Adapting forest health assessments to changing perspectives on threats – a case example from Sweden.

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Abstract A revised Swedish forest health assessment system is presented. The assessment system is composed of several interacting components which target information needs for strategic and operational decision making and accommodate a continuously expanding knowledge base. The main motivation for separating information for strategic and operational decision making is that major damage outbreaks are often scattered throughout the landscape. Generally, large-scale inventories (such as national forest inventories) cannot provide adequate information for mitigation measures. In addition to broad monitoring programs that provide time-series information on known damaging agents and their effects, there is also a need for local and regional inventories adapted to specific damage events. While information for decision making is the major focus of the health assessment system, the system also contributes to expanding the knowledge base of forest conditions. For example, the integrated monitoring programs provide a better understanding of ecological processes linked to forest health. The new health assessment system should be able to respond to the need for quick and reliable information and thus will be an important part of the future monitoring of Swedish forests.

Keywords forest health, monitoring, forest damage, resin-top disease, spruce bark beetle

Introduction

For nearly a century inventories have been used to determine the health condition of forests and the abundance of damaging agents (e.g., Thorell and Östlin 1931; Davidsson et al. 1968; Ciesla and Dounabauer 1994). In Europe, the focus on forest conditions increased during the 1980s and 90s when substantial forest damages were believed to be directly related to air pollution and acid rain (e.g., Schütt and Cowling 1985; Nihlgård 1985). As a result, coordinated monitoring programs were established in 1985 within the framework of the United Nations Economic Commission for Europe (UNECE) International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests) (www.icp-forests.org). This program is included in the Working Group on Effects (WGE) of the Convention on Long-Range Transboundary Air Pollution (CLRTAP) (Lorenz 2005; Sliggers and Kakebeeke 2004). The survey programs, ICP Forests Level I and Level II, have since been the foundation for forest condition monitoring. In the Level I inventory, crown condition and damage assessments are carried out in a sparse systematic transnational sample network (Lorenz 2010). In North America, concerns about the effects of air pollution led to the establishment of the Forest Response Program (FRP) of the National Acid Precipitation Assessment Program (NAPAP) in the US (Loucks 1992; Innes 1993). In Canada, the Acid Rain National Early Warning System (ARNEWS) was initiated, but later replaced by other programs within the Canadian Forest Service (http: // cfs.nrcan.gc.ca).

The effect of long-range air pollution on forest health has been intensively debated since the 1980s. While studies on the role of air pollution on forest health have largely concluded that no clear relationships exist (e.g., Binkley and Högberg 1997), forest damages still cause major problems for society. There are many examples of severe damages to forests (e.g. Manion 1991), such as the mountain pine beetle outbreak in North America (Tkacz et al. 2008) and the oak decline in Europe (Thomas et al. 2002). Damages as a result of extreme weather due to foreseen climate change have also occurred including the severe drought in Europe in 2003 (Rebetez et al. 2006). Further damages resulting from outbreaks of new types of pests and diseases are expected (Allen 2009). Southern pest and disease species may spread northwards or have outbreaks more frequently in a warmer climate. In addition, an increasing number of exotic pests and diseases may establish in new areas, for example the pinewood nematode (*Bursaphelenchus xylophilus*; Mota et al. 1999) and the Diplodia blight caused by *Sphaeropsis sapinea* (Jeger and Pautasso 2008).

In Sweden, several outbreaks of forest pests and diseases have been registered during the last decade. These include spruce bark beetles (*Ips typographus*; Lindelöw and Schroeder 2008), *Gremmeniella abietina* (Wulff et al. 2006), ash dieback (*Chalara fraxinea;* Bakys et al. 2009), and resin-top disease (*Cronartium flaccidum*; described in this article). In most cases, damages at the national level have not been substantial; however, they have had severe local impacts. As a result of sparse monitoring networks, it has been difficult to quantify the magnitude of damages and acquire useful data for mitigation programs. Due to the changing perspectives on forest damages and the anticipated outbreaks of both known and unknown pests and diseases, a new system for forest health monitoring is currently being established in Sweden. The system is being developed from the point of view that forest health information is primarily acquired to support decision making. The decision makers involved range from governmental organizations responsible for mitigation strategies, information, and law enforcement to landowners who try to avoid severe damages (e.g., Davis et al. 2000). Therefore, the forest health information needs to be multi-dimensional. At a strategic level (cf. Barth et al. 2007) there is a need for information to support assessments of general risks for pest and disease outbreaks as well as actual damages due to both biotic and abiotic causes. Based on this information, forest agencies may recommend new silvicultural policies, law enforcement, and additional tailored monitoring schemes. Forest owners may adapt management practices to decrease the risk of pest populations reaching critical levels (Seely et al. 2004). Short-term planning involves decisions for implementation of specific mitigation schemes, such as when a major damage outbreak has occurred or is about to occur due to large pest populations. In these situations, forest agencies may be in charge of implementing coordinated mitigation schemes and the landowners may need to implement more than regular management (Lindelöw and Schroeder 2008). There is a need for detailed information on the specific damage that has occurred, often for limited geographic regions.

In addition to information for decision making, there is a general need for increased knowledge of damage agents and damage-causing factors. This knowledge may also be crucial for successful implementation of mitigation schemes.

The objective of this paper is to describe the revised Swedish system for forest health monitoring, which was developed to meet the needs for both strategic and operational decision making. In addition, we present three case examples to illustrate how the system is implemented.

The revised Swedish health assessment system

The new Swedish forest health assessment system is based on cooperating components which target different needs. The expected outcome will be to provide a broad spectrum of information needed for decision making.

The comprehensive monitoring system is divided into strategic monitoring, operational inventories of forest damages, and research-related monitoring (Figure 1). Strategic monitoring in sparse large-scale networks provides information on long-term changes over time. This trend information allows forestry professionals to be better prepared to adapt to changes in damage patterns. Detected changes may also indicate disturbances that require additional evaluation. An early indication of biotic or abiotic damages and a first assessment of the extent, causes, and consequences may also be obtained through the internet-based reporting and assessment system “SkogsSkada” (www.skogsskada.slu.se). However, tailored regional inventories are sometimes needed to obtain reliable information for operational decision making and to support strategic planning. Through research projects and the intensive monitoring program, the knowledge base continuously expands. The main objective of the intensive monitoring program is to increase the understanding of the abiotic and biotic processes related to forest damages.

Information for strategic-level decision making.

Time series of damages of known abiotic and biotic agents and pest population levels are core concerns involved in strategic-level decision making. For reliable time series, data must be consistent over time and accurate enough so that changes can be correctly assessed. These requirements generally imply the use of probability sampling methods and strict assessment protocols (e.g., Thompson 1992). Trend estimation, which can be applied in regression analysis or in generalized linear models taking into account autocorrelation, requires that the sample sizes are large enough to maintain low levels of sampling error (e.g., Meynard et al. 2007; Hanewinkel et al. 2008).

National Forest Inventories (NFIs) are a primary source of data for national and large area assessments of the state of the forests (McRoberts et al. 2009). The Swedish NFI is designed as a stratified systematic cluster sampling with a combination of permanent and temporary plots (Ranneby et al. 1987, Axelsson et al. 2010). Measurements are carried out annually from early May to mid-October on a sample systematically distributed over the entire country. Information is collected on tree, stand, and site data, as well as observations on damages (Axelsson et al. 2010).

In Sweden, measurements on the ICP Forests Level I plots have been conducted jointly with the NFI (Wulff et al. 2006), but are now completely integrated in the NFI. In 2009, this became part of a new European initiative, Further Development and Implementation of an EU-level Forest Monitoring System (FutMon) (www.futmon.org) under the EU Life+ program. One objective of the FutMon project is to create a new large-scale representative monitoring grid by combining the existing Level I and NFI networks. By merging ICP Forests Level I with the NFI, the leading idea of a common, broader, and larger sample is obtained. A drawback is that the remeasurement interval of NFI plots in Sweden is five years instead of one year; however, the sample is nine times larger, e.g., over a five-year period the NFI sample is about 27 000 plots. However, even with the larger sample size of the NFI, only the rather common and easily detectable damages are meaningfully included (Table 1; additional background information is given in Appendix 1). Data quality plays an important role in interpreting the results and care must be taken so that the damages and damaging agents included are assessed with relevant accuracy (Ferretti et al. 2009). This involves limiting the list of agents to look for and continuous training and testing of the field crews (Ringvall et al. 2005; Wulff 2007). In addition to biotic damages, abiotic damages such as storm damages are included in the NFI. Symptoms and damaging agents used in the NFI are shown in Table 2.

The NFI design makes it difficult to monitor rapid changes, e.g., insect populations during the vegetation period. Also, in order to maintain high-quality assessments there is a limit to the number of damage agents that can be included. Thus, in addition to measurements in the NFI, long-term monitoring of insect populations on separate plots is conducted as part of the Swedish system. Since 1995, monitoring of the spruce bark beetle (*Ips typographus*) has been conducted in four regions. Beetle activity and density is assessed using pheromone traps during the flight period. The same monitoring system has been used in Norway since 1979 (e.g. Ökland and Björnstad 2003). In Sweden, trees killed by the spruce bark beetle are also surveyed on stand edges to assess the relative damage level (Lindelöw and Schroeder 2001).

Case example - spruce bark beetle monitoring

During the 1990s there was a fear of substantial tree mortality due to spruce bark beetle following increases in the bark beetle population. As a result of a new forestry act in 1994, monitoring of the spruce bark beetle (*Ips typographus*) was introduced in 1995. The main objective was to provide annual risk assessments for tree mortality due to bark beetle attacks and provide the Swedish Forest Agency with a tool to apply specific mitigation schemes. The monitoring of the spruce bark beetle is ongoing in eight regions along a climatic gradient known to have experienced considerable tree mortality caused by this insect. This long-term monitoring aims to assess changes in flight onset in spring and cease flight in autumn, occurrence of sister flights, and emergence and flight activity of the new generation (indicating bivoltism). Analysis of trap catches also includes predatory beetles (*Thanasimus* spp.) that are attracted to and caught in the pheromone traps as well. The long-term catches of predator/prey may elucidate the population dynamics of the spruce bark beetle. Thus, in addition to providing information to forestry professionals on beetle activity levels, the monitoring data are used in different research projects for developing population models related to a changing climate and forest structure and management (Jönsson et al. 2009). After the winter storm "Gudrun" in 2005, the monitoring results in spring 2005 indicated a low population level followed by a rapid increase in the subsequent years (Figure 2). The results of the onset and progress of the flight were published on the home page of the Swedish Forest Agency to inform forest owners and forest managers.

Information for operational-level decision making

For operational-level decision making, data collection needs to be adapted to the specific needs of a certain damage mitigation scheme. The first step is to identify locally important pest and disease outbreaks; however, with sparse monitoring networks this is problematic (cf. Table 1). As a result, obtaining reports about where pest and disease outbreaks occur is a core issue. In addition to subjective observations and communication to Forest Agency officers, an internet-based reporting system has been developed where observed damages can be reported (e.g., by Forest Agency officers). The system is named "SkogsSkada" (translation: "ForestDamage") and comprises a damage diagnosis function, fact sheets, records, maps, and up-to-date information about recent damages. Detailed information including photos on approximately 200 species of insects, fungi, and vertebrates, allow users to make a rather accurate diagnosis using the system. The reporting system is easy to access to report observed damages and the results are displayed on maps. Up-to-date information regarding outbreaks, exotic species, and other issues related to forest damages are also provided on this website (www.skogsskada.slu.se).

Once damages are judged to have reached a degree where intervention is required, there is often a need to collect additional information to support specific mitigation decisions. This can be conducted in many different ways. Reports to "SkogSkada" (as well as other reports) allow searches to geographically delimit the area of concern. Specific inventories, tailored to provide information relevant for the specific scheme being elaborated, can thus be directed to the areas where pest or disease outbreaks occur. At this stage, basic information in terms of forest type maps can be utilized in case the damaging agent is known to attack only a certain tree species.

The inventories are developed in close collaboration between the Forest Agency, researchers, and monitoring experts. Currently, the expert knowledge linked to the Swedish NFI is utilized for developing cost-effective inventories of this kind. Flexibility and knowledge capacity for rapid development of robust tailored inventory schemes are crucial in this case, which means it should not directly be connected with the NFI, although the estimates can be a useful supplement to the national inventories. A case example on the inventory of resin-top disease in northern Sweden in 2007 and 2008 is presented below.

Case example - target tailored inventory of resin-top disease

The recent unexpected outbreak of resin-top disease (a rust disease caused by either *Cronartium flaccidum* or *Peridermium pini)* in northern Sweden and Finland seems to be caused by an unusually virulent fungal population since it also frequently attacks young pines. Research in Finland has shown that *C. flaccidum* can occur in northern Fennoscandia as long as a suitable alternative host, in particular *Melampyrum sylvaticum*, exists (Kaitera et al 2005). Recent DNA-studies have shown that the alternate host-dependent form *C. flaccidum* dominates in northeastern Sweden where the damages are more severe (Hansson pers. com)

Scots pine (*Pinus sylvestris*) is the main tree species in the forests of northern Sweden. Severe outbreaks of resin-top disease cause large economic losses due to damages in young pine stands. To meet the demands for information about the occurrence, expected spread, and management practices to decrease damages caused by resin-top disease, a target tailored inventory was carried out.

The inventory was designed as a stratified cluster sampling with clusters of plots randomly located in randomly sampled stands where at least 65 percent of the basal area was made up of Scots pine and Lodgepole pine (*Pinus contorta* Dougl. Ex. Loud. Var. *latifolia* Engelm.) . All living trees with a height exceeding 50 percent of the mean height of the tallest conifers of the stand were included. Infected pines were counted. Each sampled stand was classified according to disease occurrence: (i) infected stand (occurrence of infected pines); or (ii) diseased stand (more than 10 percent of the pine trees infected). The estimator used and the precision of the estimate is described in Appendix 2.

The total area of infected young pine forest in northern Sweden was estimated at 130 000 ha, which corresponds to 34 percent of all young pine stands with mean height one to four meters (Table 3). The area of diseased stands was estimated at 33 000 ha. Diseased and infected stands occurred throughout the surveyed area (Figure 3). The results from the inventory indicate that infection of resin-top disease is more common in stands on rich sites (Figure 3).

As a result of the inventory, forest owners were advised to regenerate with tree species resistant to resin-top disease, such as Norway spruce (*Picea abies* (L.) Karst.) and Russian larch (*Larix sibirica / sukaczewii*) on rich sites. Although no infection was seen in Lodgepole pine, Scots pine trees in mixed stands were affected. Kaitera and Nourteva (2008) recommend Lodgepole pine in areas suffering from severe pine stem rust epidemics, such as resin-top disease and Pine twisting rust. However, Scleroderris canker (*Gremmeniella abietina*) has infected Lodgepole pine on rich sites in harsh areas, i.e., low temperature sum (Karlman et al. 1994); therefore, there is some hesitation to recommend any large-scale regeneration by this species.

Data provision for knowledge expansion

There is a growing demand for further knowledge about forest pests, diseases, and damages, especially to support decision making in forest management. Thus, in addition to the components described above, which focus on providing information for decision making, the monitoring framework also contains parts that target knowledge expansion. The main objective of intensive monitoring of forest ecosystems is to increase the understanding of the abiotic and biotic processes related to forest damages.

Between 1995 and 1997 Sweden established more than 200 ICP Forests Level II plots in managed forest. The aim was to examine correlative relationships between damage-causing factors and effect parameters, e.g., drought and tree growth or nitrogen deposition and insect damages. Approximately 50 of these plots are equipped with deposition and soil water solution collectors and are still intensively monitored, while the sampling intensity for the other 150 plots is very low.

Development of the more research- and process-orientated measurements considers a chain of events including two or more variables and involving a number of compartments in intensive monitoring. This is primarily implemented as activities related to the Integrated Monitoring (IM) program within the Convention on Long-Range Transboundary Air Pollution (CLRTAP) in Sweden.

Case example – Integrated Monitoring

The integrated monitoring of air pollution effects on ecosystems (IM) program is a process-oriented program working on a catchment approach identifying cause-effect relationships (Lundin et al. 2001). The monitoring program includes ecosystem studies at the drainage basin level with assessments of hydrological and chemical budgets, investigations in soil processes, and effects on biota, primarily vegetation. The aims are to collect relevant background data from reference areas that can be used to separate anthropogenic disturbance by air pollution on the ecosystem from natural variation. By model means, calculation of the effects of air pollution would be possible. Such model simulations could also be used for prognoses of the future environmental status.

The IM sites are located in protected areas where there has been little forestry activity for many decades. Atmospheric deposition of pollutants and anthropogenic-induced climate change are the only human disturbances. In Sweden, the programme is carried out on four sites distributed along a north-south gradient corresponding to temperature, climate, and air pollution deposition gradients. At the sites, input from deposition and output by runoff water are determined together with internal processes in vegetation compartments, soil, and groundwater. A total ecosystem approach is implemented. Similar investigations are conducted in over 20 countries and on more than 50 sites in the ECE region within the international IM Programme.

Because the IM programme is carried out in protected forest, the impacts of silviculture cannot be assessed. To provide better scientific information, each IM site in Sweden is combined with two FutMon sites located in managed forests, for a total of 12 sites. Important issues in managed forests include water budgets, turnover of elements in the ecosystem, climate change impacts, and carbon sequestration. Results from the IM activities show that deposition of heavy metals has been high and the current storage in the soils may affect soil biological activity and leaching (Figure 4). Mercury is of special interest as it may be methylized and leached and has substantial deteriorating effects on limnic life. Such conditions have been shown in the IM programme and with soil disturbances during forestry activities the outflows seem to increase. Scenarios including forest harvesting activity have been developed through dynamic modelling.

Discussion and conclusion

Wulff et al. (2006) and Nevalinen et al. (2010) have shown that monitoring networks, such as national forest inventories, have good potential to describe large forest damage outbreaks. However, there are limitations and data from large-scale surveys often provide insufficient information for the management of forests in connection with damage mitigation schemes (Moffat et al. 2008). It is important to understand that monitoring is not limited to data collection, data storage, and evaluation. The monitoring programs should also be conclusive and should provide sufficient information so that to managers can properly implement practices (Ferretti 2009).

Good monitoring programs should provide information to governmental bodies and large forest owners for general long-term policy development, as well as provide a basis for proper management and evaluation of the intended effect of forest management practices (Lovett et al 2007). Huge efforts are put into monitoring forests health; however, in many cases there is a need for a thorough analysis of whether the aims and directions are in accordance with the present and future requirements (e.g. Percy and Ferretti 2003). Accurate, user-specific information is essential. As Moffat et al. (2008) points out in their evaluation of the European forest monitoring program, more efforts should be placed on providing decision makers with appropriate information. The development of the Swedish forest health monitoring system is well in line with these observations.

However, the irregularity in the occurrence of forest pest and disease outbreaks makes it difficult to meet the information requirements when only utilizing large-scale monitoring programs. Therefore, it is questionable whether forest health assessments in sparse plot networks should continue to be the backbone of societal schemes for acquiring information about forest damages. Instead, monitoring activities adapted to different needs combined with research, as in the Swedish model, is proposed as the building block of a better strategy. The Forest Health Monitoring program in the US uses a similar approach to information gathering and following up regulations in different steps (http://fhm.fs.fed.us/fact/index.htm). This is achieved by integrating a nationwide network of forest health plots as a subset of the more extensive national forest inventory (Shawn 2008).

In addition to the long-term monitoring of known biotic damages and their impacts, the target tailored inventories provide information on the less common and irregularly occurring forest pest and diseases, thus facilitating decisions in connection with specific mitigation activities. An effective reporting and diagnostic component is a core part of the system; furthermore, the reporting system has to be simple and easily accessible. Similar systems to the Swedish "SkogsSkada" have been developed in Norway (www.skogoglandskap.no/temaer/skogskader) and Finland (www.metla.fi/metinfo/metsienterveys/index.htm). Detecting future risks and long-term changes is a challenge in terms of international cooperation as a result of differences in assessment methods; however, harmonizing data for more effective collaborative management is a driving force to improved monitoring. Detecting rapid changes in forest conditions requires an early warning system; therefore, cooperation between countries increases the possibility of making accurate decisions.

From an organization point of view, stability as well as flexibility is important. The data provision for strategic decisions needs to be conducted in a stable long-term monitoring environment, which facilitates meaningful interpretation of time series. On the other hand, the data provision for operational decisions must be very flexible and able to quickly adapt to new situations. Also, it must be arranged so that field staff can be engaged with short notice, and thus be employed for similar activities during other times of the year. A solution to this in the Swedish case is to utilize field staff from the NFI on a temporary basis for the operational inventories.

In addition to the information demands for strategic and operational decisions, there is also a need for continuous knowledge development, not least with regards to the new types of damages that may occur due to a changing climate (Tkacz et al. 2008, Percy et al. 2002). In addition, there are many damage symptoms for which the causes are poorly known (Bréda et al 2006).The new strategy proposed to detect and survey outbreaks in Sweden will create a solid foundation and preparedness to respond to the need for up-to-date reliable information. This new system for forest health monitoring is believed to be an important part of future monitoring of Swedish forests. It is likely that pest and diseases outbreaks will continue to occur and for forestry in a changing climate it is important to have systems available that secure long-term sustainable forestry.

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Appendix 1. Required sample for a given precision

We assume that the sample plots within the Swedish NFI would be allocated through simple random sampling (e.g. Gregoire and Valentine 2008). Table 1 shows the number of plots in the Swedish NFI required to provide a certain precision of area estimate within a pest or disease outbreak area, provided that the true area proportion of damages within the outbreak area is five percent. The precision is presented as the coefficient of variation, i.e., the standard error of the estimated proportion divided by the true proportion. (No prior information regarding the location of the outbreak is assumed and thus the sample plot density is assumed to be the same in the entire country.)

The figures in the table are compiled based on the following assumptions:

- The survey is conducted through simple random sampling.

- In reality the number of plots within the outbreak area would be a random number; however, in the calculations we used the expected value of the number of sample plots, which is: $m = \frac{a}{A} * n$. In this formula, *a* is the area of the region within which outbreaks occur, *A* is the area of Sweden, and *n* is the total number of plots in the entire survey.

- The proportion, *p*, damaged forest within the outbreak area was estimated as: $\hat{p} = \sum_{i=1}^{m} I_i / m$; here, *I* is an indicator variable equal to one if a plot is damaged, and zero otherwise.

- The variance of the estimated proportion is: $Var(\hat{p}) = p(1-p)/m$. The coefficient of variation is obtained as the square root of the variance divided by the true proportion and multiplied by 100 for given percentage.

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Appendix 2. Area estimates

Ratio estimation applies auxiliary information to improve the area estimate (Thompson 1992). An estimate of the total infected area was obtained using the stand area in ratio estimation.

$$\widehat{Y}_r = r \cdot A$$

Where, A is the total area of the target region and r the sample ratio

$$r = \frac{\sum_{i=1}^{n} y_i}{\sum_{i=1}^{n} a_i}$$

where, n is the number of plot clusters, a_i is the area of stand I, and y_i is the area of stand i in cases where it was infected, or zero otherwise. The variance estimator was:

$$V\hat{a}r\widehat{Y}_r = A^2 \cdot \frac{n}{\left(\sum_{i=1}^{n} a_i\right)^2} \cdot s^2$$

where,

$$s^2 = \frac{\sum_{i=1}^{n} \left(y_i - r \cdot a_i\right)^2}{(n-1)}$$

The coefficient of variation (CV, %) was derived as

$$CV = \frac{\sqrt{V\hat{a}r(\widehat{Y}_r)}}{\widehat{Y}_r} \times 100$$

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Figure Caption

Fig. 1 An overview of the revised Swedish forest health monitoring system.

Fig. 2 Average number of *Ips typhographus* caught in pheromone traps in four areas in southern Sweden during 1995-2010.

Fig. 3 Infection of Resin-top disease in young pine stands (mean height 1 – 4 m) in northern Sweden. Area divided into rich sites (field layer blueberry, grass, or herb type) and poor sites (field layer lingonberry, other dwarf shrubs, or lichens type). Bars with different letters are significantly separated at the 0.05 level.

Fig. 4 WATBAL modeling of Hg input, output and accumulation in the ICP IM catchment Gammtratten, SE16, north Sweden (Lundin et al., 2008).

Table 1 The minimum number of plots required within the Swedish NFI (assuming simple random sampling of plots with proportional allocation) to obtain a certain precision within an area where outbreaks occur. In this example the true proportion of damaged plots is 5 percent.

Table 2 Damage symptoms and damaging agents included in the Swedish NFI

Table 3 Infection of Resin-top disease in 2008. The area of infected young pine stands (Scots pine; *Pinus sylvestris* and/or Lodgepole pine; *Pinus contorta*) more than 7/10 of the basal area and with a mean height one to four meters in northern Sweden