participants mention that it should be based on remote sensing technologies and the possibilities with using AI. The system also needs to be validated through field testing.

Most of the participants suggests that the creators of this kind of system should be researchers or authorities to avoid conflicts of interest and to ensure objectivity, specifically if forest owners would have access to the tool. SCA expresses the topic with the following "*It is easiest to consider it credible if the sender is an organisation like SLU or the Swedish Forest Agency, where there are no apparent interests behind, stating 'you need to go out and harvest your forest now'*", which other participants echoed with similar statements.

3.3.2 Expectations

During previous ESBB outbreaks the participants experienced challenges with the lack of resources for detecting and harvesting infested areas, transporting the harvested wood to the industry, and finding solutions for the overflow of spruce wood that the industry in Sweden could not handle. Today they use a combination of different monitoring tools and their own experiences within the company in order to take actions regarding ESBB management. The idea of an early warning system is to make explicit predictions by using models using data and detect ESBB early.

Several participants mean that an early warning system could help with applying the most appropriate actions at the right time in order to keep populations low and ensure timber value. SCA expresses the possibilities of an early warning system *"The potential is that they could provide an early signal that can be monitored with high precision in both time and space, at the individual tree level—offering greater opportunities to implement the appropriate measures."*.

Other expectations of an early warning system for ESBB are more efficient planning. Several participants mean that it would be beneficial if they know in advance where future damage will occur and to what level of damage it will lead to, since it would give them the possibility to be proactive. Furthermore, several participants lift the possibility of spending less time searching for infested trees, and that an early warning system potentially could help with targeting ground surveys more effectively.

An early warning system might provide information that would be beneficial for planning of resources in a longer perspective. Stora Enso is one of the bigger forest owners and they express this matter as *"It would provide good advance information on what we will be dealing with next fall or summer. It would be an advantage to know what we are up against. [...] what is needed is a forecast saying this is what we need to manage this year*.". Södra also lift the need of better tools for communicating. However, all of the participants expressed some concern with implementing an early warning system. These challenges are addressed below.

3.3.3 Challenges

According to the participants, field visits and harvest site planning are some of the most time-consuming tasks when it comes to ESBB monitoring and management. Several participants argue that even if there was an early warning system available, the field visits are still unavoidable. ATA Timber lifts the question about how much time such a system would gain, and if it those extra days are profitable for the company since there are still the requirements of resources in order to take actions *"It is unclear whether so much time and research need to be spent on predicting where the spruce bark beetle might potentially appear, as one still has to go out and inspect the forest. Sure, an early warning system might detect them a few days earlier, but the question is how much can be gained from those days, considering that it still requires entrepreneurs to be available."*.

Early detection also requires knowledge of inspectors, entrepreneurs and forest owners. Understanding an early warning system, what it means and how it can be used could be challenging. SCA expresses the importance for knowledge in consideration of an early warning system *"You also need to consider expertise, as it raises certain questions, such as: 'What is happening here? How high is the risk that it will continue?"*. Norra Skog and Holmen are also lifting the importance of education and competence development, both within and outside of their organisations.

Several participants are questioning what adverse impacts an early warning system could have on forest owners. Furthermore, they are questioning if it could cause concern and lead to unwanted conflicts. Norra Skog lifts an example *"For example, there have been cases where maps have been sent to forest owners, almost scaring them. If there were an objective system that everyone could rely on, it would make things easier for everyone. Something like, "It's only 10%."*. SCA talks about how an early warning system possibly could indicate increased expectations that more ESBB infested areas could be dealt with, which might not be achievable because of the lack of resources *"A concern is that it raises a lot of expectations that we can manage bark beetles and the damage they cause, even though we may not be able to, and it could also create unnecessary worry."*.

Many of the forest companies in this study have invested time and money in different monitoring tools, including pheromone traps, drones, GIS and remote sensing. Several participants express that they have a way of working with ESBB today that works for them, and that the damages caused by ESBB are currently low. The costs of investing and implementing a new system is thereby highly relevant. Sveaskog expresses this as *"One should probably not rely 100% on such systems, but rather use them as tools. [...] Then, one might ask if it's worth it – a high cost but little assistance, in which case it could be too expensive."*.

All of the participants experience a recent decline in ESBB population and damages, and several participants express that it is a challenge to maintain and develop more knowledge during inter-outbreak periods. Many forest companies and owners have other pests to manage that are considered more urgent. For example, Stora Enso said *"All other types of damage as well – we would really like to have a system to help identify all kinds of forest damage. We need guidance on how to manage our forests in a way that makes them more resistant to such damage. When it comes to bark beetles, we've found a way to handle the damage. It feels a* *bit easier now with the bark beetles, as we're seeing fewer beetles in the traps, and we have an established method that we feel quite confident with."*.

Experienced challenges with other forest pests or other damaging agents are also influenced on where the company is active, geographically.

4. Discussion

The aim of this study was to assess the available monitoring tools and early warning systems for ESBB outbreaks in Sweden. The second aim was to develop an understanding of how these methods are used and to address forest practitioners' attitudes towards the development of a comprehensive early warning system.

From the literature study and the interviews, it is shown that there is no explicit early warning system available for the general public to use to predict and prevent ESBB outbreaks in Sweden. However, the interviews did give insight on how forest companies in Sweden use the current tools for ESBB monitoring to make predictions and take actions for ESBB infestations. These results gave a more realistic and complex picture to the initial research questions, adding to the literature study, and are therefore valuable in themselves. The interviews provide rich understandings on why the forest companies interviewed here have not developed or adopted an explicit early warning system. The forest practitioners' attitudes indicate that while the introduction of an early warning system for ESBB outbreaks is perceived positively, there is some scepticism regarding its actual implementation due to some experienced challenges that were lifted in the interviews. The main challenges identified in the results can be summarised as the following: will the early warning system be profitable?; possibly give rise to unwanted conflicts with forest owners and; if it is a prioritisation for the forest company to invest in a system for ESBB outbreaks when the current risk for ESBB outbreaks is low in comparison to other forest pests. These identified challenges, along with current use of early warning in Swedish forestry practises, and future possibilities are discussed below.

4.1 Early warning for ESBB in Swedish forestry practises

The forest companies in this study were not very familiar with an explicit early warning system for ESBB outbreaks like the ones developed in Austria and Slovenia (i.e. de Groot & Ogris 2022; BOKU University 2024). Only one forest company mentioned their efforts in trying to implement a similar system, but without expected results.

In Sweden, no explicit open access early warning system is available. Although forest companies are using a combination of several tools for ESBB outbreak management, the development of a system combining data from these tools to formulate predictions have not been developed. However, they all monitor ESBB and make implicit predictions based on experience and the results of their monitoring. Decision-making in ESBB management is often experience-based

(Kautz et al. 2023), which the interviews also indicated. Furthermore, they use information from different monitoring tools in combination with accumulated experience with ESBB, such as previous sanitary fellings, observations, knowledge about ESBB ecology or amount of fuelwood harvested in the previous years, to plan, prioritise harversting sites, and take actions. It should be noted that these predictions are used to plan management actions and necessary resources to conduct, for example, ground surveys and targeted harvesting in ESBB infested areas.

There is a gradient in complexity in information use and application from monitoring to early warning to early warning systems, which makes definitions rather fluid. However, the use of an early warning system based on the results of this study, would mostly refer to the possibility to be one step ahead in their yearly planning of production. Since ESBB damaged trees have a lower value in the industry than normal timber, it is important for both forest companies and forest owners to ensure that the infested wood reaches the industry before the damage has decreased the economic value of the wood (Hlásny et al. 2021).

The participants wish to be able to predict the magnitude of damage they will have to manage more accurately. They would like to know how much they can afford to not deal with. One important function of early warning for them is to organise resources in the most effective manner. That would include decisions on prioritisation of infested forest stands at high risk of damages.

4.1.1 Monitoring tools

Monitoring tools such as pheromone traps seems to be a method that all participants use to get an indication of when the swarming starts and the size of the population. Data from pheromone traps are often used to develop models based on ESBB phenology (Baier 2007; Ogris et al. 2019; BOKU University 2024). However, with the cessation of the outbreak, many of the forest companies are removing their traps from their lands and are relying on the Swedish Forest Agency's traps instead. If pheromone traps are not used to track swarming periods, communication between different stakeholders in the forest supply chain becomes even more important so that ESBB attacks can be detected early. Swarming periods indicates when forest practitioners or owners need to be more observant for damages, and when the harvested wood need to leave the site to limit further distribution of ESBB.

The participants conduct ground surveys on a regular basis, which they experience is unavoidable since damages need to be confirmed in the field. Furthermore, selected areas need to be visited in order to plan harvesting actions. Ground surveys are considered time-consuming, yet also considered by the participants as one of the most accurate and most difficult monitoring method to replace (Kautz et a. 2023).

Risk maps and remote sensing technologies are used by most forest companies in this study. However, what remote sensing tools they use and expected results varied.

4.2 Attitudes of an early warning system

All of the participants agree that an explicit early warning system for ESBB could be helpful. However, the attitudes towards an early warning system also indicated that there is some scepticism regarding its actual implementation, which reflects a somewhat contradictory stance. Several factors could contribute to this, for example, local or regional differences in climate, experience with ESBB outbreaks, risk predictions for future ESBB outbreaks, the results/functioning of their current used practices for early warning and ESBB management, costs for investing in this type of system, and if an open access system could raise concerns that could lead to unwanted conflicts. Another possible factor is the current state of the ESBB population and the fact that the forest companies are experiencing low amounts of damages caused by ESBB recently. Investing in and introducing an early warning system for ESBB outbreaks when the risk of outbreaks are low may not be economically motivated, especially when there are other forest pests that are of higher priority for forest management. This could open up for discussion about future possibilities for developing early warning systems for multiple forest pests.

The credibility of a potential early warning system for ESBB outbreaks is important. The creators are preferable researchers or an authority to avoid any conflict of interest.

Some participants express their concerns with the fact that they probably would not be able to harvest all of the infested areas in "the right time" even if they had a system that would warn early, and some mean that a warning signal for ESBB could stress or upset forest owners. The early warning system could indicate that more sanitary harvesting is necessary, and if there is a lack of resources it might become a problem from a forest company perspective. This could possibly give rise to unwanted conflicts. However, it could also help with planning and organising of resources when it comes to identifying ESBB and/or forest harvest. These are both factors that need to be taken into account when implementing this kind of open access system. If an early warning system for ESBB outbreaks was more viewed as a tool for keeping populations of ESBB low during endemic densities, it might be more useful for the forest companies. The system could reduce or replace the use of tools like drones, and limit the time needed to look for ESBB presence in the forests. If the population is constantly kept low by active management, the risk of outbreaks in the future could be reduced in the landscape.

4.3 Future challenges and possibilities

ESBB will remain, and might pose an increased threat to Norway spruce (plantation) forests in the future. New outbreaks can be expected in the foreseeable future (Seidl et al. 2016). Development of an explicit early warning system would be one way to prepare for the threat, in addition to current management practises. Due to its elongated territory, Sweden covers several different climatic zones and daylight regimes. The geographical extend of the forests owned/managed by the forest companies will affect the attitude to the perceived threat of ESBB. At the Northen latitude the threat of large volumes killed by ESBB is significantly lower compared to the Southern latitudes. The participants also mention the trade-offs with management of other types of damage, for example ungulate grazing and other forests pests. These trade-offs are a contributing factor to the increased use of spruce trees in forest plantations, even if the growing conditions are not optimal.

Several of the participants see a current trend in managing their forest with forestry management methods such as continuous-cover forestry. How these management methods could affect the development of ESBB damage in the future is discussed along with random factors that an early warning system might have trouble detecting. ATA Timber addresses concerns with ESBB related consequences related to alternative forestry management methods *"In the long term, there could be issues, especially if spruce is planted on unsuitable soil and because researchers and others predict that it will become warmer. Many people today are focused on selective cutting and continuous-cover forestry, which could potentially promote the development of the spruce bark beetle in the future. Partly because it opens up stands that are not accustomed to sunlight, and partly because it makes them more susceptible to wind damage, leading to more windthrown trees at the edges that attract the beetle. Additionally, it becomes harder to retrieve these windthrown trees as young growth emerges in between".* An early warning system for ESBB would have to take into consideration of random factors, climate change and alternative forestry management methods to clear-cut forestry, which several participants mention as a potential challenge when it comes to the credibility of the system. Future forestry management will have to address mentioned trends about alternative forest management methods, not only at the stand but also at the landscape level. The overall complexity of decision-making regarding ESBB in relation to timber production and the risk of other disturbances necessitates a continued close collaboration between the forest sector and researchers in forest science and application of scientific knowledge in decision-making.

The forest supply chain in Sweden is complex and has many dimensions. Most forest companies are multi-layered organisations designed to address or encounter this complexity. In this study, the participants have a central role in their company regarding forest management and are directly involved in ESBB related questions, but might not work directly with planning of harvesting routes, nor are in direct contact with forestry entrepreneurs or forest owners. This means that there are different levels of decision making when it comes to ESBB related problems and the actual prioritisation of which stands should be harvesting at what time. Therefore, for future research it would be relevant to investigate the details of how decision making around monitoring, control of resources and prioritisation of stands for harvesting is done in practice.

Future research into the development and useability of early warning systems for ESBB outbreaks would benefit from involving more forestry companies and conducting more interviews. Future research could also target methods to measure the costs of implementing an early warning system for ESBB outbreaks, assessing what the forest companies are actually willing to pay for it.

5. Conclusion

There are several ways for forest companies to monitor ESBB outbreaks and to work with early warning, including ground surveys, pheromone trap catches, risk maps, remote sensing and phenology modelling. The results of this study showed that these different monitoring tools are often combined in practice. Based on the information from combining different monitoring tools and own experience with ESBB, forest companies make interpreted predictions and take management actions regarding ESBB infestations. However, limitations in planning and logistics are hampering adequate responses to information gained from monitoring efforts. An explicit early warning system for ESBB infestations could help stakeholders in the forest sector to keep population densities low during endemic periods, save timber value and help forest companies with planning of resources. However, future research is needed to address the challenges with implementing an early warning system for ESBB infestations. To fully understand the feasibility and application of early warning to control ESBB population, future research could also aim at investigating the attitudes of forest company field personal, production operators or forest owners towards an early warning system for ESBB. Especially as the forest supply chain is complex and has many dimensions.

References

Abdollahnejad, A., Panagiotidis, D., Surový, P. & Modlinger, R. (2021). Investigating the Correlation between Multisource Remote Sensing Data for Predicting Potential Spread of Ips typographus L. Spots in Healthy Trees. *Remote sensing (Basel, Switzerland)*, 13 (23), 4953-. https://doi.org/10.3390/rs13234953

Annila, E. (1969). Influence of temperature upon the development and voltinism of Ips typographus L. (Coleoptera, Scolytidae). *Annales zoologici fennici*, 6 (2), 161–208

Anderbrant, O., Schlyter, F. (Lund Univ. (Sweden). Dept. of A.E. & Birgersson, G. (1985). Intraspecific competition affecting parents and offspring in the bark beetle Ips typographus. *Oikos*, 45 (1), 89–98. https://doi.org/10.2307/3565226

Arnberger, A., Ebenberger, M., Schneider, I.E., Cottrell, S., Schlueter, A.C., von Ruschkowski, E., Venette, R.C., Snyder, S.A. & Gobster, P.H. (2018). Visitor Preferences for Visual Changes in Bark Beetle-Impacted Forest Recreation Settings in the United States and Germany. *Environmental management (New York)*, 61 (2), 209–223. https://doi.org/10.1007/s00267-017-0975-4

Baier, P., Pennerstorfer, J. & Schopf, A. (2007). PHENIPS—A comprehensive phenology model of Ips typographus (L.) (Col., Scolytinae) as a tool for hazard rating of bark beetle infestation. *Forest ecology and management*, 249 (3), 171–186. https://doi.org/10.1016/j.foreco.2007.05.020

BOKU University (2024). Release: The Bark Beetle Dashboard. https://boku.ac.at/en/news/newsitem/79397 [2024-10-24].

Bozzini, A., Francini, S., Chirici, G., Battisti, A. & Faccoli M. (2023). Spruce Bark Beetle Outbreak Prediction through Automatic Classification of Sentinel-2 Imagery. *Forests*, 14 (6), 1116-. https://doi.org/10.3390/f14061116

Christiansen, E. (2008). Eurasian Spruce Bark Beetle, Ips typographus Linnaeus (Coleoptera: Curculionidae, Scolytinae). Encyclopedia of Entomology

Denzin, N.K. & Lincoln, Y.S. (2018). *The SAGE handbook of qualitative research*. Fifth edition. Sage.

de Groot, M. & Ogris, N. (2019). Short-term forecasting of bark beetle outbreaks on two economically important conifer tree species. *Forest ecology and management*, 450, 117495-. https://doi.org/10.1016/j.foreco.2019.117495

de Groot, M. & Ogris, N. (2022). Combining an Occurrence Model and a Quantitative Model for the Prediction of the Sanitary Felling of Norway Spruce Because of Bark Beetles. *Forests*, 13 (2), 319-. https://doi.org/10.3390/f13020319

de Groot, M., Ogris, N. & Kobler, A. (2018). The effects of a large-scale ice storm event on the drivers of bark beetle outbreaks and associated management practices. *Forest ecology and management*, 408, 195–201. https://doi.org/10.1016/j.foreco.2017.10.035

Faccoli, M. and Stergulc, F. (2006), A practical method for predicting the short-time trend of bivoltine populations of *Ips typographus* (L.) (Col., Scolytidae). *Journal of*

Applied Entomology, 130: 61-66. https://doi.org/10.1111/j.1439-0418.2005.01019.x

Fritscher, D. & Schroeder, M. (2022). Thermal sum requirements for development and flight initiation of new-generation spruce bark beetles based on seasonal change in cuticular colour of trapped beetles. *Agricultural and forest entomology*, 24 (3), 405–421. https://doi.org/10.1111/afe.12503

Hlásny, T., König, L., Krokene, P., Lindner, M., Montagné-Huck, C., Müller, J., Qin, H., Raffa, K.F., Schelhaas, M.-J., Svoboda, M., Viiri, H. & Seidl, R. (2021). Bark Beetle Outbreaks in Europe: State of Knowledge and Ways Forward for Management. *Current forestry reports*, 7 (3), 138–165. https://doi.org/10.1007/s40725-021-00142-x

Ips typographus (C.Linnaeus, 1758) in GBIF Secretariat (2023). GBIF Backbone Taxonomy. Checklist dataset https://doi.org/10.15468/39omei accessed via GBIF.org on 2024-09-12.

Jeger, M., Bragard, C., Caffier, D., Candresse, T., Chatzivassiliou, E., Dehnen-Schmutz, K., Gilioli, G., Jaques Miret, J.A., MacLeod, A., Navajas Navarro, M., Niere, B., Parnell, S., Potting, R., Rafoss, T., Rossi, V., Urek, G., Van Bruggen, A., Van der Werf, W., West, J., Winter, S., Kertész, V., Aukhojee, M. & Grégoire, J. (2017). Pest categorisation of Ips typographus. *EFSA journal*, 15 (7), e04881-n/a. https://doi.org/10.2903/j.efsa.2017.4881

Johansson, T., Sveriges lantbruksuniversitet & Sveriges lantbruksuniversitet (2015). *Åkergranens stamvolym och virkesutbyte : funktioner för skattning av stamvolym och virkesutbyte hos unga - medelålders granar*. Sveriges lantbruksuniversitet.

Kautz, M., Peter, F.J., Harms, L., Kammen, S. & Delb, H. (2023). Patterns, drivers and detectability of infestation symptoms following attacks by the European spruce bark beetle. *Journal of pest science*, 96 (1), 403–414. https://doi.org/10.1007/s10340-022-01490-8

Metria (2023). *Värmen har väckt granbarkborren – ökar risken för nya stora skogsskador*. https://metria.se/kunskap/varmen-har-vackt-granbarkborren-vilket-okar-risken-for-nya-stora-skogsskador [2024-10-01]

Netherer, S., Schebeck, M., Morgante, G., Rentsch, V. & Kirisits, T. (2022). European Spruce Bark Beetle, Ips typographus (L.) Males Are Attracted to Bark Cores of Drought-Stressed Norway Spruce Trees with Impaired Defenses in Petri Dish Choice Experiments. *Forests*, 13 (4), 537-. https://doi.org/10.3390/f13040537

Ogris, N., Ferlan, M., Hauptman, T., Pavlin, R., Kavčič, A., Jurc, M. & de Groot, M. (2019). RITY – A phenology model of Ips typographus as a tool for optimization of its monitoring. *Ecological modelling*, 410, 108775-. https://doi.org/10.1016/j.ecolmodel.2019.108775

Schebeck, M., Dobart, N., Ragland, G.J., Schopf, A. & Stauffer, C. (2022). Facultative and obligate diapause phenotypes in populations of the European spruce bark beetle Ips typographus. *Journal of pest science*, 95 (2), 889–899. https://doi.org/10.1007/s10340-021-01416-w

Schroeder, M. & Sveriges lantbruksuniversitet. Institutionen för ekologi (2023). *Skyddade områden och granbarkborre : en kunskapssammanställning med fokus på biologi, spridning av angrepp och bekämpning*. Institutionen för ekologi, Sveriges lantbruksuniversitet.

Seidl, R., Schelhaas, M. & Lexer, M.J. (2011). Unraveling the drivers of intensifying forest disturbance regimes in Europe. *Global change biology.*, 17 (9), 2842–2852. https://doi.org/10.1111/j.1365-2486.2011.02452.x

Seidl, R., Müller, J., Hothorn, T., Bässler, C., Heurich, M., Kautz, M. & Kaplan, I. (2016). Small beetle, large-scale drivers: how regional and landscape factors affect outbreaks of the European spruce bark beetle. *The Journal of applied ecology*, 53 (2), 530–540. https://doi.org/10.1111/1365-2664.12540

Senf, C., Seidl, R. & Hostert, P. (2017). Remote sensing of forest insect disturbances: Current state and future directions. *International journal of applied earth observation and geoinformation*, 60, 49–60. https://doi.org/10.1016/j.jag.2017.04.004

Skogforsk (2022). *Skogsskötsel för minskade viltbetesskador.* https://www.skogforsk.se/cd_20221201110152/contentassets/313f8a9aa9714bfbb1dd34c511ba5b3d/skogsskotsel-for-minskade-viltbetesskador--en-handledning-for-viltanpassad-skogsskotsel.pdf [2024-11-06]

Skogforsk (2023). *Nu svärmar granbarkborren.* https://www.skogforsk.se/nyheter--press/nyheter/2023/nu-svarmar-granbarkborren/#:~:text=Skogforsk%20deltog%20i%20skogsbrukets%20projekt%20Stoppa%20borrarna,%20som%20leddes%20av [2024-10-01]

Stora Enso (n.d.). *Kontakta oss.* https://www.storaenso.com/sv-se/contact-us [2025-01-22]

Swedish Forest Agency (2024a). *Bekämpning av granbarkborre.* https://www.skogsstyrelsen.se/bruka-skog/skogsskador/insektsskador/granbarkborre/bekampning-av-granbarkborre/#:~:text=Bek%C3%A4mpning%20av%20granbarkborre%201%20Upparbeta%20vindf%C3%A4llen%20Nedbl%C3%A5sta%20eller,och%20plock%20vinter%20...%206%20%C3%96vriga%20metoder%20 [2024-10-01]

Swedish Forest Agency (2024b). *Granbarkborre.* https://www.skogsstyrelsen.se/granbarkborre#:~:text=Granbarkborren%20%C3%A4r%20den%20insekt%20som%20g%C3%B6r%20mest%20skada%20p%C3%A5%20v%C3%A5ra [2024-10-01]

Swedish Forest Agency (2024c). *Nu svärmar granbarkborren – att ta bort vindfällen kan rädda skog.* https://www.skogsstyrelsen.se/nyhetslista/nu-svarmar-granbarkborren--att-ta-bort-vindfallen-kan-radda-skog/ [2024-09-26]

Swedish Forest Agency (2024d). *Kartor över skador på skog.* https://www.skogsstyrelsen.se/sjalvservice/karttjanster/kartor-over-skador-pa-skog/ [2024-10-01]

Swedish Forest Agency (2024e). *Skogsträd*. https://www.skogsstyrelsen.se/aga-skog/skogstrad/ [2024-11-06]

Swedish Forest Agency (2024f). *Tecken på angrepp av granbarkborre.* https://www.skogsstyrelsen.se/bruka-skog/skogsskador/insektsskador/granbarkborre/tecken-pa-angrepp-av-granbarkborre/ [2025-01-02]

Swedish Forest Agency (2024g). *Övriga bekämpningsmetoder mot granbarkborre.* https://www.skogsstyrelsen.se/bruka-skog/skogsskador/insektsskador/granbarkborre/bekampning-av-granbarkborre/ovriga-bekampningsmetoder/#:~:text=Feromonf%C3%A4llor%20placeras%20p%C3%A5%20hyggen%20och%20st%C3%B6rre%20luckor%20i,f%C3%B6rsedda%20med%20feromon%20innan%20sv%C3%A4rmningens%20start%20p%C3%A5%20v%C3%A5ren. [2025-01-02]

Swedish University of Agricultural Science (2023). *Produktiv skogsmark.* https://www.slu.se/centrumbildningar-och-projekt/riksskogstaxeringen/statistik-om-skog/senaste-statistiken/produktiv-skogsmark/ [2024-11-06]

Weddle, H., & Oliveira, G. (2024). Imagining New Possibilities Through Participatory Qualitative Methods. *International Journal of Qualitative Methods*, *23*. https://doi.org/10.1177/16094069241301983

Wermelinger, B. (2004). Ecology and management of the spruce bark beetle Ips typographus—a review of recent research. Forest ecology and management, 202 (1), 67–82. https://doi.org/10.1016/j.foreco.2004.07.018

Weslien, J. (1992). Effects of mass trapping on Ips typographus (L.) populations. *Journal of applied entomology (1986)*, 114 (3), 228–232. https://doi.org/10.1111/j.1439-0418.1992.tb01120.x

Weslien, J., Rosenberg, O. & Schroeder, M. (2023). *Granbarkborren och dess fiender övervintring i stående träd vintern 2021/2022*

Weslien, J., Öhrn, P., Rosenberg, O. & Schroeder, M. (2024). Effects of sanitation logging in winter on the Eurasian spruce bark beetle and predatory long-legged flies. *Forest ecology and management*, 554, 121665-. https://doi.org/10.1016/j.foreco.2023.121665

Popular science summary

Hur ska vi stoppa granbarkborren? Det är en stor och omdiskuterad fråga inom skogssektorn som fått mycket uppmärksamhet i Sverige och Europa, särskilt efter många år med storskaliga utbrott och ekonomiska förluster. Sedan torkan 2018 har granbarkborren dödat ungefär 34 miljoner kubikmeter gran i Sverige. Utbrotten som kom efter torkan 2018 var starten på ett intensivt arbete mellan skogsföretag, myndigheter och forskare för att rädda granen och stoppa borrarna.

Granbarkborren svärmar på våren när det börjar bli varmt, och då letar de efter försvagade granar att angripa och föröka sig i. Angrepp av granbarkborre leder ofta till att granarna dör och förlorar mycket av sitt ekonomiska värde. Väldigt gynnsamma förhållanden och förutsättningar för granbarkborrarna (exempelvis varma somrar eller stormar som orsakar mycket vindfällen) kan leda till storskaliga utbrott, vilket leder till stora ekonomiska, sociala och ekologiska förluster. Risken för utbrott i framtiden ökar på grund av klimatförändringarna och det finns ett stort behov av att upptäcka angrepp av granbarkborre i ett tidigt skede för att minska skadornas omfattning, förhindra spridning och rädda virkesvärdet på granen.

Syftet med denna studie är att förstå omfattningen av de olika verktyg som används idag för att övervaka granbarkborrens aktivitet och spridning, och att förstå hur svenska skogsföretag använder dessa verktyg samt hur de ser på införandet av ett mer omfattande varningssystem för utbrott av granbarkborre. En litteraturstudie genomfördes för att kartlägga de olika verktygen, och intervjuer genomfördes med åtta olika svenska skogsföretag.

Resultatet av litteraturstudien visade att fältundersökningar, feromonfällor, riskkartor, fjärranalys och fenologiska modeller är vanliga verktyg som används idag. Vidare visade litteraturstudien att forskare i Slovenien och Österrike har utvecklat tidiga varningssystem för utbrott av granbarkborre som finns tillgängliga för skogsägare att använda i dessa länder.

Resultatet av intervjuerna visade att olika verktyg för att övervaka granbarkborrens aktivitet och spridning kombineras med egna erfarenheter av granbarkborren (exempelvis vart granbarkborren orsakat skada tidigare) för att fatta beslut gällande åtgärder för att förebygga och förhindra spridning, och för att planera och organisera resurser, samt för att skapa en uppfattning av skadornas omfattning. Vidare visade resultatet att det på flera sätt kan vara värdefullt med ett tidigt varningssystem för granbarkborre, eftersom det kan bidra till att angrepp upptäcks tidigt vilket ökar chanserna till att virkesvärdet räddas. Det upplevs som positivt om ett tidigt varningssystem kan effektivisera förebyggande planering och ge företagen mer exakta framtidsbedömningar av granbarkborreskador. Enligt respondenterna är det viktigt att ett tidigt varningssystem är trovärdigt och lätt att använda, speciellt om det ska vara tillgängligt för skogsägare.

Det förekommer flera utmaningar med att införa ett sådant system, som exempelvis involverar kostnader för att införa och använda systemet (lönsamhet), andra skogliga skadegörare som för tillfället har högre prioritet än granbarkborren (den nuvarande risken för granbarkborreutbrott anses vara låg), att oavsett tidig varning krävs det fortfarande resurser för att få ut granarna ur skogen vid rätt tidpunkt (återigen lönsamhet och eventuell begränsning av resurser), samt en eventuell negativ påverkan på skogsägare om varninssystemet skapar oro eller leder till oönskade konflikter (exempelvis om avverkning inte är möjlig inom ”rätt tid” för att rädda virkesvärdet). Dessa utmaningar behöver tas i beaktning vid införandet av ett tidigt varningssystem för granbarkborre. Sammanfattningsvis är de svenska skogsföretagen positiva till införandet och utvecklingen av ett tidigt varningssystem för utbrott av granbarkborre, men det finns också en viss skepsis inför det. Denna till synes motsägelsefulla inställning behöver undersökas vidare i framtida forskning eller praktiska tillämpningar. Framtida undersökningar kan med fördel inkludera fler skogsföretag och intervjuer, och/eller andra aktörer som till exempel skogsägare, för att skapa en bättre förståelse för utvecklingen, tillämpningen och införandet av ett tidigt varningssystem.

Appendix 1

Intervjuguide

Med ditt godkännande kommer intervjun att spelas in. Den beräknas ta max en timme. Materialet kommer att raderas efter användning och ditt namn kommer inte att publiceras i arbetet.

Inledning

- Kort information om mig och studien

Inledande frågor

- Berätta lite om dig själv, din arbetsroll och erfarenhet med granbarkborre

Användning av tidiga varningssystem

- Hur arbetar ni med utbrott av granbarkborre?
- Har ert arbetssätt kring granbarkborre förändrats efter tidigare utbrott?
- Samlar ni egen data om granbarkborre?
    - *Hur använder ni den?*
    - *Gör ni egna prognoser?*
    - *Gör ni egna prognoser utifrån någon annan insamlad data?*
- Vilka faktorer/information anser ni vara viktiga för att förhindra/bekämpa utbrott av granbarkborre?
- På vilket sätt påverkar externa faktorer er strategi för att förhindra/bekämpa utbrott?

Attityder och kännedom kring tidiga varningssystem

- Vad har ni för erfarenhet av tidiga varningssystem för utbrott av granbarkborre?
- Vad anser ni att det finns för behov av tidiga varningssystem?
- Vad ser ni för möjligheter och utmaningar med att implementera tidiga varningssystem?

Användning av tidiga varningssystem i framtiden

- Vad är er uppfattning om granbarkborresituationen i framtiden?
    - Vilka resurser behövs för att förhindra utbrott i framtiden?
    - Vad är nödvändigt för att tidiga varningssystem ska anses trovärdiga?

Appendix 2

SLU
Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

Fakulteten för skogsvetenskap/
Institutionen för ekologi

Sara Åsberg
2024-10-23

INFORMATION OCH SAMTYCKESBLANKETT FÖR ATT DELTA I INTERVJU

Examensarbetet Tidiga varningssystem för utbrott av granbarkborre undersöker vilka varningssystem som finns tillgängliga i Sverige, samt hur de används och upplevs av skogsföretag och skogsägare.

Du inbjuds att delta i en intervju som är ungefär 1 timme lång. Med ditt samtycke kommer intervjuerna att spelas in. Inspelningen kommer att raderas efter transkribering. Materialet kommer sedan att användas i examensarbetet som kommer att publiceras. Din underskrift nedan betyder att du väljer att delta i studien och godkänner att SLU behandlar dina personuppgifter i enlighet med gällande dataskyddslagstiftning och lämnad information.

Vår behandling av dina personuppgifter bygger på att dina personuppgifter behandlas med ditt samtycke. Du kan när som helst ta tillbaka samtycket och uppgifterna får då inte bevaras eller behandlas vidare utan annan laglig grund. Du kan ta del av det som registrerats om dig eller ha synpunkter på behandlingen eller de uppgifter som samlats in genom att kontakta: Sara Åsberg (XXX@stud.slu.se) eller handledare Maartje Klapwijk (XXX@slu.se).

Ort / Datum ………………………………… Namnteckning …………………………………

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