Potential of mapping forest damage from remotely sensed data

Kartering av skogsskador från fjärranalysdata

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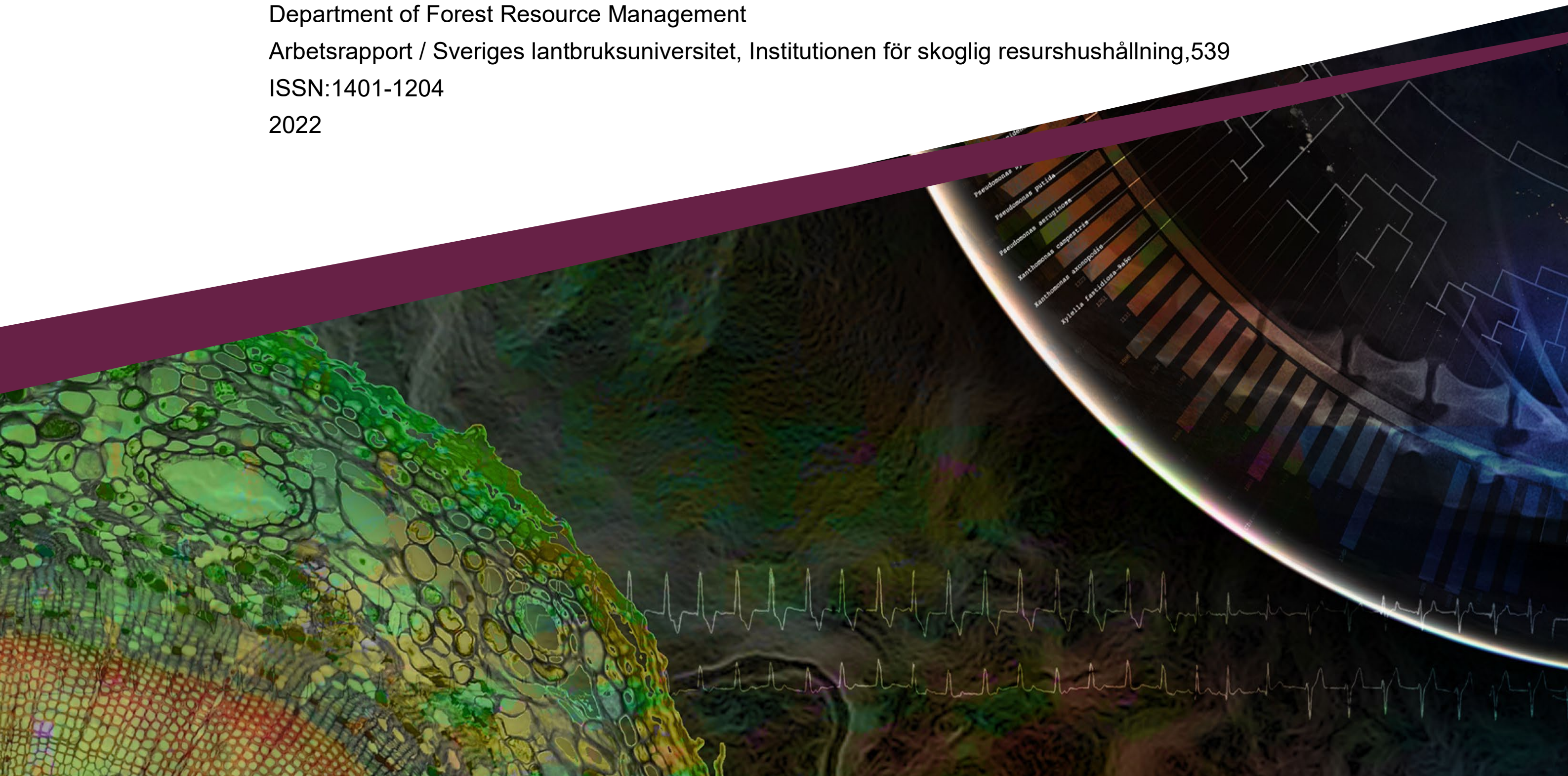

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Abstract

Remote sensing is an efficient tool for mapping, monitoring, and assessing forest damage and the risk of damage. This report presents ongoing research on those topics with preliminary results as well as research planned by the Department of Forest Resource Management, SLU in Umeå, in the near future. The damage types include spruce bark beetle attacks, storm damage, and forest fire. The report also outlines proposed continued research in the area and possible collaborations within and outside SLU.

Keywords: Forest damage, remote sensing, spruce bark beetle attacks, storm damage, forest fire

Sammanfattning

Fjärranalys är ett effektivt verktyg för att inventera och kartera skogsskador och risker för skogsskador. Denna rapport presenterar pågående forskning inom området med preliminära resultat liksom forskning som planeras i närtid vid Institutionen för Skoglig Resurshushållning. Skadorna inkluderar granbarkborreangrepp, stormskador och skogsbrand. Rapport beskriver även förslag till fortsatt forskning inom området samt möjliga samarbeten inom och utanför SLU.

Keywords: Forest damage, remote sensing, spruce bark beetle attacks, storm damage, forest fire

Table of contents

Abbreviations

SLU	Swedish University of Agricultural Sciences
LNU	Linnaeus University
RS	Remote Sensing
SAR	Synthetic Aperture Radar
ALS	Airborne Laser Scanning
NFI	National Forest Inventory

1. Introduction

Remote sensing (RS) is an efficient tool for mapping, monitoring, and assessing forest damage and the risk of damage. The Division of Forest Remote Sensing in the Department of Forest Resource Management, SLU in Umeå, conducts research on RS techniques for mapping and monitoring of forest and vegetation. The mapping and monitoring can result in quantitative estimates, for example, stem volume, or classification into discrete classes, for example, tree species. Time-series of data can provide information also about changes in the forest such as damage and growth. Many platforms can carry sensors for RS. Drones, helicopters, and airplanes are feasible to acquire high-resolution data, for example, laser scanning data and aerial photographs. Satellites, for example, Sentinel-1 and Sentinel-2 provide free radar and optical data, respectively, of low to intermediate spatial resolution (i.e., 10-60 m) and at a high temporal resolution (ESA 2018). This enables fast and easy detection of substantial changes in the forest.

From a RS perspective, forest damage can be divided into mechanical (i.e., abiotic damage), for example, from wind, snow, or fire, and vitality loss and stress (i.e., biotic damage), for example, from drought, insects, or fungi. Mechanical damage can most readily be detected using 3D remote sensing data while vitality loss is more visible in spectral data. In both cases, analysis of time-series data is key. Successful analyses are dependent on accurate reference data (i.e., surveyed occurrences of damage), which may be provided by controlled experiments. This is particularly useful for rare forest damage, since it is otherwise difficult to collect enough reference data in an area covered by an acquisition of RS data. Furthermore, RS-based assessment of typical damage in young forests is more challenging, for example, damage from browsing or fungi, such as Gremmeniella, than damage common in more mature forests. Lack of reference data is a potential limitation for remote sensing of forest damage, which has been addressed in a report to the Forest Damage Center (title: Forest Damage Database – a possibility for remote sensing applications).

This report presents ongoing RS research on analysis of forest damage and risk of damage with preliminary results as well as research planned in the near future.

It also outlines proposed continued research in the area and possible collaborations within and outside SLU.

2. Spruce bark beetle attacks

2.1. Early detection

The spruce bark beetle is the insect that causes most damage to spruce forests in Sweden. To counteract further infestations, it is desirable to find ongoing infestations while the larvae remain in the trees and transport the trees out of the forest to avoid a second swarming (SFA 2021). However, it is difficult to detect the infestations that early because the spruces still have green crowns at that stage (Abdullah et al. 2018). Some types of RS data respond better to the decreased moisture (Hollaus and Vreugdenhil 2019; Ulander et al. 2021) and discoloration than the human vision (Abdullah 2019), thus potentially enabling earlier detection.

The Division of Forest Remote Sensing has developed RS techniques for early detection from three types of data: satellite optical imagery, multispectral photogrammetry from drone images, and radar satellite data. The results have this far revealed the spectral characteristics of the damage before and during the early-stage infestations and been the basis for early detection using Sentinel-2 images (Huo et al. 2021). A controlled experiment was conducted in 2021 at the test site Remningstorp in southern Sweden where ~ 200 infested trees were monitored individually. Our preliminary results suggest that only 15% of the trees showed significantly different spectra during 1 – 5 weeks of infestation, and 87% to 94% of the trees showed significantly different spectra during 10 – 15 weeks of infestation (Huo et al. 2022). In addition, the Department of Space, Earth and Environment at Chalmers University of Technology has built a radar system in collaboration with us that was mounted on a 50 m tall tower at Remningstorp in 2016 (Ulander et al. 2016) to monitor a spruce stand that was later infested by spruce bark beetles in 2018. The continuous monitoring from the radar tower made it possible to efficiently identify the signatures (i.e., reflectively) caused by the spruce bark beetle infestations. In a recent study, the effects of the spruce bark beetle infestations resulted in decreased reflectivity at P-, L- and C-band measurements from the tower (Ulander et al. 2021). The reduction was observed at an earlier stage for lower radar frequencies (P- and L-band), which are more likely sensitive to tree water content.

The results demonstrate the potential for satellite synthetic aperture radar (SAR) to detect spruce bark beetle infestations over large areas with high resolution.

We propose to continue the experiment using drone images that started in 2021 for a longer time period to cover the variations between years and weather conditions. We also propose to explore the potential of hyperspectral images for early detection. If that results in similar conclusions, we propose to discuss the need for early detection with stakeholders and end-users.

2.2. Damage mapping

Methods of wall-to-wall mapping of forest mortality have been developed using RS data, including vegetation indices. Most vegetation indices use ratios of wavelength bands (Friedl 2018). They are designed to maximize sensitivity to vegetation characteristics while minimizing confounding factors such as soil background reflectance, directional, or atmospheric effects (Fang and Liang 2014). However, loss of biomass may be more accurately mapped directly from the spectral values since they are sensitive to shadows, especially in boreal forests where the sun angle is low. Time-series analysis adds the time dimension to the data and focuses on the changing trend of certain objects. The hypothesis is that the beetle attacks have a unique temporal characteristic compared to other forest disturbances, and it could be used to identify spruce bark beetle damage for large-area mapping. The Division of Forest Remote Sensing plans to generate annual infestation maps using our newly proposed vegetation index, NDRS. The maps will cover southern Sweden from 2018-2021. The maps are used for risk analysis related to nature conservation areas in collaboration with the Department of Ecology, SLU in Uppsala. We propose to develop the methodology of using time-series of satellite images further to identify forest areas damaged by spruce bark beetles.

2.3. Risk analysis

Factors influencing the attack probability include soil nutrients (e.g., nitrogen, phosphorus, and magnesium), soil moisture/water supply, the proportion of stand borders exposed to the south and west, the wind exposure, the proportion of trees with heart rot, the age of the stand, the trend in radial growth, and the proportion of spruce. Remote sensing provides large amounts of data and wall-to-wall maps of damaged areas and environmental factors to support risk analysis.

The Division of Forest Remote Sensing is working on risk analysis at individual-tree level. Damage maps will be created from drone images, and the occurrence of infestations will be connected with soil wetness and solar radiations derived from elevation models. Additional environmental factors will be tested, including the distances to the previous infestations, forest gap fraction, and proportion of deciduous trees. We propose to develop such an analysis further in collaboration with the Swedish National Forest Inventory (NFI), the Division of Forest Planning in our department, and the Department of Ecology, SLU in Uppsala.

3. Storm damage

The number of major storms has increased dramatically, and the direction of climate change indicates no tendency for them to decrease. After severe storms, there is an urgent need for rapid assessment of affected areas to direct recovery operations. The Swedish Forestry Act requires that no more than 5 m^3/ha of fresh dead wood is left in the forest after June (SFA 2022) due to the increased risk of insect damage, for example, by spruce bark beetles, which populations can grow rapidly. Still, the most common approach for assessing storm-damaged forests is by manual survey, or after major events by visually outlining damaged areas from a helicopter. Both are obviously time-consuming and inefficient, with a substantial proportion of randomness involved. The primary RS platforms feasible for assessing storm damage are based on aerial platforms (i.e., drones, airplanes) or satellites.

Satellite images are a feasible alternative for rapid wall-to-wall mapping of larger areas. A challenge is the limitation of consistent acquisitions of useful data, where cloud and during the winter also light conditions restrict optical sensors. Synthetic aperture radar (SAR) can overcome such problems, and free alternatives (e.g., Sentinel-1) currently provide data regularly every 6 days of Sweden (ESA 2018). After the storm Gudrun in 2005, data from two SAR satellites were analyzed. It was concluded that the unfavourable frequency band and coarse resolution were limiting successful detections (Ulander et al. 2005). The current stage therefore requires research on how satellite SAR data can best be used for detecting and assessing storm-damaged forests. There is currently no active research in Sweden addressing this topic, largely due to the practical challenges of arranging a proper research setup. There is an urgent need for a thorough field inventory and to collect RS data in an affected area by the next storm.

The main research questions related to using SAR for mapping storm damage involve different processing methods (e.g., backscatter, polarimetry, interferometry), image resolution (about 1-40 m pixels – a balance related to resolution and coverage), and radar wavelength. The wavelength determines what types of storm damage can be detected and which processing methods can be used.

Storm-damaged forest is clearly visible in high-resolution aerial images, although such images are expensive and provide a complex task for automated analyses. The Division of Forest Remote Sensing has developed a new and very promising method to assess the total damaged wood volume in an area using only strip-sampled high-resolution aerial images (Ellingsson 2018). Based on a line intersection survey performed by manual interpretation of the images, the method rapidly provides objective and accurate estimates. Results are expected to be obtained very fast if the approach is applied to drone data. Current research is aiming at developing a new methodology to rapidly assess the total damage levels after a major storm event in very large areas using many drone missions optimally allocated by SAR satellite data.

4. Forest fire

Forest fires are natural hazards and part of the succession of natural forest ecosystems, but are usually limited in managed forests. The intensity and frequency of forest fires have, however, recently increased, thus causing serious consequences for the environment, society, and economy. Last decades both spaceborne and airborne RS platforms with improved instruments (e.g., optical, thermal infrared, and microwave sensors) have been rapidly developed for forest fire research and management (Szpakowski and Jensen 2019). Global coverage and frequent visits of optical and SAR satellites play a crucial role in forest fire monitoring. In addition, laser scanning penetrates the forest canopy and is an efficient tool for assessing fire hazards and fire effects on vegetation with finer scale.

Optical and SAR satellite data are widely used in detection and risk assessment of fires also in the Nordic countries (Milz 2013), but research using RS data in forest fire assessment has been limited. Recent studies have evaluated, for example, regrowth of vegetation after fire using satellite images (Beckius 2018), predicting canopy-fuel parameters using airborne laser scanning (ALS) data and aerial images (Maltamo et al. 2020), and testing methods for wildfire detection with multispectral RS and deep learning (Hu 2021).

Recent studies by the Division of Forest Remote Sensing have been focusing on delineation of fire area and assessment of canopy status in post fire aerial images (Österström 2008), classification of fire severity using both spectral data from satellite and aerial images (Straker 2016) and structural metrics based on photogrammetry and quantifying post-fire fallen trees using bi-temporal ALS data (Bohlin et al. 2017). Other recent work by the division includes: aerial image interpretation of vegetation before and after a fire in Västmanland 2014 (Nilsson et al. 2014), damage assessment using photogrammetry in Västmanland, and testing different forest fire spreading models using RS-based data in fire areas (Burman et al. 2016). We have also tested the use of thermal cameras on drones during a prescribed fire in 2016 (Ljungbergslaboratoriet 2016).

The division has potential to develop methods for characterizing fuel structure, fire effects on vegetation and vegetation recovery based on state-of-the-art RS data.

Rough fuel type maps are available over the whole of Sweden (MSB 2015), which are based on the reclassification of satellite- and ALS-based Swedish land cover map (SEPA 2014), i.e., tree species and soil types. We would like to study if the state-of-the-art RS, such as high-density ALS data and multispectral satellite data combined with accurately collected field data of Swedish fuel types could improve the fuel type mapping. An on-going project in the Department of Forest Ecology and Management, SLU in Umeå, will create new, more accurate classifications of Swedish fuel types based on experimental burnings and expert classifications of forest fuels, which could be used as reference data for new, more accurate RS-based wall-to-wall fuel maps.

Successful forest fire research applying RS benefits from good co-operation with experienced fire researchers and fire ecologist. We have close contact with fire behavior researcher Anders Granström at SLU in Umeå and his contact network in Sweden and abroad, but our network would benefit from growing further for future applications. There is, for example, forest fire research on going at SLU in Alnarp, Lund University and RISE. Further, more collaboration is needed with the Swedish Civil Contingencies Agency (MSB) and the Swedish Forest Agency and industry to improve preparedness and decision support. Our close collaboration with the Division of Forest Planning is also valuable when producing RS-based data and tools for decision making.

5. Modeling and mapping of risk of forest damage

Remote sensing can be used as an efficient tool in risk assessment, i.e., in prediction of risk of damage, which is valuable information for decision making of forest planning. Remote sensing can be used to detect and map the trees, stands and forest areas with highest risk of damage based on the spectral or structural (3D) information. Comprehensive training data (i.e., empirical field measurements or expert knowledge) are usually needed for risk models to link the RS metrics and damage risk. Remote sensing has been widely applied for risk assessment of forest fires (Gabban et al. 2008; Gale et al. 2021; San-Miguel-Ayanz et al. 2003), but recently also studies about risk assessment of storm/wind (Gopalakrishnan et al. 2020; Suvanto et al. 2019) and snow damage of forests (Lehtonen et al. 2021) have gained more focus.

There are only a few published studies about using RS data in assessment of risk of forest damage in the Nordic countries. Existing studies using RS data have mainly been focusing on mapping the risk of forest wind/storm and snow damage in Finland, where also national risk maps have been produced (Suvanto et al. 2019). In Sweden, national risk maps have been created for spruce bark beetles (SFA 2020) and for rough fuel types (MSB 2015) based on a combination of expert knowledge and RS data. Other examples of risks that can be mapped are insect outbreaks, drought, game, flood, and fire.

In addition to mapping risk of damage directly using RS metrics, many RS-based datasets and maps can be used as a basis for risk assessment, such as forest attributes (e.g., stem volume, tree species) and soil wetness. Improving the estimation of those variables would therefore improve the risk assessment of forest damage too. The Swedish Forest Agency base their risk map of spruce bark beetles on a combination of different RS-based datasets, such as tree species from the Swedish Land cover map (SEPA 2014), stem volume from the National forest attribute map (Nilsson et al. 2017), a soil moisture map (Ågren et al. 2021) and border to clear-cuts derived from satellite images.

The Division of Forest Remote Sensing is interested in developing risk maps for wind and snow damage, spruce bark beetle attacks and, for example, improving the mapping of fuel types for assessment of risk of forest fires (see section Forest Fire). These topics are already connected to previous or existing work by the department, but it would be positive to develop and apply RS for risk assessment of any forest damage. One option would be to use the wind and snow damage data from the NFI together with existing RS and weather data to predict the risk of wind and snow damage in forest landscapes. In Finland, similar approaches are applied nationwide based on NFI field plots and satellite data. It is important to test if this approach could be improved by using ALS data, also from two time points, with a combination of other RS-based datasets (i.e., satellite images, forest attribute maps, soil moisture data, etc.). These are steps to create risk maps over the whole of Sweden. In addition, increasing knowledge and availability of training datasets of insect outbreaks would enable mapping of risk areas for, for example, spruce bark beetles more accurately.

Development of methods for modeling and mapping risk of forest damage benefits from a good collaboration both with the experts on different forest damage, but also with the end-users of risk models and maps. It is also important to collaborate with researchers of forest planning to analyze risks and develop tools for risk assessment of forest damage, which can then be used to support decision making in forest planning and in different impact analyses (e.g., the forestry decision support system Heureka). Therefore we have an interest to collaborate with the Division of Forest Planning.

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