Jordbruksverket

Strategies for detection and delimitation surveys of the pine wood nematode in Sweden

- It is not possible to design a detection survey that under Nordic conditions ensures an early detection of the pine wood nematode because this would require an unrealistic large number of samples.
- To the current detection survey, i.e. sampling on clear-cuts of logging residues colonized by Monochamus beetles, surveys in areas close to the sources of possible introductions should be added.
- The maximum infested area when eradication is still an option should be defined in the coming Swedish contingency plan.

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Foreword

The Swedish Board of Agriculture is as the Swedish Plant Health Authority currently developing its capability for handling detection of plant pests and pathogens that are new for the country and may cause severe damages if established. One example of such a pest is the Pine Wood Nematode Bursaphelenchus xylophilus, that may cause damages to Swedish pine forests if established and impacts on trade of wood products. Thus, a specific contingency plan should be prepared for handling such a situation.

The specific requirements for control of an outbreak of the Pine Wood Nematode in the EU are defined in Commission Decision 2006/133/EC, currently under revision. This Commission Decision also includes requirements for all EU Member States to carry out surveys in order to detect occurrence of Pine Wood Nematode as early as possible after an introduction with the aim of increasing the probability of a successful eradication.

The specific regulations of the Commission Decision is to a large extent based on the recommendations given by EPPO in the EPPO standards on Phytosanitary measures, Bursaphelenchus xylophilus and its vectors: procedures for official control and on National regulatory control systems, PM 9/1. Guidance for planning and performing detection and delimitation surveys are also given by EU Pine wood Nematode Survey Protocol from 2009.

In order to further develop strategies for detection and delimitation surveys of the PWN in Sweden, where we primarily expect a non-symptomatic occurrence, a specific project was set up. The project was financed by the Swedish Civil Contingencies Agency. This report includes the result of the project. In agreement with the Department of Ecology at the Swedish University of Agricultural Sciences, that was contracted for the project, was decided that the report should be written in English and with a summary in Swedish.

Martin Schroeder professor at the Department of Ecology at the Swedish University of Agricultural Sciences, Uppsala, has written this report and is responsible for the content.

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Cover photo: Martin Schroeder.

Male of *Monochamus galloprovincialis* on bransch of Scots pine (*Pinus sylvestris*). *Monochamus galloprovincialis* is the vector of the pine wood nematode in Portugal.

Hane av kronbock (*Monochamus galloprovincialis*) på tallkvist (*Pinus sylvestris*). Kronbock är vektor för tallvedsnematoden i Portugal.

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Summary

The pine wood nematode, Bursaphelenchus xylophilus, is a serious forest pest in Asia and recently also in Portugal. The risk for establishments in other European countries has been concluded to be high. An establishment in Sweden could result in large economic losses for forestry and also influence other values (e.g. biodiversity and recreation).The aims of the report are to: (1) evaluate and improve the ongoing survey aimed at detecting the pine wood nematode if present in Swedish forest and (2) develop a survey for delimiting the infested area if detected in Swedish forest. If we assume that an establishment of the pine wood nematode in Sweden will not cause symptoms in infested pine trees it is not possible to develop a survey that ensures early detection. This means that if it is detected it has most probably already been established for a long time and thus also already spread over a too large area for eradication to be a possibility. If early detection is the main aim of the survey one possibility could be to direct the ongoing survey more towards industrial areas or other locations to which much material is imported. It is also important to further increase the knowledge about commodities and trade routes that may pose a risk for introductions of the pine wood nematode. Also the delimitation survey (aimed at delimiting the area infested by the pine wood nematode after an introduction) suffers from the problem of a low probability of detection of infested substrates if the surveyed area is too large. One way of reducing this problem is to reduce the surveyed area to an area somewhat larger than the maximum area of eradication. This strategy requires that such a maximum area of eradication is determined in the contingency plan for the pine wood nematode.

Contents

1. Objectives of the report

The pine wood nematode (PWN), *Bursaphelenchus xylophilus*, is a serious forest pest in Asia and recently also in Portugal. A pest risk analysis conducted by EPPO concludes that the risk for entry of PWN is high (EPPO 2009a, b). An establishment in Sweden could result in economic losses for forestry and also negatively affect biodiversity and recreational values (Jordbruksverket 2008). Thus, a contingency plan in case of an introduction will be established by the Swedish Board of Agriculture in a near future (examples of measures presented by Jordbruksverket 2008, Skogforsk 2010). The objectives of the present report are: (1) to evaluate and suggest improvements of the ongoing Swedish detection survey for PWN and (2) to develop a delimitation survey for PWN, suitable for Swedish conditions, in case of an introduction. In the report I primarily assume that if PWN is established in Sweden it will be asymptomatic (i.e. that an establishment of PWN in Sweden will not result in pine wilt disease symptoms). This means that detection and delimitation surveys cannot primarily be based on sampling of trees with symptoms. The aim of the report is to discuss which principles that should guide the design of the surveys and not to give definite numbers of samples required. Important gaps of knowledge are also identified. The suggested survey procedures follow the general outlines of FAO-IPPC for surveillance (IPPC 1997) and determination of pest status in an area (IPPC 1998).

2. Conclusions

If we assume that PWN in Sweden is asymptomatic, i.e. pine wilt disease (PWD) does not develop, it is not possible to design a detection survey that ensures an early detection because this would require an unrealistic large number of samples. Thus, if PWN is discovered by the current detection survey it will most probably already have been present in Sweden for several years and thus will also be distributed over a far too large area for eradication to be an option.

The only situation when the detection survey may result in an early detection is if there is specific information about a very recent possible introduction which could be used for planning the geographic location of the detection survey. Thus, it is important to develop methods for acquiring such information as efficiently as possible, including an intensive sampling of imported material like e.g. wood packaging material imported from risk countries. But still, such an approach will never end up in a foolproof system detecting every possible introduction of PWN.

If early detection is the major aim of the detection survey it should be considered to add or even replace the current survey (i.e. sampling of *Monochamus*-colonized logging residues on clear-cuts) with a survey in urban and industrial areas where introductions of PWN are most probable. Such a survey should be directed towards Scots pine trees showing symptoms that could indicate PWD and could also include trapping of *Monochamus* beetles with odor-baited traps. The disadvantage of this strategy is that we do not know for sure that PWN in Sweden will result in PWD-symptoms, that there are many such urban and industrial areas where an introduction could take place and that the populations of *Monochamus* beetles may be low in such areas.

Also the delimitation survey, following a detection of PWN, faces the problem of a low probability of detection if the sampled area is too big. One way of addressing this problem is to plan the sampling based on the maximum PWN-infested area when eradication is still an option. This strategy will restrict the delimitation survey to this maximum area of eradication plus an extra buffer zone. If PWN is found in the buffer zone eradication is not an option. The risk with this approach is that PWN still may be present outside the buffer zone even though it is not recorded in the buffer zone.

Decision makers may determine a required statistical confidence level with which the delimitation survey should demonstrate absence of PWN in the buffer zone outside the area of eradication. They may also consider if an eradication attempt at all should be launched considering the uncertainty if PWN already is established outside the delimited area.

If the delimitation survey demonstrates that PWN is already distributed over a too large area for eradication to be an option it may still be of interest to delimit the infested area (containment). But such a delimitation survey, which will include large areas, faces the same problem as described for the detection survey above (i.e. a low probability of detection of all infested areas). Thus, there should be strong arguments for starting such a survey.

3. Introduction

3.1 Pine wood nematode and Monochamus beetles

PWN is the causal agent of pine wilt disease (PWD), a serious threat to native pine forests in eastern Asia and Europe (Mamiya 1988, Dwinell 1997, Togashi & Shigesada 2006). The nematode is indigenous to North America where it is never a primary pathogen of native pines. PWN is vectored between host trees by cerambycid beetles of the genus *Monochamus* (Linit 1988, Mamiya 1988). The beetles and nematodes develop within the wood of conifer trees. Dispersal juveniles of PWN move into the respiratory system of the beetles before they emerge. After emergence the adult beetles feed on bark on living conifers. The nematodes leave the beetles and may enter the living trees via the feeding wounds made by the beetles. If it is a susceptible pine species, and the number of transmitted nematodes exceeds a threshold and climatic conditions are suitable, PWD will develop which generally will result in tree death. After feeding, the beetles are attracted to dying or recently cut trees where they mate. The female beetle excavates egg pits in the bark, in which the eggs are laid, and through which the nematodes may infest the wood. In North America, where PWN does not kill native trees, PWN reproduces in cut trees or trees dying for other reasons than PWD. In such a situation (saprophytic life cycle) living trees generally represent a dead end for PWN because no *Monochamus* beetles will be able to colonize them (as long as the trees are healthy) and thus there will be no vector to transport the nematode to new host substrates. In contrast, in areas where the nematode is able to kill large number of trees (e.g. Japan, China and Portugal) the beetles, and PWN, primarily reproduce in trees killed by PWN. A general description of the PWN-*Monochamus* system in Swedish is available in Schroeder & Magnusson (1989).

3.2 History of pine wood nematode in Europe and Sweden

In 1984 PWN was detected by the Finnish Plant Quarantine Service in wood chips imported from North America (Rautapää 1986). As a result, import of untreated conifer wood to Europe from areas infested by PWN was banned. In 1999 the occurrence of PWN was notified by the Portuguese plant health authority. Since then the PWN has spread to large parts of Portugal and has killed large numbers of pines. As a result of the establishment in Portugal, yearly PWN-surveys in the forest, and of imported wooden packaging material, have been conducted in Sweden since 2000. So far more than 3000 samples from the Swedish forest have been processed and all have been negative (Swedish Board of Agriculture 2010). In contrast, PWN has been intercepted at several occasions in wood packaging material imported to Sweden. In 2008, PWN was detected in one dead tree in Spain (Extremadura region), close to the Portuguese border. In the same year live PWN was also found in 13 cases (out of 160 samples) in wood packaging material coming from Portugal to Sweden (despite the rules for treatment of wood from Portugal) (Swedish Board of Agriculture 2008). In 2009 PWN was also recorded to occur in Madeira, Portugal (European Commission 2010). In 2010, PWN was recorded again in Spain (Galician region) in one tree close to the Portuguese border (EPPO 2010b).

4. *Monochamus* species in Sweden

4.1 Species

Only species of the cerambycid genus *Monochamus* have been demonstrated to function as vectors of PWN (Linit 1988, Mamiya 1988). In Sweden we have three native species of *Monochamus*: *M. sutor* L., *M. galloprovincialis* Olivier and *M. urussovii* (Fischer von Waldheim). The *M. galloprovincialis* of northern Europe are described as a separate race (*M. galloprovincialis pistor*; black legs and antenna) compared with the *M. galloprovincialis* of central and southern Europe (the nominate race *M. galloprovincialis galloprovincialis*; red-brown legs and antenna). The biology of the three species in Sweden is described in Ehnström & Axelsson (2002) and Ehnström & Holmer (2007). *Monochamus sutor* is distributed all over Sweden and common in many regions, especially from the province of Dalarna and further north. *Monochamus galloprovincialis* is rare but locally not uncommon in the southeastern coastal areas of Sweden. The species is recorded from most parts of Sweden but many of the inland records may instead have been *M. sutor* because it is hard to discern the two species based on morphological characters (except for genitalia). Thus, the distribution of *M. galloprovincialis* is still unclear and needs to be clarified. *Monochamus urussovii* is a rare species which in recent time only have been recorded from a few localities in the provinces of Ångermanland and Norrbotten in Northern Sweden. Historical records exist from several provinces. *Monochamus urussovii* is included in the Swedish red list (Gärdenfors 2010).

4.2 Breeding substrate

All three species reproduce in newly dead conifer wood: *M. sutor* in both Norway spruce (*Picea abies* L. (Karst.)) and Scots pine (*Pinus sylvestris* L.), *M. gallo-provincialis* in Scots pine and *M. urussovii* in Norway spruce. *Monochamus sutor* prefers sun-exposed breeding material (Trägårdh 1929, Schroeder & Lindelöw 2003). Thus, in Sweden the major source of breeding material is constituted by logging residues on clear-cuts like tops of Norway spruce and Scots pine, and branches of Scots pine. It is generally not found on dead standing trees with the exception of burned trees, which generally are heavily colonized, or high stumps on clear-cuts (Trägårdh 1929, Schroeder et al. 1999). *Monochamus sutor* seems to be a species that are adapted to disturbances like forest fires and storm-fellings. In contrast, *M. urussovii* has mainly been recorded within old-growth spruce stands (Ehnström & Axelsson 2002). *Monochamus galloprovincialis* generally attacks branches on dead or dying Scots pine trees in sun-exposed pine forest (e.g., on sandy soils or on rocky grounds) (Ehnström & Axelsson 2002) but have also been found in logging residue on clear-cuts (Magnusson & Schroeder, 1989; Schroeder, personal observation). More exactly how the habitat and substrate requirements differ between *M. sutor* and *M. galloprovincialis* is still unclear. None of the species breed in low stumps.

4.3 Maturation feeding

Directly after emergence from their breeding material adults of all three *Monochamus* species conduct maturation feeding of bark on branches of living conifers. Maturation feeding by adult *Monochamus sutor* has been observed on both Scots pine and Norway spruce branches and spruce needles in the field (Forsslund 1934) and on branches of both tree species in the laboratory (Schroeder & Magnusson 1992). *Monochamus galloprovincialis* and *M. urussovii* adults presumably conduct their maturation feeding on the same tree species as they breed in.

4.4 Developmental time

The developmental time of *M. sutor* is one year in southern and two years in central and northern Sweden (Ehnström & Holmer, 2007). The adults may be found from the middle of May (southern Sweden) to the end of August. Adults of *M. galloprovincialis* and *M. urussovii* generally occur from June to August (Ehnström & Holmer 2007, Schroeder unpublished). The developmental time of *M. galloprovincialis* is stated in the literature to generally be two years but occasionally one year (Ehnström & Holmer, 2007). My own observation from logging residues from the province of Uppland is one year. There is no published information about the developmental time of *M. urussovii* but given its northern distribution it should be at least two years. All three species hibernate as larvae.

4.5 Capacity to vector pine wood nematode

Of the species present in Sweden *M. galloprovincialis* act as vector for PWN in Portugal (*M. sutor* and *M. urussovii* do not occur in Portugal) while for the other two species no records of association with PWN have been published so far. But it is likely that also *M. sutor* and *M. urussovii* are able to act as vectors for PWN. In Sweden *M. sutor* is associated with the nematode *Bursaphelenchus mucronatus* (Magnusson & Schroeder 1989), a very close relative to the PWN, sharing the same biology but without being pathogenic. In an experiment, *B. mucronatus* was vectored by *M. sutor* to branches of Scots pine and Norway spruce by maturation feeding beetles and to stem sections of both tree species by egg-laying females (Schroeder & Magnusson 1992). In Japan, *M. urussovi* has been demonstrated to be associated with *B. mucronatus* (Togashi et al. 2008). There are examples of other *Monochamus* species which is vectoring both PWN and *B. mucronatus*, e.g., M. *galloprovincialis* (Magnusson & Schroeder 1989) and *M. alternatus*. Thus, it is likely that also *M. sutor* and *M. urussovii* may act as vector for PWN. This means that one vector which is distributed all over the country (*M. sutor*) may be available if PWN is introduced to Sweden. Thus, in the following text the main emphasis is on *M. sutor* as a potential vector even though also *M. galloprovincialis* may be important especially in the south-eastern coastal regions of Sweden.

4.6 Dispersal biology

An understanding of the dispersal biology of the vector beetles is necessary for reliable estimates of rate of spread of PWN after an introduction. : The main reasons for dispersal in *Monochamus* beetles are: finding of living trees for maturation feeding, finding of mates and finding of dying or newly dead conifers suitable for egg-laying. Finding of living conifers for maturation feeding will generally not require any long distance dispersal. In contrast, finding of suitable breeding material may require long distance dispersal because newly dead trees are not to be found everywhere, and especially not if they should be sun-exposed (preferred breeding material for *M. sutor*). Unfortunately, there is no information about the dispersal capacity of *M. sutor*. In a laboratory study (flight mill) the North American *M. carolinensis* was able to fly up to 10 km during a single flight event (Akbulut & Linit 1999). It is not known how flight performance on a flight mill relates to flight capacity in the field. But the facts that the beetles feed as adults, may survive for several weeks and thus have the opportunity to make several dispersal flights, indicate that they during their life span can disperse many km´s.

In Sweden more than 95 % of the forest land is managed. The managed stands are rather dense and thus wind-felled trees, standing dying trees and tops remaining from thinnings in older stands generally are shaded. Thus, tops and remaining low-quality stem parts on clear-cuts, and maybe also left stems after precommercial thinnings that are sun-exposed (because the stand has not yet closed), should constitute the major part of the breeding resource for *M. sutor*. Although field studies comparing the importance of clear-cuts, precommercial thinnings and closed stands for *M. sutor* reproduction yet not have been conducted, expert experience is in accordance with the assumption that clear-cuts constitute the most important habitat (more uncertain about the importance of precommercial thinnings). From this follows that a large part of each *M. sutor* generation, that has developed in clear-cuts, has to emigrate to new fresh clear-cuts in the adjacent forest landscape. This is because uncolonized logging residue will dry out to the next season and remaining large-diameter stem parts may already been colonized by *M. sutor* or other bark- and wood-boring insects. There may be some new input of breeding material in the form of wind-felled trees from the stand edges facing the clear-cuts but not in all clear-cuts every year. An analyses of clear-cuts in the provinces of Dalarna and Värmland in Sweden and Østfold in Norway (including about 20 000 clear-cuts) revealed that the mean shortest distance to the nearest clear-cut (fresh or one year old) is 1170 m with 95% of the shortest distances in the range of 66 – 5112 m (Økland et al. 2010). Because all individuals will not be able to find the closest clear-cut (they may fly in the wrong direction) the distances will on average be longer. In addition, there is also the possibility that the beetles will visit several clear-cuts. Thus, PWN, if vectored by *M. sutor*, can be expected to rapidly spread in the forest landscape.

4.7 Availability of breeding material

Given the assumption that logging residues constitutes the major part of the breeding material for *M. sutor* forest statistics can be used for estimating the amount of habitat available each year. In 2008 140 000 ha were clear-cut (only including clear-cuts larger than 0.5 ha and thus the true areal will be somewhat larger) (Swedish Forest Agency 2009). The average size given in applications for clear-cuttings in 2008 was 4.3 ha (smaller in southern Sweden and larger in northern Sweden). Thus, the yearly number of clear-cuts should be about 32 500 in Sweden. Applications for retrieval of logging residues from clear-cuts covered about 60 % of the clear-cut area (85 000 ha) in 2008 (Swedish Forest Agency 2009) which will reduce the amount of potential breeding material even though not all residues are removed from harvested clear-cuts. The number of tree tops remaining after clear-cutting, without retrieval of tops for bioenergy purposes, could be assumed to be on average 500/ha. In addition, also some branches of pine may be utilized.

4.8 Pine wood nematode introduction

The most likely way of introduction is that PWN-infested *Monochamus* beetles emerge from imported wood material (e.g. packaging material) and fly out in the forest (2009a, b). There are several reports, of interceptions of living *Monochamus* in imported material (Brasch et al. 2000; Cocquempot & Lindelöw 2010), from Austria (living *Monochamus* spp. larvae and adult *M. alternatus,* (Tomiczek et al. 2003)), France (*M. alternatus* adults, (Christian Cocquempot personal communication)), Germany (adult *M. alternatus* recorded from wood packaging material originating in China (Cocquempot 2006)). Beetles emerging from the imported material will first do a maturation feeding of bark on branches of living pines or spruces and thus may transmit PWN to these trees. As long as PWN-infested trees are in good condition the transmitted nematodes will not be able to multiply within the tree and disperse from these trees (because *Monochamus* cannot colonize healthy trees). But, if PWD develops or the trees are weakened by other factor (e.g., wind-felled or weakened by fire) the trees may be colonized by *M. sutor* (or *M. galloprovincialis)* and as a result PWN may be vectored to new trees. A more likely way of introduction into Sweden (and other countries where development of PWD is unlikely) is via the egg-laying of the introduced beetles in newly dead or dying conifers. It has been demonstrated that even unmated *Monochamus* females may oviposit and transmit PWN to the breeding substrate (Akbulut & Linit 1999). In the dead wood object PWN multiplies and may move into native *M. sutor* (or *M. galloprovincialis*) beetles that reproduce in the same wood object. In the following beetle generations the proportion of infested *Monochamus* individuals may increase as a result of infested and uninfested parent beetles sharing breeding material. Thus, it could be enough with one unmated PWN-infested *Monochamus* female emerging from imported material for an establishment in a Swedish *M. sutor* (or *M. galloprovincialis*) population. The establishment of a non-idigenous *Monochamus* species or a non-indigenous population of a native species (e.g. *M. galloprovincialis galloprovincialis)* is thus not a prerequisite for PWN to be established in Sweden.

5. Planned actions if the pine wood nematode would be detected in Sweden

In 2008 an analysis of consequences of an introduction of PWN to Sweden was conducted by the Swedish Board of Agriculture (Jordbruksverket 2008). In the analysis two main strategies after a PWN introduction were formulated: (1) eradication by felling all conifers in an area of 3 or 5 km radius and (2) containment of the nematode within the infested area by creating a zone, 3 or 5 km wide, free from host trees around the infested area. All conifers within this zone are cut down. In both cases, a 10 km wide surveillance zone is established outside the infested area. Within this zone, the presence of PWN is intensively monitored. In a later report (Skogforsk 2010) the logistics and costs of eradication by felling all conifers within an area with a diameter of 16 km and containment as described above was evaluated. A definite Swedish contingency plan has yet not been decided. The strategies described above are similar to the procedures suggested by EPPO but the distances differ somewhat (EPPO 2010a).

The survey strategy proposed in the following text is based on an eradication felling with a maximum diameter of 16 km (Skogforsk 2010). If this is changed in the definite plan also the surveys need to be adjusted.

6. Pine wood nematode surveys

The objectives of the present report are: (1) to evaluate and improve the ongoing Swedish detection survey for PWN and (2) to develop a delimitation survey for PWN, suitable for Swedish conditions, to be used in case of an introduction. The aim of the detection survey is to determine whether PWN is present or not in Sweden. The aim of the delimitation survey is to determine the extent of the area infested by PWN after an initial detection. This information is vital for decisions about expensive control or eradication measures (Skogforsk 2010). The ongoing detection survey is based upon the EU Pinewood Nematode Survey Protocol 2009 and the document Nordic Pine Wood Nematode Survey, Draft Manual 2000-02-11 by Magnusson et al. At present there is no developed Swedish plan for a delimitation survey in case of an introduction. General guidance on sampling to detect PWN has earlier been published (e.g. Schröder et al. 2009, European Commission 2009). The present plan differs from the earlier ones by being specifically designed for Nordic conditions. An important part of the background work has been the development of a simulation model with which we have been able to test the efficiency of detection and delimitation surveys for eradication of PWN after an introduction (Økland et al. 2010).

6.1 Detection survey

Detection surveys were started in Sweden and the other Nordic countries in 2000 (in the year after the first detection of PWN in Portugal in 1999). The survey has two aims: (1) to determine if Sweden is free of PWN or not (presence or absence) and (2) early detection of PWN- introductions. Early detection is necessary for eradication to be a realistic option. As discussed below it is very hard to design a survey that fulfills these aims. So far the survey has mainly been directed towards *Monochamus*-colonized logging residues on clear-cuts because this is the most efficient way of finding *Monochamus*-colonized material. By developing a simulation model we have been able to test the probability of detecting PWN after an introduction with this sampling method (Økland et al. 2010). The results of the simulations are not encouraging. It generally took several years according to the model before PWN was detected after an introduction and then it was spread over a too large area for eradication to be a realistic option. I have not been able to find a solution to this problem. But, below some suggestions will follow about how to some extent improve the on-going survey and a general discussion about the efficiency.

6.1.1 Sampling of *Monochamus* beetles or wood

Both the vector beetles themselves, and wood to which PWN may have been vectored, can be sampled. When choosing what to sample, the efficiency of the sampling (costs for obtaining the samples, probability of detecting PWN if present) is important. Living *Monochamus* beetles can be collected either directly on newly cut conifer logs (to which they are attracted for mating and egg-laying), in traps placed at such logs or in traps baited with attractants. Recently attractive odor baits have been developed for *M. galloprovincialis* in southern Europe (Ibeas et al. 2007; Francardi et al. 2009; Pajares et al. 2010). Operative baits are now also commercially available. In the summer of 2011 I tested these baits in Sweden and could demonstrate that they also are attractive for *M. sutor* and the northern race of *M. galloprovincialis* (unpublished results from a project conducted in cooperation with Juan Pajares, University of Vallodolid, Spain).

To collect living beetles without traps requires that they have emerged from their breeding material and warm sunny weather (when the beetles are active). Thus, the time period for sampling is rather limited (preferably June, July and first half of August) and the method is very dependent on the weather (if cold or rain no beetles will be active). Thus, to use traps baited with attractants is a more efficient method. The disadvantages with traps are (1) the cost for the traps and attractants, (2) the cost spent on setting up the traps, and (3) the cost spent on travelling around and emptying the traps. One problem is also that the beetles preferably need to be alive when dissected for nematodes. Thus, the traps need to be emptied at least once a week and provided with food for the beetles (fresh pine twig). In addition, the beetles must be kept alive until they arrive at the nematode laboratory. If a nematode laboratory outside Sweden is used for analyzing the samples it may also be a problem to send living *Monochamus* beetles to another country.

As a result of the strong association between PWN and *Monochamus* beetles the most efficient way of sampling wood is to focus on dead wood objects with the characteristic larval galleries or emergence holes of *Monochamus* beetles. But also living trees with symptoms that could indicate the presence of PWD could be sampled. Sampling of living trees without symptoms or dead wood without signs of *Monochamus* colonization should generally not be conducted (with the exception of a situation when it is strongly suspected that PWN-infested *Monochamus* beetles have conducted their maturation feeding in an given location). The easiest way to find dead wood colonized by *Monochamus* is to search for cutting residues (tops, large branches, low quality stem parts) on clear-cuts (see above). The advantages with this method are: (1) a rather high probability of finding colonized objects, (2) long time period for sampling (all year around except for when deep snow), (3) many available clear-cuts spread out all over Sweden, and (4) available GIS data on exactly where these clear-cuts are located and the age of the clear-cuts. Some disadvantages are that: (1) in some areas suitable clear-cuts may not be available, (2) if specific risk areas are identified (e.g. close to urban areas) there may not be any clear-cuts at all or of suitable age there, (3) we do not know to what extent *M. galloprovincialis* reproduce in logging residues.

To conclude, sampling of *Monochamus*-colonized logging residues on clear-cuts seems to be a superior sampling method compared to sampling living beetles with traps if samples from many distant localities are the goal. But, sampling with baited traps is an interesting compliment for areas lacking suitable clear-cuts and for assuring that also *M. galloprovincialis* populations are included in the surveys. Thus, a combination of sampling of *Monochamus*-infested wood on clear-cuts and traps baited with odor baits is the method advocated in the following text.

6.1.2 Risk areas

As a result of the extremely small probability of finding a single location of an introduction among all possible clear-cuts (140 000 ha of final cuttings in 2008 in Sweden (Swedish Forest Agency 2009)) it is very important to focus the survey to areas with enhanced risk for introductions (i.e. risk areas). A major problem is that it is hard to define specific risk areas. A recent study has demonstrated a strong relationship between the value of international trade and the number of established non-indigenous bark and ambrosia beetles (Marini et al. 2011). For PWN risk areas could be locations to which large quantities of timber historically has been, and is, imported. But it could also be areas into which goods in wood packaging material is imported which then include many locations in Sweden. Thus, as a first step, an analysis of quantitative information about how such imported wood packaging material, originating from areas where PWN is present, is distributed over the country would be valuable. As a second step, specific information about the possibility of presence of living PWN and/or *Monochamus* beetles in wood packaging material (despite regulations about treatment) imported from certain countries could further be used for guiding where to sample. Such information may in some cases be obtained from other countries (their reports about interceptions) but also by inspections conducted in Sweden. Thus, it would be a good strategy to find out more about the distribution of "risky" wood packaging material within Sweden and to increase the amount of inspections of this kind of material to increase the quality of the risk area definitions.

6.1.3 Selection of clear-cuts to sample in risk areas

To minimize the time spent on travelling during sampling it is reasonably to choose one or a few regions to sample in each year. After having decided in which part of the country the yearly detection survey should be conducted (based on the analysis of risk areas) the clear-cuts to be sampled should be selected. For this a national GIS-layer over all clear-cuts, produced by the Swedish Forest Agency, could be utilized. The GIS-layer is based on an interpretation of differences between satellite images (using the computer program Enforma®, resolution 25 x 25 m) from the previous and current summer. In the attribute table there is information about year of clear-cutting and size. The information should be available at latest in April during the second summer after the final cutting (personal communication, Anders Persson, Swedish Forest Agency). This means that clear-cuts created e.g. in the winter of 2008/2009 will be included in the GIS-layer in the spring of 2010. For some districts the information might be available earlier. Thus, with this information the field inspection can be planned to include clear-cuts close to certain risk areas and clear-cuts close to roads to minimize the time spent on moving between sampling locations. For younger clear-cuts (which not yet have appeared in the GIS-layer) it might be a possibility to use the applications for clear-cuttings that all forest owners have to send to the Swedish Forest Agency before cutting. A problem with this information is that you cannot be sure that the cutting has been conducted.

It is not known how the density of PWN changes over time in dead wood objects. But, based on the developmental time of *M. sutor* it should be safe to include up to three year old clear-cuts in southern Sweden (mainly one year generation time) and up to four years old clear-cuts in northern Sweden (mainly two year generation time).

6.1.4 Sampling of wood on clear-cuts

The sampling of logging residue in clear-cut areas could be conducted all year around except when there is a snow cover. This means May to October in northern Sweden and at least March to November in southern Sweden depending on the snow situation. But, in order to give time for a delimitation survey (in case of detection) before the start of the flight period of *Monochamus* beetles, the survey should at latest be conducted in early autumn. Preferably it should be conducted by the same persons each year because it is important to be able to recognize the larval galleries and adult emergence holes of *Monochamus* and the sampling procedure will be known. It is also important that the field inspectors are interested in the project which will increase the quality of the survey. Presently the surveys are conducted by personal from the Swedish Board of Agriculture and generally the same persons conduct the surveys each autumn. Other possibilities would be to use personal involved in the NILS (Nationell Inventering av Landskapet i Sverige)-surveys (which have a lot of field experience but not from this particular system) or that the department of Ecology, SLU (Swedish University of Agricultural Sciences) conduct the surveys. Some disadvantages with using field assistants from the NILS-project are that they are generally not available until late September and that there is no guarantee that the same persons are available from year to year. Also the alternative that SLU is responsible would mean that there is no guarantee that the same persons are involved, especially if there is no secure long-term funding for the surveys (we would have to rely on temporarily employed field assistants). An advantage of SLU being responsible would be that we would be able to more efficiently collect other information regarding e.g. amounts of suitable breeding material on clear-cuts. To conclude, the current system is probably the best way to organize the survey.

The optimal spatial allocation of the decided number of samples may vary depending on the specific situation. If there is a suspected point of introduction of PWN (e.g. urban area to which wood packaging with PWN has been imported) samples could be allocated in a zone around the suspected place of introduction in which all suitable clear-cuts are sampled and with a high number of samples from each clear-cut. If, on the other hand, there is no specific point of introduction the clear-cuts chosen for sampling may be spread out over a larger area and the number of samples per clear-cut reduced to increase the area sampled.

For each sample at least the following information shall be recorded: sample ID, geographic location (X and Y coordinates), kind of sampled area (e.g. clear-cut or living tree), tree species, kind of material (e.g. branch from living tree with PWD symptoms; logging residue: stem part, top or branch), and signs of *Monochamus* activity (egg pits, larval galleries or emergence holes). When sampling logging residues on clear-cuts preferably also inspected wood objects without *Monochamus* activity should be recorded. These data may be used for estimates of proportion of *Monochamus* colonized wood objects of different kinds.

6.1.5 Sampling in other areas than clear-cuts

In or close to urban or industrial areas, where a higher risk of introduction seems likely (as a result of large quantities of imported goods), it is generally not possible to find clear-cuts or clear-cuts of suitable age. In this situation odor-baited traps may be a good option to sample *Monochamus* beetles for the presence of PWN. Such traps should preferably be placed in sun-exposed conditions (e.g. gaps in the forest, forest edges or in open forest stands). The advantage of this strategy is that it increases the possibility of an early detection because the sampling is conducted close to the sources of possible introductions. Thus, the possibility of a successful eradication after detection could be assumed to be higher compared with the survey conducted on clear-cuts.

It cannot be ruled out that an introduction of PWN in Sweden may result in PWD. Thus, it may be a good strategy to also sample Scots pines showing symptoms that could indicate PWD in industrial areas where a higher risk of an introduction seems likely. In such urban areas trees may be stressed, and the temperature may also on average be somewhat higher, which may increase the possibility of PWD-symptoms. As mentioned above, the advantage of this strategy is that it increases the possibility of an early detection because the sampling is conducted close to the sources of possible introductions. The disadvantage is that we do not expect that PWN in Sweden will result in PWD-symptoms. Such surveys should be conducted in late summer when PWD-symptoms possibly may have developed after a hot summer and when there is still time for a delimitation survey before the emergence of the next generation of *Monochamus* beetles. Besides PWN, there also exist a number of other non-indigenous pests (e.g., Asian longhorn beetle, emerald ash borer) that are at risk of being introduced and for which urban areas could be risk areas. Thus, one possibility could be yearly surveys including also these species. To conclude, in urban areas odor-baited traps and surveys for pine trees showing symptoms that may indicate the presence of PWN may be a good compliment to the ongoing survey on clear-cuts.

6.1.6 Number of samples

A very important question is how many samples that should be taken each year. The answer to this question depends on: (1) the required probability of detection, (2) how fast after an establishment that PWN should be detected, and (3) the costs of the detection survey in relation to the gains in case of a successful eradication. The ongoing detection survey in Sweden (and the other Nordic countries) is based upon the document Nordic Pine Wood Nematode Survey, Draft Manual 2000-02-11 (Magnusson et al., 2000). In this document it is suggested that about 3000 samples per country (summed over several years) is needed. The assumptions for this figure are: (1) that there is a similar probability of finding PWN regardless of location, (2) PWN is assumed to occur in a frequency of at least 0.001 of *Monochamus*-colonized wood objects and (3) the statistical significance level is set to 0.05. The number of samples needed (N) was calculated from the formula:

N = ln(statistical significance level)/ln(1 – probability of a positive find)

The two first assumptions above may be appropriate if PWN has been present in a country for many years allowing dispersal and population build up all over the country. When the detection survey started in the Nordic countries this was a possibility that could not be ruled out. But now, after several years of sampling without positive findings in any of the Nordic countries, this possibility is highly unlikely. Thus, the main aim of the detection survey should now be an early detection of new establishments to increase the possibility of eradication. It is obvious that the two first of the assumptions mentioned above are violated directly after an introduction of PWN. In such a situation PWN will only be present in a very restricted area and thus also the frequency of occurrence will be very low. Then over the years the area of distribution will increase and also the frequency of occurrence. In a Nordic modeling project we have addressed this latter situation (Økland et al. 2010). We used a simulation model approach to test one example of the draft contingency plans (the Norwegian, Mattilsynet 2007) for PWN eradication. This plan is similar to the suggested eradication measures for Sweden (Jordbruksverket 2008, Skogforsk 2010). The results of the simulations were used to evaluate the probability of eradication of the pest by the proposed measures should PWN be detected in Norway. Sensitivity analyses were used to analyse the influence of the biological parameter assumptions for the model results, and to analyse how changes in the parameters of the PWN survey and the draft contingency plan of Norway can increase the probability of successful eradication. In the model we assume that import of one PWN infestation (a PWN-infested beetle, e.g. *M. galloprovincialis* or *M. alternatus*) leads to PWN-infection of dead wood objects utilized by the local *Monochamus* populations which in turn start a spread of PWN to an increasing proportion of the existing native *Monochamus* population and its breeding objects. The model keeps track of PWN-infested objects of Scots pine and Norway spruce.

In Norway an average number of 420 samples have been collected per year from an area of 78540 km^2 (10 circles of 50 km radius defined as risk areas) (Magnusson et al. 2007). Based on estimates of number of dead wood objects per km^2 these 420 samples represent 0.02 % of the available dead wood objects estimated to be colonized by *Monochamus* beetles. These figures are of the same magnitude as for Sweden: the total area of forest land in Sweden is about 220 000 km^2 and the average number of samples per year is of the same magnitude as in Norway. In the model simulations we assume one entry of PWN somewhere within the Norwegian survey area and the model was then run for 20 years to record the final eradication success when applying the Norwegian contingency plan (Mattilsynet 2007). With the present Norwegian detection survey the probability of detection in the first year was very low (0.013 %) and the average number of years until detection was 14. This is not surprising considering the low proportion of *Monochamus*-colonized dead wood objects sampled (0.02 %). Even if the number of samples was strongly increased to 60 000 per year the probability of detection only increased to 17 %. As the number of infested dead wood objects built up exponentially, the first detection in many cases consisted of several infested objects.

The model-estimated probability of detection is conservative in several ways. It does not take into account that establishment could occur outside the survey areas, that PWN in some cases may not be detected in samples from infested wood objects and that human-mediated dispersal of PWN-infested wood could increase the rate of spread (Robinet et al. 2009).

To conclude, it is not possible to take enough sample to obtain a useful statistically secured early detection (e.g. confidence level 95 % or 99 %) when the risk areas are large. Thus, it is important to use all available information to try to identify especially risky areas when deciding where to sample from year to year. This part should also be further developed based on: (1) Analyses of available information about trade. Are there special locations in Sweden into which especially risky imports are directed? Risky could e.g. mean from areas where PWN is present and treatment of wood packaging material is not satisfactory. (2) More inspection of wood packaging material (and other potential pathways) for the presence of both PWN and vector beetles. This work needs to be continuously upgraded because the situation may change.

6.1.7 Sample analyses

Besides PWN, also the presence of *B. mucronatus* should be recorded in the analyses of the sampled material. This is one way of controlling the quality of the survey. If there are no records at all of *B. mucronatus* this could indicate a problem with the sampling procedure or the analyses. Also, over time we can learn more about the distribution of *B. mucronatus* in Sweden. This information may be relevant in the future when we hopefully learn more about the relationship between PWN and *B. mucronatus* (e.g. if the presence of *B. mucronatus* in some way reduce the possibility of establishment of PWN in a situation without PWD). If possible, it would also be interesting to test if the recorded *B. mucronatus* all are native or if some of them origin from introductions from other parts of the world. If such introductions have occurred it means that they almost certainly have been caused by non-indigenous *Monochamus* beetles (could be of the same species that we have in Sweden or of non-indigenous species depending on the country of origin). This would indicate that the risk for an introduction of also PWN is high. But, if several such introductions could be documented from areas where also PWN occurs, it could indicate that in areas where PWN so far is not known to occur there exists some kind of resilience against an establishment of PWN (i.e. that PWN for some reason have problems to establish under Nordic conditions).

6.2 Delimitation survey

If PWN is detected in the Swedish forest, planning of a delimitation survey should be immediately started. It is very important that the quality of this survey is high. The results of the delimitation survey will form the basis for decisions about which eradication or containment measures that should be applied and how they will be spatially delimitated. The eradication measures are very expensive (European Commission 2010), and may also have large impacts on e.g. biodiversity, and thus it would be a great failure if such measures are launched and it later on is discovered that PWN already were distributed over a larger area, or on more locations, than the delimitation survey indicated.

In the delimitation survey both sampling of *Monochamus*-colonized wood objects and odor-baited traps should be utilized to maximize the probability of achieving a correct delimitation of the infested area. The sampling of wood will reflect the situation last summer, or two summers ago in areas with a two year generation time of *Monochamus*, when the egg-laying females and the males transmitted PWN to the fresh wood. In contrast, trapped beetles will reflect the current distribution of PWN. In case PWN is detected in an area with only a few or without clear-cuts it will be much harder to find *Monochamus*-colonized wood objects (e.g. wind-felled trees or dead branches). Thus, in such a situation the major sampling effort may be traps. If PWN is detected in the autumn sampling of wood can directly be used to delimitate the infested area while traps cannot be used until the next summer.

Even if large resources are invested in a delimitation survey it is of course not possible to sample all *Monochamus*-colonized wood objects or flying *Monochamus* beetles everywhere. Thus, a plan for the allocation of the resources available for sampling is needed. In the following text I suggest such a sampling plan. This plan is based on the fact that eradication by cutting all conifer trees is only an option if the PWN-infested area is less than a certain area (may be defined in the coming Swedish contingency plan) dependent on the characteristics of the forest that have to be cut and the benefits from a successful eradication.

Thus, the first aim is to assess if the requirements for eradication is fulfilled (i.e. infested area not too large). This assessment will be based on high intensity sampling of a restricted area (adjusted to be somewhat larger than the maximum size of PWN-infestations that may be treated with the eradication measures) and other available information. If the infested area is too large for eradication, the objective of the sampling will be to evaluate which parts of the country that are infested by PWN. I advocate this strategy instead of the alternative strategy of a low intensity sampling of a very large area which at first may be tempting because a second detection far away from the first one might directly result in abandoning the idea of eradication. But, such a low intensity sampling will result in a low proportion of sampled *Monochamus*-colonized wood objects or flying beetles which means that the probability of missing PWN-infested objects or beetles will be high (especially at a low infestation level). Such an effect was also demonstrated by the simulation model when the size of the observation zone was increased (Økland et al. 2010). A problem with the advocated strategy is that PWN may be present also far away from the point of detection as a result of long dispersal of a few individuals of the vector beetle from a single introduction or that several independent introductions have taken place (e.g. compare with the example of the parasite *Echinococcus multilocularis* that was recently discovered in a fox sampled from the province of Västra Götaland in Sweden but later on also in foxes from two other locations far away from the first record (in the provinces of Södermanland and Dalarna)). Such far away infestations will not be detected with the present strategy. Thus, when deciding if to eradicate or not, this risk must be considered. The risk of long dispersal is especially high if the location of detection is far away from any possible source of introduction (i.e. the introduction has occurred far away from the location of detection). The risk of several independent introductions is hard to evaluate without detailed information about the introduction.

The delimitation survey plan can be divided into the following three steps, ordered chronologically, and is based on a scenario that PWN is detected in only one locality. If PWN is detected in several locations, demonstrating an infested area too large for eradication, the procedure starts directly with step 3B.

1. Evaluation of the possible way of introduction and selection of survey sites for a first sampling.

2. Conduct first sampling for decision about if to eradicate or not.

3. A. If eradication is still an option after first sampling: An evaluation if infested material may have been transported out of the area and a second sampling to further secure the negative result of the first sampling.

   B. If eradication is not an option after first sampling: Planning of sampling for analyses about which parts of Sweden that are infested to obtain containment.

6.2.1 Step 1: Possible way of introduction

Directly after detection an evaluation should be made of the most likely path way of introduction. In best case (but probably not) such an evaluation could answer questions about: (1) exactly where the introduction took place, (2) when it was introduced (how many years ago) and (3) from which kind of material it was introduced. Information about the time since introduction is of interest when making assumptions about how far away from the place of introduction it may have spread. Information about source of introduction (kind of material and country of origin) could be used for guidance about other possible places of introductions in Sweden and other countries.

6.2.2 Step 1: Selection of survey sites for a first sampling

If the analysis of possible way of introduction is successful (i.e. that it is possible to demonstrate where and how long ago the introduction took place), the results will be used when selecting survey sites for a first sampling. If not, the selection of survey sites will be centered on the point of detection.

For the sampling of *Monochamus*-colonized wood objects the following procedure should be applied. Based on applications for final cuttings (for the last year clear-cuts which are not yet included in the GIS-layers based on satellite images, see above) and the national GIS-layer for older clear-cuts (produced by the Swedish Forest Agency) a GIS-layer including all clear-cuts within a radius of about 18 km around the point of detection is established. This work should be done by the Forest Agency because they have all the data. The suggested 18 km radius is based on a maximum area of eradication with an 8 km radius which has been used as an example in an earlier report (Skogforsk 2010) and an extra 10 km zone (this figures could be adjusted depending on the situation) to check for further infestations. Clear-cuts older than three years in southern Sweden and four years in northern Sweden should be avoided (depending on developmental time of *Monochamus*, see above). To sample clear-cuts of different ages gives a possibility to get some data on how long time PWN has been established in the surveyed area. If PWN is present in dead wood objects for several years after *Monochamus* has emerged even older clear-cuts could be included in the sampling, but we do not know if this is the case. Based on national statistics of clear-cut area per year (Swedish Forest Agency 2009), and assuming 100 % of forest in the landscape, a circular area with 18 km radius would include about 3000 ha of clear-cuts of the ages 1 – 4 years (but this figure could of course vary a lot depending on local conditions). With an average clear-cut size of 4.3 ha (Swedish Forest Agency 2009) this would correspond to about 700 clear-cuts.

Sampling of flying *Monochamus* beetles should be conducted during the summer following detection of PWN. Traps on fresh clear-cuts (cut during the previous winter) will sample *Monochamus* beetles immigrating from the surrounding landscape while traps on one- to two-year-old clear-cuts may sample the new generation of beetles that emerge from the logging residue. Traps within forest may sample *Monochamus* beetles reproducing in dead wood objects within the forest (e.g. *M. galloprovincialis* in pine stands). It remains to be tested which of these alternatives that are the most efficient method of collecting large numbers of beetles.

6.2.3 Step 2: First sampling

All *Monochamus*-colonized wood objects should be sampled on the clear-cut of detection. A high proportion of infested objects indicates that the introduction has taken place several years ago because it means that several PWN-infested *Monochamus* females have originally colonized the clear-cut. How large proportion of the *Monochamus*-colonized wood objects that should be sampled on the other clear-cuts within the 18 km radius depends on the resources available (money, field inspectors, number of samples that can be processed by the nematode laboratories) and the required statistical confidence level of absence of PWN. In Norway it has been estimated that about 300 wood objects suitable for *Monochamus*-colonization occurs per km^2 and in the model we assumed that 10 % of these were colonized based on Norwegian data (Økland et al. 2010). For Sweden we have no data on density of dead wood objects suitable for *Monochamus* colonization. Assuming that the major part of suitable objects consists of tops on clear-cuts, and assuming that on average 500 conifer tops per ha are produced at a final cutting, the 3000 ha of clear-cuts (circular area with 18 km radius, clear-cut age 1- 4 years) would include 1.5 million tops. Assuming that 50 % of these tops are either removed (used for energy) or destroyed by forest machinery (e.g. scarification), and that 10 % of the remaining tops are colonized by *Monochamus*, results in 75 000 tops. How large proportion of these that should be sampled depends on the required statistical level of confidence. The figures above are unfortunately very uncertain and Swedish field studies are needed for more reliable estimates.

Probably several hundreds of traps need to be used to be able to discover also very low PWN infestation rates. One advantage with using traps in a delimitation survey compared with in a detection survey is that all the traps will be situated within a restricted area which will make the set out and emptying of the traps more efficient.

The proportion of *Monochamus*-colonized wood objects or *Monochamus* beetles that are PWN-infested may give information about the spatial distribution within the geographic range of an infested area. The proportion could be expected to be higher in the central area of an infestation compared with at the range edge.

Because it could not be excluded that symptoms of PWD might occur under Swedish conditions (Jordbruksverket 2008) the field inspectors should look for, note and sample trees with such symptoms when out in the field collecting the wood samples from the clear-cuts. If PWD could be demonstrated to occur (i.e. the presence of PWN in trees or branches with symptoms) also such symptoms should be used in the delimitation survey. In addition, the occurrence of PWD would be of a large interest when estimating the economic consequences of PWN establishment in Sweden and other countries. It may also influence the decision about how much money to spend on eradication attempt. Especially trees at edges bordering clear-cuts where *Monochamus* beetles have emerged may have been exposed to maturation feeding by the beetles and may also be somewhat stressed which may increase the risk for PWD to develop. Thus, such stand edges with pine trees should be checked which should be easy.

If an introduction has taken place it is also possible that a non-indigenous *Monochamus* species has been able to establish. If this is the case it might have implications for the eradication or containment measures. The easiest way to find out which species that is vectoring PWN is to bring colonized wood objects to the laboratory and collect the emerging adult beetles which are easy to identify. But this requires access to totally escape-safe laboratories to avoid the risk of further spreading PWN within the country. A safer way would be to cut out living *Monochamus* larvae in the field and store them in ethanol (or freeze them) for later identification based on larval characteristics (not so easy) or by DNA-techniques (markers may not yet be developed for all species).

6.2.4 Step 3A: Evaluation if infested material may have been transported out of the area

It is very important to try to map all transports of potentially PWN-infested wood that have taken place from the infested area and evaluate if these may have spread PWN outside the delimited area. These transports may include timber, pulpwood, logging residues for energy purposes and fire wood to be used locally.

6.2.5 Step 3A: Selection of survey sites for a second sampling in case the first sampling indicate that eradication is still an option

The motives for a second sampling are: (1) Based on the result of the first sampling the spatial direction of the second sampling can be adjusted. It might be that PWN is only found on clear-cuts in a certain part of the area included in the first sampling. (2) An extra 10 km zone beyond the boundary of the survey zone in the first sampling (this figure can be adjusted) can be considered to check for the presence of PWN at larger distances from the point of detection. This is especially important if PWN- and *Monochamus*-colonized dead wood objects and PWN-infested beetles are abundant within the maximum area of eradication since the risk of long-distance-dispersing beetles increase with population size and since the proportion of PWN-infested *Monochamus* should decrease at the edge of the range of distribution.

6.2.6 Step 3B: Selection of survey sites if first or second sampling indicates that eradication is not an option

In this case the aim is to delimit PWN-infested parts of Sweden from regions free of PWN. Since such a survey needs to include large areas it will face the same problem as described above for the detection survey (i.e. that an unrealistic high number of samples is required). Another problem is that the survey needs to be repeated because PWN may continue to spread over larger and larger areas both by vector dispersal and by human transports (Robinet et al. 2009). Thus, there should be strong arguments for starting such a survey with the aim to achieve containment. But, EU-regulations will probably require that surveys are conducted (Commission Decision 2006/133/EC, under revision).

6.2.7 Organization of delimitation survey

The survey plan described above is based on the existence of a contingency plan in which the maximum area of a PWN-infestation is defined for eradication to be an option. Thus, such a plan needs to be decided in the near future.

The intensity of the sampling for delimiting the area of eradication or for delimiting which parts of Sweden that are infested (in case of no eradication) is dependent on which statistical level of confidence that is needed by the decision makers. It is important that this issue is handled because it will have consequences for the resources (e.g., money, field inspectors, capacity for PWN analyses of collected samples) needed for the survey.

A plan for how to recruit and educate at short notice the field inspectors required for the delimiting survey is needed.

To successfully conduct the steps described above requires a tight cooperation with the Swedish Forest Agency (both at the local and central level), forest companies and private forest owners operating in the area and experts on *Monochamus* beetles and PWN to be able to adapt to different situations that might develop. How this should be organized needs to be planned.

7. Gaps of knowledge

Which are the absolute densities of *Monochamus*-colonized wood objects (number per ha forest land) in different regions of Sweden? With this information the proportion of wood objects sampled can be quantified and thus also the probability of detection for a chosen infestation level. This information is especially important during a delimitation survey. This information could be retrieved by field inspections of large number of clear-cuts in different regions of Sweden. By estimating the proportion of colonized wood objects in relation to e.g. clear-cut size, tree species and other clear-cut variables simple models could be developed for estimating density of *Monochamus*-colonized wood objects.

How many beetles will an odor-baited trap catch and in which kind of habitats should they be placed to catch the highest number of beetles (e.g. fresh clear-cuts of spruce, fresh clear-cuts of pine, or older clear-cuts with emerging new generation beetles). These questions need to be addressed with field experiments.

How large is the dispersal capacity of *M. sutor*? The answer to this question is of vital importance for assessments of how fast PWN will spread after an introduction (and also for assessments of the efficiency of the suggested corridor containment method). This question could be addressed by a combination of laboratory and field experiments. With a flight mill the mean and maximum dispersal capacity of *M. sutor* could be estimated in the laboratory. Adult beetles are attached to an arm fixed to a vertical spindle rotating in a pivot. By recording the number of revolutions and the time spent flying, flight distance and velocity can be calculated. This technique has already been successfully used for a North American *Monochamus* species (Akbulut & Linit 1999). In summer newly emerged beetles (from field-collected colonized wood objects placed in emergence cages in the laboratory) could be released in the field and their dispersal monitored. Two techniques are available: individually marked beetles and harmonic radar in combination with marked beetles. Mark-recapture has already been used for Asian and North-American *Monochamus* species while harmonic radar successfully has been used for another cerambycid beetle, the Asian longhorn beetle (Williams et al. 2004).

What is the geographic distribution of *M. galloprovincialis* in Sweden and which kinds of forest stands does the species inhabit? *Monochamus galloprovincialis* is the vector of PWN in Portugal. Thus, it is important to include populations of this species in the Swedish detection survey which may not be the case at present. The questions can be addressed with field experiments utilizing odor-baited traps catching adult beetles (the two species cannot be discriminated based on larval galleries in colonized wood).

How to identify risk areas? This question should be further addressed. It might be possible to use information about trade in combination with information about findings of PWN and vectors (both from Swedish inspection and from other countries) in different kinds of material from different countries in a more systematic way. This kind of evaluation needs to be done continuously as a response to findings of PWN in new regions and new information about interceptions.

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8. Strategier för inventering i syfte att upptäcka och avgränsa förekomst av tallvedsnematoden i Sverige

– förkortad svensk version av rapporten

Förord

Jordbruksverket utvecklar för närvarande, i sin egenskap av svensk växtskyddsmyndig-het, sin förmåga att hantera upptäckt av nya växtskadegörare som kan orsaka allvarliga skador om de skulle etableras. Ett exempel på en sådan skadegörare är tallveds-nematoden, *Bursaphelenchus xylophilus*, som kan orsaka skador på svensk skog, i första hand tallskog, och påverka handeln med virkesprodukter, om den etableras. Därför bör en specifik beredskapsplan tas fram för att förbereda hantering av en sådan situation.

Särskilda krav för hantering av ett utbrott av tallvedsnematoder finns angivna i Kommissionens Beslut, 2006/133/EG, för närvarande under revidering. Kommissionens Beslut innehåller också krav på att EU-länderna ska utföra inventeringar för att upptäcka förekomst av tallvedsnematoder så tidigt som möjligt efter en introduktion i syfte att öka möjligheten att åstadkomma en utrotning.

De särskilda kraven i Kommissionens Beslut 2006/133/EG, bygger till stor del på de rekommendationer som ges av EPPO i deras normer för fytosanitära åtgärder för *Bursaphelenchus xylophilus* och dess vektorer: Förfaranden för offentlig kontroll och för nationella lagstadgade kontrollåtgärder, PM 9/1. Vägledning för planering och utförande av inventeringar i syfte att upptäcka och avgränsa förekomst av tallveds-nematoder finns också i ”EU Pine wood Nematode Survey Protocol” från 2009.

I syfte att vidareutveckla strategier för inventeringar för att upptäcka och avgränsa förekomst av tallvedsnematoder i Sverige, där vi i första hand väntar oss icke-symptomatisk förekomst, har ett särskilt projekt initierats av Jordbruksverket. Projektet har finansierats genom medel från Myndigheten för Samhällsskydd och Beredskap. Denna rapport innehåller resultatet av projektet. I överenskommelsen med Institutionen för Ekologi, Sveriges lantbruksuniversitet, som har kontrakterats för uppdraget, ingår att rapporten skulle skrivas på engelska men med en svensk sammanfattning.

Professor Martin Schroeder, Institutionen för Ekologi, Sveriges lantbruksuniversitet, Uppsala har skrivit rapporten och ansvarar för innehållet.

Karin Nordin

Sammanfattning

Tallvedsnematoden (*Bursaphelenchus xylophilus*) är en ekonomiskt betydelsefull skadegörare på tallskog i Asien, och på senare år även i Portugal i Europa. Risken för introduktioner även i andra europeiska länder har bedömts vara stor. En etablering i Sverige skulle kunna resultera i stora ekonomiska förluster för skogsbruket och även påverka andra värden (t.ex. biologisk mångfald och friluftsliv). Rapportens mål är att: (1) utvärdera och förbättra den pågående inventeringen med syftet att upptäcka eventuella introduktioner av tallvedsnematoden i svensk skog och (2) utveckla en inventeringsmetod som skall användas för avgränsning av koloniserat område om den påträffas i svensk skog. Om vi antar att en introduktion av tallvedsnematoden i Sverige inte leder till symptom hos infekterade tallar är det inte möjligt att utveckla en inventering som garanterar tidig upptäckt. Detta innebär att om den upptäcks är det mycket sannolikt att den redan under lång tid funnits i landet och därmed också hunnit sprida sig över ett alltför stort område för att en utrotning skall vara möjlig. Om en tidig upptäckt är inventeringens huvudsyfte kan en möjlighet vara att inrikta den pågående inventeringen mer mot industriområden eller andra platser dit mycket material importeras. Det är också viktigt att ytterligare öka kunskapen om gods och handelsvägar som kan utgöra en risk för introduktioner av tallvedsnematoden. Även avgränsnings-inventeringen (som syftar till att avgränsa området som är koloniserat av tallveds-nematoden efter en introduktion) drabbas av problemet med en låg sannolikhet för upptäckt av befintlig förekomst av tallvedsnematoden om det inventerade området är för stort. Ett sätt att minska detta problem är att begränsa inventeringen till ett område som är något större än den maximala area som är aktuell för ett utrotningsförsök. Denna strategi bygger på att en sådan maximal area för utrotning definieras i handlingsplanen för tallvedsnematoden.

Sammanfattande slutsatser

- Det är inte möjligt att för Nordiska förhållanden utforma en inventering som säkerställer en tidig upptäckt av tallvedsnematoden, eftersom detta skulle kräva ett orealistiskt stort antal prov.
- Förutom den nuvarande inventeringen, dvs provtagning på kalhyggen av hyggesrester som koloniserats av tallbockar, bör också utföras inventeringar nära platser där risken för introduktioner av tallvedsnematoden bedöms vara särskilt stor.
- Den maximala koloniserade ytan för vilken utrotning av tallvedsnematoder fortfarande kan vara ett alternativ, bör definieras i den kommande svenska beredskapsplanen.

8.1 Syftet med rapporten

Tallvedsnematoden (*Bursaphelenchus xylophilus*), som är inhemsk i Nordamerika, är en ekonomiskt betydelsefull skadegörare på tallskog i Asien, och på senare år även i Portugal i Europa. Risken för introduktioner även i andra europeiska länder har bedömts vara stor. En etablering i Sverige skulle kunna resultera i stora ekonomiska förluster för skogsbruket och även påverka andra värden (t.ex. biologisk mångfald och friluftsliv). Rapportens mål är att för tallvedsnematoden (1) utvärdera och förbättra den pågående inventeringen med syftet att upptäcka eventuella introduktioner av tallvedsnematoden i svensk skog och (2) utveckla en inventeringsmetod som skall användas för avgränsning av koloniserat område om den påträffas i svensk skog. I rapporten har jag utgått ifrån att en eventuell etablering av tallvedsnematoden i Sverige inte kommer att leda till att träd blir sjuka och dör, vilket också verkar vara det mest sannolika scenariot. Detta innebär att inventeringarna inte primärt kan inriktas på tallar som uppvisar symptom av s.k. vissnesjuka. Jag har också utgått från de åtgärder som är föreslagna att vidtas om tallvedsnematoden påträffas ute i svensk skog (se nedan).

8.2 Slutsatser

Om vi antar att en introduktion av tallvedsnematoden i Sverige inte leder till symptom (vissnesjuka) hos infekterade tallar är det inte möjligt att utveckla en inventering som garanterar tidig upptäckt. Detta innebär att om den upptäcks är det mycket sannolikt att den redan under lång tid funnits i landet och därmed också hunnit sprida sig över ett alltför stort område för att en utrotning skall vara möjlig.

Enda möjligheten till tidig upptäckt är om man har indikationer på att en introduktion nyligen kan ha skett i ett specifikt område och därmed kan styra inventeringen till detta område. Det är därför viktigt att utveckla metoder för att på bästa sätt fånga upp denna typ av information (genom analyser av vart de största mängderna av riskabelt gods tar vägen i Sverige och genom ökade nationella inspektioner av importerat material). Men även med bättre kunskaper om detta så kan man inte räkna med att fånga upp alla tänkbara introduktioner.

Om en tidig upptäckt, som möjliggör ett utrotningsförsök, är inventeringens huvudsyfte kan en möjlighet vara att utöka den pågående inventeringen, eller helt ersätta den, med en inventering i industriområden i städer (dit mycket material importeras) med hjälp av fällor betade med doftbeten och av levande tallar med symptom (döende grenar, döende träd). Fördelen med denna strategi är att den ökar sannolikheten för en tidig upptäckt efter som inventeringen sker nära de tänkta introduktionsplatserna. Nackdelen är att vi inte vet om tallvedsnematoden verkligen orsakar symptom på levande träd i Sverige och om vi kommer att fånga speciellt många tallbockar med fällor i sådana miljöer.

Även avgränsningsinventeringen (som syftar till att avgränsa området som är koloniserat av tallvedsnematoden) drabbas av problemet med en låg sannolikhet för upptäckt av befintlig förekomst av tallvedsnematoden om det inventerade området är för stort. Ett sätt att minska detta problem är att begränsa inventeringen till ett område som är något större än den maximala area som är aktuell för ett utrotningsförsök. Denna strategi bygger på att en sådan maximal area för utrotning definieras i handlingsplanen för tallvedsnematoden.

Beslutsfattare kan bestämma sig för med vilken statistisk sannolikhet en avgränsnings-inventering skall styrka att tallvedsnematoden inte förekommer utanför ett eventuellt utrotningsområde. De kan också överväga om utrotningsförsök (som kan vara ekonomiskt mycket kostsamma) överhuvudtaget skall göras med tanke på risken för att tallvedsnematoden kanske också finns utanför ett avgränsat område.

Om en avgränsningsinventering visar att tallvedsnematoden redan är spridd över ett alltför stort område för att ett utrotningsförsök skall kunna göras kan det fortfarande vara intressant att försöka avgränsa vilka delar av Sverige som är fria från tallvedsnematoden. Men en sådan inventering, som innefattar stora geografiska områden, har samma problem med låg sannolikhet för upptäckt som beskrivits tidigare. Den måste dessutom löpande uppdateras.

8.3 Bakgrund

Tallvedsnematoden sprids mellan träd med skalbaggar av släktet tallbockar (*Monochamus*). Både skalbaggarna och nematoderna utvecklas i barrträdsved. Innan den fullbildade skalbaggen lämnar sitt utvecklingsmaterial kryper nematoderna in i skalbaggens andningssystem. Efter att de fullbildade tallbockarna kläckts från sitt utvecklingsmaterial gör de ett mognadsgnag av bark från grenarna av levande barrträd. Nematoderna kan då lämna tallbocken och invadera trädet. Om trädet är mottagligt (dvs. mottagligt trädslag och lämpligt klimat) leder det till att trädet dör och att nematoderna förökar upp sig till höga antal. Trädet blir därmed också lämpligt som utvecklingsmaterial för tallbockar som då lägger sina ägg där och den nya generationen tallbockar kan då fungera som vektorer för nematoderna till nya träd. Efter sitt mognadsgnag söker tallbockarna upp nyligen döda barrträd att lägga ägg i. Även i samband med äggläggningen kan nematoderna lämna tallbocken och invadera veden och där föröka upp sig och sedan invadera den nya generationen av tallbockar som utvecklats där. Det är denna den s.k. saprofytiska livscykeln som är den viktiga i områden där tallvedsnematoden inte dödar träd (t. ex. i Nordamerika).

8.4 Tallbocksarter i Sverige

I Sverige förekommer tre tallbocksarter: tallbock (*M. sutor*), kronbock (*M. galloprovincialis*) och granbock (*M. urusssovii*). Tallbock är spridd över hela landet och vanlig inom stora delar av landet. Kronbock är ovanligare och förekommer förmodligen framförallt längs sydöstra Sveriges kusttrakter men artens utbredning är dåligt känd. Granbock är i nutid bara påträffad på några få lokaler i norra Sverige. Det är därför mest sannolikt att det är tallbock (dvs. *M. sutor*) som kommer att vara vektor för tallveds-nematoden om den introduceras i Sverige men även kronbock kan spela en viktig roll. Tallbock utvecklas i solexponerade nyligen döda tallar och granar. I Sverige verkar hyggesavfall utgöra det huvudsakliga förökningsmaterialet. Utvecklingstiden är ett år i södra och två år eller längre i norra Sverige. Alla tallbocksarterna övervintrar som larv. Direkt efter kläckning från utvecklingsmaterialet gör de ett mognadsgnag av bark på levande barrträd. Tallbock (*M. sutor*) har ännu inte påvisats att fungera som vektor för tallvedsnematoden. Men det mest sannolika är att den skulle fungera alldeles utmärkt. För detta talar att den är vektor för den inhemska nematoden *Bursaphelenchus mucronatus* som är mycket närstående tallvedsnematoden men inte patogen. Det finns flera exempel på andra tallbocksarter i andra länder som fungerar som vektor för bägge dessa nematodarter. Kronbock är den art som fungerar som vektor för tallvedsnematoden i Portugal.

8.5 Åtgärder om tallvedsnematoden påträffas i Sverige

Någon definitiv åtgärdsplan för vad som skall göras om tallvedsnematoden påträffas etablerad i Sverige är ännu inte fastslagen (men se Jordbruksverket 2008 och Skogforsk 2010). Men två huvudalternativ som diskuterats är (1) utrotning genom att alla barrträd fälls inom det smittade området och (2) inneslutning genom att alla barrträd fälls i en korridor som innesluter det koloniserade området med avsikten att förhindra en naturlig spridning ut från det smittade området.

8.6 Inventering för upptäckt av introduktioner av tallvedsnematoden

Denna inventering startade i Sverige år 2000 (året efter upptäckten av tallvedsnema-toden i Portugal). Inventeringen har två mål (1) att bestämma om Sverige är fritt från tallvedsnematoden eller inte och (2) att upptäcka eventuella introduktioner så tidigt att ett utrotningsförsök skall vara möjligt. Som diskuteras nedan är det mycket svårt att utforma en inventering som uppfyller dessa mål. Hitintills har inventeringen varit inriktad på tallbocksangripet hyggesavfall eftersom detta är den effektivaste metoden att hitta tallbocksangripet material. Med hjälp av en simuleringsmodell (Økland et al. 2010) har vi testat hur sannolikt det är att en introduktion skall upptäckas med den pågående inventeringen. Resultaten av simuleringarna är inte uppmuntrande. Oftast tar det många år innan en introduktion upptäcks och den är då spridd över ett alltför stort område för att ett utrotningsförsök skall var praktiskt möjligt.

8.6.1 Provtagning av levande tallbockar eller ved

Man kan analysera både fullbildade tallbockar och ved för förekomst av tallvedsnematoden. Tallbockar kan under sommaren fångas i fällor betade med attraktiva doftämnen som är kommersiellt tillgängliga. Några nackdelar med att använda fällor är: (1) att de måste dessa tömmas minst en gång i veckan eftersom tallbockarna måste vara levande för att man skall kunna analysera om de bär på tallvedsnematoder, (2) det är resurskrävande att sätta ut fällor och dessutom innebär det en kostnad att köpa fällor och doftbeten. Om man analyserar ved skall man framförallt inrikta sig på ved som bär spår av tallbocksangrepp (äggläggningstrattar, larvgångar eller kläckhål som är lätta att känna igen). Det enklaste sättet att hitta tallbocksangripna vedobjekt är att inspektera toppar av gran och tall och större tallgrenar på hyggen. Denna typ av material kan inspekteras hela året med undantag för när det ligger snö. Det finns dessutom många hyggen spridda i landskapet och också information om var de är belägna och hur gamla de är. Slutsatsen blir därför att provtagning av tallbocksangripna vedobjekt på hyggen är den effektivaste metoden om man vill ha prover från många olika platser spridda över ett stort geografiskt område. Men att använda fällor är en intressant möjlighet i områden där det är ont om hyggen (t.ex. i stadsnära miljöer och industriområden) och kan också vara ett sätt att säkerställa att även populationer av *M. galloprovincialis* inkluderas i provtagningen. Jag föreslår därför en kombination av de två metoderna.

8.6.2 Riskområden

Det är viktigt att fokusera inventeringen till områden med särskilt hög risk för introduktioner. Därför bör metoder för att spåra sådana områden vidareutvecklas. Sådana metoder bör innefatta analyser av i vilken typ av material som tallvedsnematoder kan förekomma och vart sådant material tar vägen i Sverige. Denna typ av information kan fås dels från erfarenheter från andra länder och dels genom täta egna inspektioner av importerat material.

8.6.3 Val av hyggen att för provtagning i riskområden

För att minska restiden är det rimligt att välja en eller några få regioner som inventeras varje år. Lämpliga hyggen att inventera kan lämpligen väljas ut med hjälp av Skogsstyrelsens GIS-skikt över avverkade hyggen. Nya hyggen läggs löpande in i detta skikt senast på våren under andra sommaren efter avverkningen. I GIS-skiktet finns uppgifter om avverkningsår och hyggesstorlek. Om man vill hitta yngre hyggen kan man gå på de avverkningsanmälningar som Skogsstyrelsen tar emot. Det är inte känt under hur länge tallvedsnematoden finns kvar i död ved men upp till tre år gamla hyggen i södra Sverige och fyra år gamla hyggen i norra Sverige bör vara säkra att utnyttja.

8.6.4 Provtagning

För att ge möjlighet till genomförandet av en eventuell avgränsningsinventering (om tallvedsnematoden påträffas) innan den nya generationen tallbockar kläcks, bör inventeringen av tallbockskoloniserad död ved genomföras senast under tidig höst. Det bästa är om samma personer genomför inventeringen varje år. Beroende på situationen kan antingen de samplade hyggena väljas glest över ett större riskområde där ingen särskild misstänkt plats för introduktion är känd eller tätt över ett mindre område koncentrerat runt en misstänkt plats för en introduktion.

För varje provtaget objekt bör åtminstone följande information noteras: prov nummer (ID), geografisk position (X och Y-koordinater), typ av område (hygge, bestånd av levande träd), trädslag, typ av material (t.ex. gren från levande träd, avverkningsmaterial: topp, gren, stamsektion), typ av spår av tallbock (äggläggningstratt, larvgångar, kläckhål).

8.6.5 Provtagning i andra områden än hyggen

I stadsnära områden och industriområden, där risken för en introduktion av tallvedsnematoden kan vara hög, kan det vara svårt att hitta hyggen. I denna situation kan fällor vara ett bra alternativ. Fördelen med denna strategi är att den kan leda till en tidigare upptäckt jämfört med inventeringen av hyggen ute i skogen. Därigenom ökar också sannolikheten för en lyckad utrotning efter en upptäckt.

Det kan inte uteslutas att en introduktion av tallvedsnematoden i Sverige leder till vissnesjuka på tall (dvs. symptom). Därför kan det vara en bra strategi att ta prover från tallar med symptom i industriområden i städer där risken för en introduktion kan tänkas vara högre. Nackdelen med denna strategi är att vi inte säkert vet att tallvedsnematoden ger symptom på infekterade tallar i Sverige.

8.6.6 Antal prov som krävs

En viktig fråga är hur många prov som behöver tas varje år. Denna fråga har vi studerat med hjälp av en simuleringsmodell i ett norsk – svenskt samarbetsprojekt (Økland et al. 2010). I modellen antar vi en introduktion som leder till att våra inhemska tallbockar infekteras med tallvedsnematoden t.ex. genom att dela förökningsmaterial med en exotisk tallbock. Modellen håller sedan reda på hur många vedobjekt som är infekterade med tallvedsnematoden. Simuleringarna visar att med den nuvarande provtagnings-intensiteten är sannolikheten att upptäcka en introduktion redan under första året bara någon hundradels procent och att det i medeltal tog 14 år innan en introduktion upptäcktes. Även om antalet prov ökades mer än 100 ggr (till 60 000 per år) var sannolikheten bara 17 % för upptäckt första året. Slutsatsen är att det inte är praktiskt möjligt att ta tillräckligt många prov för att garantera en tidig upptäckt.

8.7 Inventering för avgränsning av koloniserat område

Om tallvedsnematoden upptäcks i svensk skog blir nästa steg att genomföra en inventering för att avgränsa det område som nematoden har koloniserat. Resultatet av denna inventering kommer sedan att ligga till grund för ett eventuellt utrotningsförsök eller andra åtgärder. Eftersom ett fullskaligt utrotningsförsök är mycket kostsamt vore det ett stort misslyckande om det i efterhand visar sig att nematoden även finns utanför det avgränsade området. Det är därför mycket viktigt att avgränsningsinventeringen håller hög kvalitet.

En avgränsningsinventering bör innefatta både provtagning av tallbockskoloniserad död ved och doftbetade fällor för att maximera sannolikheten att avgränsningen blir korrekt. De två metoderna skiljer sig också åt på så sätt att förekomsten av nematoder i död ved återspeglar utbredningsområdet för smittade tallbockar för ett eller två år sedan (beroende på hur gammalt hygget är och vilken utvecklingstid tallbockarna har i området) medan fällorna visar utbredning just för tillfället. Om tallvedsnematoden upptäcks i ett område med få hyggen kan fällor bli det huvudsakliga inventeringsinstrumentet.

Även om stora resurser satsas på en avgränsningsinventering är det naturligtvis inte möjligt att sampla alla tallbocksangripna objekt eller alla tallbockar. Man måste därför bestämma sig för hur man vill allokera resurserna. Mitt förslag är att man utgår från den maximala area som man kan tänka sig att genomföra ett utrotningsförsök över och sedan lägger till en zon runt detta område på förslagsvis 10 km. Om tallvedsnematoden påträffas också i denna yttre zon kan man direkt avskriva alternativet med ett utrotningsförsök. Fördelen med denna strategi är att man ökar andelen av alla tillgängliga tallbocksangripna vedobjekt och tallbockar som ingår i provtagningen och därmed också sannolikheten att upptäcka nematoden om den finns där. Den motsatta strategin, dvs. att ta prover från ett stort område direkt, kan verka tilltalande eftersom det då räcker med att man hittar tallvedsnematoden på ett ställe långt ifrån den plats där den först upptäcktes för att man direkt skall kunna avskriva ett utrotningsförsök. Men problemet med denna strategi är att sannolikheten för upptäckt blir väldigt låg precis som diskuterats ovan när det gäller inventeringen för upptäckt (eftersom det tas prover från en väldigt låg andel av alla tallbockskoloniserade objekt).

Inventeringsplanen innefattar följande tre steg, ordande i kronologisk ordning:

1. Utvärdering av på vilket sätt introduktionen kan ha skett och planering av en första provtagning för beslut om utrotning eller inte.

2. Genomförande av första provtagningsomgången.

3. A. Om ett utrotningsförsök fortfarande är realistiskt efter första provtagningsomgången: En utvärdering av om infekterat material kan ha transporterats ut ur det avgränsade området och en andra provtagningsomgång för att säkerställa det negativa resultatet av den första provtagningsomgången.

   B. Om ett utrotningsförsök inte längre är realistiskt efter första provtagningsomgången: planering av en eventuell inventering som skall avgränsa vilka delar av landet som är fria från tallvedsnematoden.

8.8 Kunskapsluckor

Vilka är tätheterna av tallbocksangripna vedobjekt (antal per ha skogsmark) i olika delar av landet? I nuläget har vi ingen kunskap om detta. Med denna information kan andelen objekt som ingår i inventeringarna beräknas och därmed också en statistisk sannolikhet för upptäckt vid en given koloniseringsprocent. Denna information är särskilt viktig vid en avgränsningsinventering som skall ligga till grund för beslut om mycket kostsamma utrotningsförsök. Data kan tas fram genom fältinspektioner av hygges- och röjningsavfall i olika delar av landet.

Hur många tallbockar kan man fånga med en doftbetad fälla och på vilken typ av område (t.ex. färska tallhyggen, färska granhyggen eller äldre hyggen från vilken den nya generationen av tallbockar kläcks) fångar den bäst? Dessa frågor kan besvaras med fältexperiment.

Hur stor spridningskapacitet har vår vanliga tallbock? Detta är inte tidigare studerat. Svaret på frågan är av avgörande betydelse för hur fort tallvedsnematoden sprider sig efter en introduktion i Sverige och därmed också hur sannolikt det är att ett utrotningsförsök skall vara meningsfullt. Det är också av intresse för åtgärden att försöka innesluta infekterade områden med korridorer utan värdträd (dvs. hur breda korridorerna måste vara). Svaret på frågan kan fås genom en kombination av experiment i fält och på laboratorium. På laboratorium kan spridningskapaciteten uppskattas med hjälp av flygmöllor. I fält kan man använda sig av märkta djur och harmonisk radar.

Vilket utbredningsområde har kronbocken i Sverige och i vilken typ av skog förekommer den? Kronbocken är den tallbocksart som fungerar som vektor för tallvedsnematoden i Portugal. Det är därför viktigt att populationer av denna art också ingår i den pågående inventeringen för upptäckt av tallvedsnematoden. För att kunna göra detta krävs svar på ovanstående frågor vilket kan fås genom fältexperiment med betade fällor (man kan inte skilja tallbock och kronbock utifrån larvgångar och kläckhål i ved).

Hur skall särskilda riskområden kunna identifieras? En metod behövs där man mer systematiskt tar fram sådan information från handelsstatistik, uppgifter från andra länder där tallvedsnematoden och tallbockar påträffats i importerat material och genom egna inspektioner av importerat material.

9. References

Akbulut S. & Linit M.J. 1999. Flight performance of *Monochamus carolinensis* (Coleoptera: Cerambycidae) with respect to nematode phoresis and beetle characteristics. Environmental Entomology 28: 1014-1020.

Braasch H., Burgermeister W., Harmey M. A., Michalopoulos-Skarmoutsos H., Tomiczek C., Caroppo S. 2000. Pest risk analysis of pinewood nematode related *Bursaphelenchus* species in view of South European pine wilt and wood imports from Asia. Final Report of EU Research Project Fair CT 95-0083.

Cocquempot C. 2006. Alien longhorned beetles (Coleoptera Cerambycidae): original interceptions and introductions in Europe, mainly in France, and notes about recently imported species. Redia, LXXXIX: 35-50.

Cocquempot C. & Lindelöw Å. 2010. Longhorn beetles (Coleoptera, Cerambycidae). Chapter 8.1. In: Roques A. et al. (Eds) Alien terrestrial arthropods of Europe. BioRisk 4: 193-218.

Dwinell D.L. 1997. The pinewood nematode: regulation and mitigation. Annual Review of Phytopathology 35: 153-166.

Ehnström B. & Axelsson R. 2002. Insektsgnag i bark och ved. ArtDatabanken, SLU, Uppsala.

Ehnström B. & Holmer M. 2007. Nationalnyckeln till Sveriges flora och fauna. Skalbaggar: Långhorningar. Coleoptera: Cerambycidae. ArtDatabanken, SLU.

EPPO. 2009a. Report of a pest risk analysis for *Bursaphelenchus xylophilus*. 09/15450, www.eppo.org/QUARANTINE/Pest_Risk_Analysis/PRA_intro.htm

EPPO. 2009b. Pest Risk Analysis for *Bursaphelenchus xylophilus*. 09/15449 (version 2), www.eppo.org/QUARANTINE/Pest_Risk_Analysis/PRA_intro.htm

EPPO. 2010a. EPPO standards on Phytosanitary measures. *Bursaphelenchus xylophilus* and its vectors: procedures for official control. National regulatory control systems, PM 9/1(4), www.eppo.org./STANDARDS/standards.htm

EPPO. 2010b. First record of *Bursaphelenchus xylophilus* in Galicia (Spain), EPPO Reporting Service, 2010/202, No 11, www.eppo.org/PUBLICATIONS/reporting/reporting_service.htm.

European Commission. 2009. EU pinewood nematode *Bursaphelenchus xylophilus* survey protocol 2009, Health and Consumers Directorate-General. Brussels, 28 September 2009.

European Commission. 2010. Report of the commission working group on emergency measures to eradicate pine wood nematode from the Maderian outbreak. Brussels 21 January 2010.

Forsslund K.H. 1934. Tallbockens (*Monochamus sutor L.)* uppträdande på brandfält i norra Sverige sommaren 1933. Svenska Skogsvårdsförbundets Tidskrift 1934, Häfte I-II: 23-38. (In Swedish with German summary).

Francardi V., de Silva, J., pennachio F. & Roversi P.F. 2009. Pine volatiles and terpenoid compounds attractive to European xylophagus species, vectors of *Bursaphelenchus* spp. nematodes. Phytoparasitica 37: 295-302.

Gärdenfors U. 2010. The 2010 red list of Swedish species. ArtDatabanken, SLU, Uppsala.

Ibeas F., Gallego D., Diez J.J. & Pajares J.A. 2007. An operative kairomonal lure for managing pine sawyer beetle *Monochamus galloprovincialis* (Coleoptera: Cerambycidae). Journal of Applied Entomology 131: 13-20.

IPPC. 1997. Guidelines for surveillance. ISPM No. 6. Secreteriat of the International Plant Protection Convention, www.ippc.int.

IPPC. 1998. Determination of pest status in an area. ISPM No. 8. Secreteriat of the International Plant Protection Convention, www.ippc.int.

Jordbruksverket. 2008. Konsekvensanalys av angrepp av tallvedsnematod i svensk skog, Rapport 2008:19.

Linit M.J. 1988. Nematode-vector relationships in the pine wilt disease system. Journal of Nematology 20: 227-235.

Magnusson C. & Schroeder L.M. 1989. First record of a *Bursaphelenchus*-species (Nematoda) in *Monochamus* beetles in Scandinavia. Anzeiger für Schädlingskunde, Pflanzenschutz und Umweltschutz 62: 53-54.

Magnusson C., Schroeder M. & Tomminen J. Nordic Pine Wood Nematode Survey – Draft Manual 2000-02-11. The first version was presented at the working group on PWN in Brussels 2000-01-26.

Magnusson C., Thunes K.H., Nyeggen H., Overgaard H., Rafoss T., Haukeland S., Brurberg M.B., Rasmussen I., Strandennœs K-A., Økland B. & Hammeraas B. 2007. Surveillance of pine wood nematode (PWN) *Bursaphelenchus xylophilus*. Bioforsk Report 2 (104).

Mamyia Y. 1988. History of pine wilt disease in Japan. Journal of Nematology 20: 219-226.

Marini L., Haack R.A., Rabaglia R.J., Toffolo E.P., Battisti A. & faccoli M. 2011. Exploring associations between international trade and environmental factors with establishment patterns of exotic Scolytinae. Biological Invasions 13: 2275-2288.

Mattilsynet 2007. Faglig beredskapsplan for furuvednematode. Versjon 16, oktober, 2007 Mattilsynet, 2007. http://www.vkm.no/dav/2ccd4acde1.pdf

Økland B., Skarpaas O., Schroeder M.L., Magnusson C., Lindelöw Å. & Thunes K. Is eradication of the pinewood nematode (*Bursaphelenchus xylophilus*) likely? An evaluation of current contingency plans. Risk Analysis, 30: 1424-1439.

Pajares J.A., Álvarez G., Ibeas F., Gallego D., Hall D.R. & Farman D.I. 2010. Identification and field activity of a male-produced aggregation pheromone in the pine sawyer beetle, *Monochamus galloprovincialis*. Journal of Chemical Ecology 36: 570-583.

Rautapää J. 1986. Experiences with *Bursaphelenchus xylophilus* in Finland. EPPO Bulletin 16: 453-456.

Robinet C., Roques A., Pan H., Fang G., Ye J., ZhangY. & Sun J. 2009. Role of human-mediated dispersal in the spread of the pinewood nematode in China. PloS ONE 4(2): e4646.

Schroeder L.M. & Magnusson C. 1989. Tallvednematoden – ett hot mot svensk skog? Skogsfakta, Biologi och skogsskötsel nr 64, 1989. SLU.

Schroeder L.M. & Magnusson C. 1992. Transmission of *Bursaphelenchus mucronatus* (Nematoda) to branches and bolts of *Pinus sylvestris* and *Picea abies* by the cerambycid beetle *Monocamus sutor*. Scandinavian Journal of Forest Research 7:107-112.

Schroeder L.M., Weslien J., Lindelöw Å. & Lindhe A. 1999. Attacks by bark- and wood-boring Coleoptera on mechanically created high stumps of Norway spruce in the two years following cutting. Forest Ecology and Management 123: 21-30.

Schroeder L.M. & Lindelöw Å. 2003. Response of *Ips typographus* (Scolytidae: Coleoptera) and other bark- and wood-boring beetles to a flash-flood event. Scandinavian Journal of Forest Research 18: 218-224.

Schröder T., McNamara D.G. & Gaar V. 2009. Guidance on sampling to detect pine wood nematode *Bursaphelenchus xylophilus* in trees, wood and insects. EPPO Bullentin 39, 179-188.

Skogforsk. 2010. Avverkning och hantering av virke och avverkningsrester vid angrepp av tallvedsnematoder i svensk skog. Arbetsrapport nr 719, 2010.

Swedish Board of Agriculture. 2008. Notification of finding of *Bursaphelenchus xylophilus* in wood packing material sent from Portugal., Dnr 20-8741/08.

Swedish Board of Agriculture. 2010. Report on the Pine Wood Nematode Survey in Sweden 2010. Report to the EU commission 20-12-2010, Dnr 20-13553/10.

Swedish Forest Agency. 2009. Swedish statistical yearbook of 2009.

Togashi K. & Shigesada N. 2006. Spread of the pinewood nematode vectored by the Japanese pine sawyer: modelling and analytical approaches. Population Ecology 48: 271–283.

Togashi K., Taga Y., Iguchi K. & Aikawa T. 2008. *Bursaphelenchus mucronatus* (Nematoda: Aphelenchoididae) vectored by *Monochamus urussovi* (Coleoptera: Cerambycidae) in Hokkaido, Japan. Journal of Forest Research 13:127-131.

Tomiczek C., Braasch H., Burgermeister W., Metge K., Hoyer U. & Brandstetter M. 2003. Identification of *Bursaphelenchus* spp. Isolated from Chinese packaging wood imported from China. Nematology 5: 573-581.

Trägårdh I. 1929. On the injury of the pine-sawyer (*Monochamus sutor* L.) and its prevention. Meddelande från Statens Skogsförsöksanstalt 25: 171-228.

Williams D.W., Li G. & Gao R. 2004. Tracking movements of individual *Anoplophora glabripennis* (Coleoptera: Cerambycidae) adults: application of harmonic radar. Environmental Entomology 33: 644-649.

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