Forest Ecology and Management 285 (2012) 29–37

Contents lists available at SciVerse ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

A new invasive insect in Sweden – *Physokermes inopinatus*: Tracing forest damage with satellite based remote sensing

Per-Ola Olsson *, Anna Maria Jönsson, Lars Eklundh

Department of Physical Geography and Ecosystem Science, Lund University, Sölvegatan 12, S-223 62 Lund, Sweden

ARTICLE INFO

Article history:
Received 27 April 2012
Received in revised form 30 July 2012
Accepted 2 August 2012
Available online 6 September 2012

Keywords:
Physokermes inopinatus
Sooty mold
Remote sensing
Forest damage
SPOT
MODIS

ABSTRACT

Forests are important from many perspectives. Forestry delivers products such as timber, fiber and fuel; forests are also important for recreational activities as well as for the global carbon balance. Consequently, it is important to develop methods that enable efficient monitoring of disturbances, such as insect attacks, over vast forested areas. These methods can be based on remote sensing, since satellites provide images with frequent spatial coverage. Insect attacks can be detected in these satellite data if the resulting defoliation or discolouration is sufficiently severe. Satellite data also facilitates monitoring of migration patterns of invasive insects since some sensors provide time series that enables tracing of insect attacks back in time. In this study, SPOT and MODIS data were utilized to map damage in Norway spruce (*Picea abies*) caused by *Physokermes inopinatus*, and the associated black encrustation formed by sooty mold during an attack occurring 2010 in Scania, the southernmost province of Sweden. This attack is the first known presence of *P. inopinatus* in Sweden. The study shows that damage can be detected with high accuracy in satellite data. In SPOT-data, 78% of the damage was detected with an overestimation of 46%. The larger damaged areas could be detected with MODIS 16-days composite NDVI-product with 250 m resolution. In addition, the study indicates that there was damage already in 2009, the year before any damage was detected in field. Prior to 2009 no damage was detected, suggesting that this was the first year of the outbreak. This study documents the outbreak of *P. inopinatus* in S. Sweden and highlights the potential for remote sensing for monitoring and early detection of damage of this invasive insect.

1. Introduction

In late June 2010 the forest manager of Häckeberga estate (lat. 55°5′N, lon. 13°5′E) detected severe defoliation in spruce forests. The Swedish Forest Agency was contacted and a process started to identify the cause of the damage. Finally, in September it was confirmed that the outbreak was caused by *Physokermes inopinatus*, a species previously not present in Sweden. The outbreak caused damage to 1000 ha spruce forests in southern and eastern Scania and salvage cutting was performed on 400 ha (Isacsson, 2010). How and when *P. inopinatus* spread to Sweden is not known; neither are the circumstances that enabled it to initiate the outbreak. However, the event shows that it is important to be prepared for attacks by new invasive insect species, and to have access to methods that enable early detection as well as efficient mapping of the spatial extent of damage. For these reasons this study investigates how remote sensing methods can be utilized to detect and map damage caused by *P. inopinatus* in spruce forests. No other studies of *P. inopinatus* related to remote sensing are known to the authors.

1.1. Hungarian spruce scale

Hungarian spruce scale (*P. inopinatus*, *Hemiptera*: *Coccidae)* is a soft scale that was first recorded in Hungary (Danzig and Kozár, 1973). In Europe, *P. inopinatus* has been found in Hungary (Danzig and Kozár, 1973); Romania (Fetykó et al., 2010); Ukraine (Ben-Dov et al., 2012); Austria and Greece (Stathas and Kozár, 2010). Host plants are Norway spruce (*Picea abies*) and White spruce (*Picea glauca*) (Kosztarab and Kozár, 1988). Postreproductive females are 5–8 mm in diameter, kidney shaped and with a shiny brown color (Kosztarab and Kozár, 1988). Under crowded conditions the size might be as small as 3 mm. The females develop at the base of annual shoots and the base of needles (see Fig. 1-left). The scale completes one generation per year (Stathas and Kozár, 2010). The scale overwinters as 2nd instar nymph and pre-ovipositing females appear during May and June. Eggs are laid from mid-June to early August (Stathas and Kozár, 2010). Egg hatching occurs during July and August. The crawlers normally settle within a meter from their female (Marotta, 1997) but can travel further with the wind (Isacsson, 2010).

P. inopinatus feeds on the sap from the needles causing damage to the host tree (Vranjic, 1997). The feeding also has a secondary effect by producing honeydew that drips over the needles. If the

* Corresponding author.
E-mail address: per-ola.olsson@nateko.lu.se (P.-O. Olsson).

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http://dx.doi.org/10.1016/j.foreco.2012.08.003

Fig. 1. Left is *P. inopinatus* on a spruce branch with a single adult female in the upper left corner; note the round parasitoid emergence hole. Right photograph is sooty mold during an infestation. Left branch is covered by sooty mold, right branch is healthy; both branches are from the same stand and with the same degree of sun exposure. Photo: Gunnar Isacsson, the Swedish Forest Agency.

honeydew is not collected by ants or bees, or washed away by rain, a favorable condition for the growth of sooty mold is created (Isacsson, 2010; Carter, 1973). Sooty mold is a collection name for several fungal species, all of them being saprophytic (Vranjic, 1997); hence, they do not cause any direct harm to the needles. However, the mold creates a black encrustation on the needles (see Fig. 1-right) preventing light from reaching them, eventually leading to the needles being killed by the cover.

1.2. Remote sensing of insect damage in forests

Forest land cover data have traditionally been acquired by interpretation of aerial photography (Cihlar et al., 2003), but in the last decades satellite remote sensing has emerged as the major technique employed for observation of forests (Wulder and Franklin, 2003). Satellite images have lower spatial resolution than aerial photos, but they are superior for monitoring of extensive areas since large areas are covered by the images (Lefsky and Cohen, 2003). Another advantage is that satellites provide frequent coverage, and for some sensors long time-series are available (Lillesand et al., 2004). This availability of time-series with frequent coverage of vast areas is important for damage detection. There is, however, a trade-off between temporal and spatial resolution; images with high temporal resolution have lower spatial resolution. The main advantage with high spatial resolution (0.5–5 m) and medium spatial resolution (5–30 m) is that these data enable detection of damage with higher accuracy, and damage with a smaller spatial extent can be detected. Satellites with lower spatial resolution (250–1000 m) but higher temporal resolution, on the other hand, provide nearly daily coverage which facilitates the study of the dynamics of an insect attack. The area covered by low spatial resolution imagery is also larger which implies that less data and fewer images are needed to cover extensive areas compared to higher spatial resolution data. High temporal resolution and large spatial coverage enable the design of systems for efficient monitoring of damage. It also enables the design of early warning systems that might detect insect attacks in early stages. In this study the performance of both medium and low resolution data are studied.

Another consideration is how to use the reflectance data from the satellites optimally. To enhance the signal from vegetation the wavelength bands most relevant for vegetation studies should be utilized. This is achieved by the use of *vegetation indices* (VI) (McDonald et al., 1998). One major advantage is that VIs normalize external effects in the reflectance data caused for example by different sun angle or atmospheric disturbances (Running et al., 1994). VIs also compensate for effects caused by topography and background variations in reflectance. Many VIs utilize the reflectance in the red and the infrared wavelength bands (Asner et al., 2003). For vegetation the difference in reflectance between these bands is large since vegetation absorbs radiation in the visible part of the spectrum and reflects strongly in the near infrared part. The *Normalized Difference Vegetation Index* (NDVI) (Rouse et al., 1973; Tucker, 1979) utilizes this principle and is computed from the red and near infrared reflectance (McDonald et al., 1998). NDVI is the most commonly used VI (Asner et al., 2003) but it has the disadvantage that it saturates over high biomass forests (Huete et al., 1997). A *Green Normalized Difference Vegetation Index* (GNDVI), where the red band in NDVI is substituted with the green band, has also been suggested (Gitelson et al., 1996). In this study both NDVI and GNDVI are studied.

The technique used to identify damage is also important. When a forest disturbance results in a change in vegetation, such as defoliation or discolouration, the disturbance can be monitored with change detection techniques. There are two main types of change detection techniques: (1) *bi-temporal change detection*, which refers to comparisons between two points on a timescale, and (2) *temporal trajectory analysis*, which refers to analysis on a continuous timescale, such as comparisons of the phenological cycle between growing seasons (Coppin et al., 2004). The most common bi-temporal change detection technique is *univariate image differencing* (Coppin et al., 2004) in which the difference between two images obtained at different times, such as prior to and after an insect outbreak, is analyzed. Temporal trajectory analysis, on the other hand, is based on phenological cycles (Coppin et al., 2004). By studying the time trajectory during several years a "normal" trajectory is defined. When the value in a pixel departs from the normal trajectory it indicates that there is a change. For temporal trajectory analyses data with high temporal resolution must be available. In this study univariate image differencing was applied to medium resolution data and a temporal trajectory analysis was performed on low spatial resolution data.

Remote sensing of forest damage was initiated in the 1980s and several studies based on remote sensing techniques have been performed to detect general forest damage (Vogelmann and Rock, 1988; Ekstrand, 1989; Lambert et al., 1995; Ardö et al., 1997; Price and Jakubauskas, 1998). Many of these studies utilize general damage detection methods that can be applied to more specific damage detection situations, such as insect damage, storm damage or forest fire detection. However, insect damage is more difficult to detect with satellite based remote sensing techniques compared to disturbances such as wild fires and clear-cutting (Hicke and Logan, 2009). The reason for this is that in areas attacked by insects there