Trapping strategy for *Monochamus sutor* and *Monochamus galloprovincialis*: potential vectors of the pine wood nematode in Scandinavia

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**Abstract**

1. The pine wood nematode *Bursaphelenchus xylophilus* is a threat to pine forests in Europe. Annual detection, and delimiting surveys if detected, are mandatory in the European Union. The trapping of *Monochamus* beetles, vectors of pine wood nematode, is included in both types of survey.

2. The efficient use of traps increases the probability of detecting the pine wood nematode. How stand type, bait composition, wet or dry collecting jars, and trapping period during the summer affect the catches of *Monochamus* was investigated in central Sweden.

3. *Monochamus sutor* and *Monochamus galloprovincialis* occurred together in half of the trapping locations, suggesting that the two species could interact as vectors for the pine wood nematode.

4. Baited traps caught 25- to 30-fold more *M. sutor* than unbaited traps. *Monochamus sutor* was four- to seven-fold more abundant on clear-cuts than in pine stands, whereas numbers of *M. galloprovincialis* were similar in both habitats. There was no difference in catch between fresh and old clear-cuts for *M. sutor*. The addition of α-pinene to the pheromone baits increased catches of *M. sutor* by 1.6-fold on old clear-cuts, whereas there was no difference for *M. galloprovincialis*. Wet traps caught approximately two-fold more *M. sutor* than dry traps. Most *M. sutor* were caught in June and July, whereas the flight period of *M. galloprovincialis* started approximately 1 month later and peaked in July.

5. Based on the results, a trapping strategy is presented for *M. sutor* and *M. galloprovincialis* in Scandinavia.

**Keywords** *Bursaphelenchus xylophilus*, dry and wet catches, early detection, *Monochamus galloprovincialis*, *Monochamus sutor*, pine wood nematode, stand type, trapping location, trapping strategy, α-Pinene.

**Introduction**

Although the introduction of non-indigenous pest species has long been known to form a major threat to forest ecosystems (Aukema *et al.*, 2011), there has been an exponential increase in the rate at which alien species have become established in countries around the world (Seebens *et al.*, 2017). It is therefore of utmost importance that more efficient tools are developed to mitigate against any negative effects from biological invasions (Ayres & Lombardero, 2018). Eradication is often the first management strategy considered after an invasive pest species has been detected. However, because a successful eradication is more likely and the costs are also lower when populations are still small and localized (Liebhold *et al.*, 2016), efficient early detection programmes need to be developed (Liebhold, 2012; Rassati *et al.*, 2015; Trumbore *et al.*, 2015). At the early stage of an invasion when population densities are low, attractant-baited traps comprise one of the most efficient methods of detecting insects. Such traps can also be used to delimit the extent of an infested area, which is a crucial step for a successful eradication programme. Trapping programmes should be as efficient as possible to minimize the risk of false negatives (i.e. failing to detect a species despite it being present).
The pine wood nematode (PWN) *Bursaphelenchus xylophilus* (Steiner & Buhrer) is the causal agent of pine wilt disease (PWD), which forms a significant threat to native pine forests in eastern Asia and Europe (Mamiya, 1988; Dwinell, 1997; Togashi & Shigesada, 2006). The nematode is indigenous to North America, although it is not a primary pathogen of native pines there. It is vectored between host trees by cerambycid beetles of the genus *Monochamus* (Limit, 1988; Mamiya, 1988, Schröder et al., 2009). The beetles and nematodes both develop in conifer trees. Juvenile PWN move into the respiratory system of newly developed *Monochamus* beetles before they emerge. Directly after emergence, the beetles feed on the phloem of living conifers, at which time the nematodes may leave the beetles and enter the living trees via the feeding wounds made by the beetles. If it is a susceptible pine species, and if the climatic conditions are suitable and the number of transmitted nematodes exceeds a threshold, PWD may develop, which generally results in tree mortality. After feeding, the beetles are attracted to dying or recently dead trees, including cut trees and cutting residues, where they mate. The female beetle excavates pits in the bark, in which the eggs are laid, and through which the nematodes may also infest the wood.

In Europe, PWN was first detected in Portugal in 1999 and it has now spread over large parts of the country, where it causes considerable tree mortality (Mota et al., 1999; Vicente et al., 2012; Fuente et al., 2018). Thus, there is concern that PWN will also establish in other European countries, including Sweden where three potential vectors of PWN occur: *Monochamus sutor* (L.), *Monochamus galloprovincialis* Olivier and *Monochamus urussovi* (Fischer von Waldheim) (Ehnström & Axelsson, 2002; Ehnström & Holmer, 2007). *Monochamus sutor* is distributed all over Sweden and is common in many regions. *Monochamus galloprovincialis* is not as common as *M. sutor*, although it is still widely distributed. *Monochamus urussovi* is a rare species, which, in recent times, has only been recorded from a few localities. *Monochamus galloprovincialis* is the vector of PWN in Portugal, whereas, for *M. sutor*, no records of association with PWN have been published so far. However, it is likely that this species can also act as a vector of PWN because it is the vector of *Bursaphelenchus mucronatus*, which has a biology similar to that of PWN (Magnusson & Schroeder, 1989; Schroeder & Magnusson, 1992), although it does not cause PWD. Thus, the present study focuses on *M. sutor*, which reproduces in both in Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*), as well as *M. galloprovincialis*, which reproduces only in pine. Several *Monochamus* species use the same male-produced aggregation pheromone: 2-(undecyloxy)-ethanol (hereafter referred to as monochamol) (Pajares et al., 2013; Ryall et al., 2015). It was first demonstrated in *M. galloprovincialis* (Pajares et al., 2010). It is also the major component of the male-produced aggregation pheromone of *M. sutor* (Pajares et al., 2013). In field experiments, *M. sutor* was attracted to monochamol and to the bark beetle pheromone ipsenol (Pajares et al., 2013, 2017). A commercially produced bait for *Monochamus* has already been developed (Galloprouct; SEDQ SL, Spain). In addition to the *Monochamus* aggregation pheromone, and bark beetle pheromones including ipsenol, the bait also includes the monoterpenes α-pinene and ethanol. Host volatiles (α-pinene and ethanol) have been shown to increase the attraction of several *Monochamus* species to its pheromone (Allison et al., 2012; Ryall et al., 2015). Pajares et al. (2013) have shown, in a field experiment, that α-pinene either alone, or in combination with the *Monochamus* and bark beetle pheromones, does not attract *M. sutor* at trapping locations on fresh clear-cuts. However, it is not known whether this also applies to old clear-cuts, from which the natural release of monoterpenes is much lower.

Using the efficient attractants that are available for *M. sutor*, and other *Monochamus* species, adult beetles can be trapped and analyzed for the presence of PWN, comprising an important complement to other methods (e.g. collection of wood samples from objects colonized by *Monochamus*) deployed for the early detection, delimitation, eradication and control of PWN (Schroeder, 2014; Hanks & Millar, 2016). Indeed, trapping with the commercially available bait is already used in several European countries, including Sweden (Schroeder, 2014). Although the first step for efficient trapping has been fulfilled by the development of an attractive bait, other factors may also influence catches, such as stand type, if wet or dry trapping is used, and the period during the season when the traps are operated. Trap catches can be expected to differ between different stand types depending on beetle behaviour and differences in factors such as trap visibility and the aerial dispersion of the attractants from the dispensers (Strand et al., 2009; Dodds, 2011; Thistle et al., 2011). For example, in a North American study, Dodds (2011) caught approximately twice as many bark beetles and cerambycid beetles within and at the edges of stands as in clearings. The time subsequent to tree harvest may also influence the catch size in clear-cuts. The large amounts of host-tree volatiles that are released from logging residues and stumps in fresh clear-cuts may influence beetle catches by interacting with the attractants used in the traps (Schroeder, 2013). If collection cups for wet or dry trapping are used, this is yet another possible influence on the numbers of bark- and wood-boring insects that may be caught (Allison & Redak, 2017). Knowledge of the flight period with respect to the timing of trap deployment is also important in trapping programmes.

The present study addressed six specific questions: (i) how efficient is the commercial bait Galloprotect; (ii) how does stand type influence catch; (iii) how important is the addition of α-pinene to the pheromone baits for catches on old clear-cuts; (iv) how does the distance from stand edge influence catches on clear-cuts; (v) how do the numbers caught differ between dry and wet traps; and (vi) when do trap catches peak in the summer?

**Materials and methods**

Three experiments were conducted in the provinces of Uppland and Gästrikland in central Sweden. In this region, >90% of the forest land is constituted by even-aged production stands, dominated by Norway spruce and Scots pine, managed by two to three thinnings before final harvest by clear-cutting at an age of approximately 80 years. The trapping experiments were conducted on clear-cuts and in managed pine stands. In Experiment 1, catches were compared between different stand types. In Experiment 2, the effect on catches of adding α-pinene to the pheromone baits was tested as well as the importance of stand type. In Experiment 3, the influence of trap position within the clear-cut, as well as wet or dry catches, was studied. In all

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three years, traps were operated during the whole season and thus the data could also be used to study the phenology of *M. sutor* and *M. galloprovincialis*.

Experiment 1, conducted in 2012, was designed to compare trap catches in fresh clear-cuts (harvested the previous winter), 3-year-old clear-cuts and pine stands (minimum tree diameter of 15 cm at a height of 1.3 m, closed canopy; not recently thinned) and to test the efficacy of the commercial bait. The rationale behind this experiment was based on earlier studies demonstrating that habitat type may influence trap catches of bark- and wood-boring beetles (Dodds, 2011). The experiment was arranged in 10 blocks, each including all three stand-types. The mean distances between stands within blocks were: 1840 m (range 1100–4000 m) between fresh clear-cuts and pine stands; 1700 m (range 800–3200 m) between fresh clear-cuts and old clear-cuts; and 1925 m (range 850–4500 m) between old clear-cuts and pine stands. The minimum distance between blocks was 8600 m. The mean ± SE size of the clear-cuts was: fresh clear-cuts: 17.7 ± 6.1 ha; old clear-cuts: 19.6 ± 6.0 ha. In each location, two traps were placed 50 m apart and 50 m from the nearest stand edge, one baited with Galloprotect (SEDO SL) and one unbaited. Galloprotect consists of three components (separate dispensers): the conifer monoterpenes (±)-α-pinene, monochamol, and the bark beetle pheromones ipsenol and 2-methyl-3-buten-2-ol (hereafter bark beetle pheromones). The traps were baited during the period 15–24 May (within blocks the traps were baited on the same day) and emptied nine times from 30 May to 28 August. Old baits were replaced with fresh baits on the fifth emptying (19–24 July).

Experiment 2, conducted in 2013, was designed (i) to assess the effect on trap catches of adding the monoterpenes (±)-α-pinene to the traps baited with monochamol and the bark beetle pheromones when old clear-cuts are used as trapping locations and (ii) to compare catches between clear-cuts and pine stands. The rationale behind the experiment using traps with and without α-pinene was that the release of monoterpenes from logging residues is much lower on old than on fresh clear-cuts. In each of 22 1–3-year-old clear-cuts, two traps were placed 50 m apart and 50 m from the nearest stand edge. One of the traps was baited with the complete 3-component Galloprotect bait (α-pinene, monochamol and bark beetle pheromones) and the other one with only monochamol and bark beetle pheromines. The minimum distance between clear-cuts was 7500 m. The mean ± SE size of the clear-cuts was 8.6 ± 1.2 ha. In 11 of the localities, a trap baited with the complete Galloprotect bait was also placed in an adjacent pine stand, at least 200 m from the traps on the clear-cut and 20 m into the stand. The traps were baited during the period 14–16 May and emptied eight times until 2–4 September. Old baits was replaced with fresh baits during the fourth emptying (9–10 July).

Experiment 3, conducted in 2015, was designed to compare the number of beetles captured in traps set along the forest edge (hereafter border) or 50 m out in fresh clear-cuts, and between traps with wet or dry collecting jars. No kill strips were added to the dry cups. Treatments were replicated five times in a randomized block design with each block on a separate fresh clear-cut. The minimum distance between blocks was 9100 m. The traps were baited with the *Monochamus* and the bark beetle pheromones. The traps were baited on 14 May and emptied 28 times from 21 May to 7 September. The baits were changed in mid-July.

In all trapping experiments, 12-unit Multifunnel-traps fitted with bottom collection containers designed for wet trapping (Econex SL, Spain) were used, except in Experiment 3, in which collection containers designed for dry catches were also used. For wet catches, collecting containers were filled with water with some added detergent. The release rates of the tested volatiles [monochamol, host volatile (±)-α-pinene, and bark beetle pheromones racemic ipsenol and racemic 2-methyl-3-buten-2-ol] were approximately 2, 500, 2.5 and 10 mg/day, respectively (Pajares et al., 2017).

Species were identified according to the lateral pubescence on the pronotum: *M. sutor* has dense and fine hairs, whereas *M. galloprovincialis* only has a few coarser hairs (Wallin et al., 2013). In addition, all males were identified to species based on their genitalia, which confirmed the identification based on pubescence.

**Statistical analysis**

In Experiment 1, only trap catches from baited traps were included in the statistical analysis because of very low catches in unbaited traps. Data were log transformed to normalize variances and subjected to generalized linear model with treatment and block as fixed factors using R, version 3.5.1 (R Foundation for Statistical Computing, Austria). Treatment means were compared using pairwise comparisons adjusted for multiple testing with Tukey’s method using the R package emmeans. In Experiment 2, differences in catches between stand types and between traps with and without α-pinene were tested with a pairwise t-test. Only blocks with catches were included in the analyses for the two species. Thus, for *M. sutor*, n = 11 for comparison of stand types and n = 22 for comparison of traps with and without α-pinene (caught in all blocks), whereas, for *M. galloprovincialis*, n = 7 for comparison of stand types and n = 14 for comparison of traps with and without α-pinene. In Experiment 3, data were log transformed to normalize variances. The data were subjected to a generalized linear model with two fixed factors (i.e. wet/dry catches and border/clear-cut) including interaction between the two factors. The first analysis demonstrated that there was no significant interaction between the factors and thus an analysis without the interaction term was conducted.

**Results**

In total, 822 *M. sutor* and 15 *M. galloprovincialis* were caught in Experiment 1. *Monochamus sutor* was caught in all 10 blocks, whereas *M. galloprovincialis* was caught in only three of the blocks. Most individuals were caught in the baited traps for both species: 792 out of 822 for *M. sutor* and 14 out of 15 for *M. galloprovincialis*. There was a significant treatment effect on the catches of *M. sutor* (*F*₂,26 = 34.4, *P* < 0.001) and a significant block effect (*F*₁,26 = 8.8, *P* < 0.01). Catches of *M. sutor* were 5.5- to 6.7-fold higher in clear-cuts than in pine stands (Fig. 1) and these differences were significant (*P* < 0.001). Catches of *M. sutor* were slightly higher in fresh clear-cuts compared
with old clear-cuts, although this difference was not significant ($P = 0.61$). For *M. galloprovincialis*, too few beetles were caught for a statistical analysis, although the trend was that catches were similar for all three stand types (fresh clear-cuts: $0.4 \pm 0.6$ (mean $\pm$ SE); old clear-cuts: $0.6 \pm 0.6$; pine stands: $0.4 \pm 0.2$).

In total, 1474 *M. sutor* and 458 *M. galloprovincialis* were caught in Experiment 2. *Monochamus sutor* was caught in all 22 blocks, whereas *M. galloprovincialis* was caught in 14 blocks. Catches of *M. sutor* were 4.5-fold higher on clear-cuts than in pine stands and the difference was significant ($P = 0.0009$, pairwise $t$-test, $n = 11$), whereas there was no significant difference for *M. galloprovincialis* ($P = 0.629$, pairwise $t$-test, $n = 7$) (Fig. 2A). For *M. sutor*, the addition of $\alpha$-pinene significantly increased catches by 1.6-fold on old clear-cuts ($P = 0.024$, pairwise $t$-test, $n = 22$), whereas there was no significant difference in catches for *M. galloprovincialis* ($P = 0.518$, pairwise $t$-test, $n = 14$) (Fig. 2B).

In total, 956 *M. sutor* and no *M. galloprovincialis* were caught in Experiment 3. *Monochamus sutor* was caught in all five blocks. There was a significant effect of treatment ‘wet or dry catches’ ($F_{1,15} = 17.3$, $P < 0.001$). Wet catches were approximately two-fold higher than dry catches [wet catches: $64.7 \pm 7.1$ (mean $\pm$ SE); dry catches: $30.9 \pm 3.9$; $n = 10$]. There was no significant effect of treatment ‘border or clear-cut’ ($F_{1,15} = 0.87$, $P = 0.36$). Catches were slightly higher at clear-cut border than 50 m out on clear-cut [border: $28.3 \pm 9.0$ (mean $\pm$ SE); clear-cut: mean $\pm$ SE $= 21.3 \pm 6.7$; $n = 10$].

*Monochamus sutor* first appeared in the traps in late May or early June and were absent by late August (Fig. 3A,C,D). The date for 50% cumulative catch varied from 22 June to 6 July in different years. The seasonal cumulative catches of *M. sutor* did not differ much among the different stand types in 2012 (Fig. 3B). The flight period of *M. galloprovincialis* in 2013, comprising the only year with a considerable catch, started in the second half of June and ended in late August (Fig. 3C) and its 50% cumulative catch occurred approximately 1 month later than that for *M. sutor*.

**Discussion**

*Monochamus sutor* dominated the catch in the present study, with a total catch of 3252 individuals compared with 473...
Material (Trägårdh, 1929; Schroeder & Lindelöw, 2003). Thus, in Sweden, the major source of breeding material comprises logging residues in clear-cuts, such as the tops of Norway spruce and Scots pine, and branches of Scots pine (Schroeder, 2012, 2014). Monochamus sutor also breeds in burned trees (Trägårdh, 1929), although burned stands are much scarcer than clear-cuts in Scandinavia. Thus, M. sutor appears to be a species that is adapted to use substrates created by disturbances such as burned trees after forest fires, wind-felled trees after storms and logging residues after cuttings. Monochamus galloprovincialis, on the other hand, generally colonizes branches on dead or dying Scots pine trees in sun-exposed pine forest on sandy or rocky ground in Sweden (Ehnström & Axelsson, 2002; Ehnström & Holmer, 2007), although it has also been found in logging residues in Sweden and Finland (Tomminen, 1993; Schroeder, 2014). Thus, the lack of differences in catches between clear-cuts and pine stands for this species may be a result of it utilizing breeding material in both habitats (i.e. fresh pine branches on the ground broken by wind or snow, as well as dying branches on drought stressed pine trees). Also other studies, conducted in North America, have shown that Monochamus species may differ in their catchability between forest stands and more open areas like clear-cuts or Christmas tree plantations (Blatt et al., 2017; Allison et al., 2019).

There was no significant difference in catches of M. sutor between fresh and old clear-cuts. Obviously, the high release rates of monoterpenes, including α-pinene (a major monoterpene in both spruce and pine), from the fresh logging residues and stumps did not strongly increase the attraction of beetles to the attractants used in the trapping experiment. In 1–3-year-old clear-cuts, from which the release of monoterpenes decreased strongly compared with that from fresh clear-cuts, the addition of α-pinene to the monochamol and bark beetle pheromone baits increased catches of M. sutor by 1.6-fold, whereas there was no increase in catch for M. galloprovincialis. Thus, the two Monochamus species rely mainly on bark beetle pheromones and their own pheromone when flying around searching for suitable breeding material and mates.

Fresh clear-cuts offer a lot of suitable breeding material for M. sutor (i.e. conifer tops and branches) in contrast to old clear-cuts where the substrates are too dry or have already been colonized by other insects (Schroeder, 2012, 2014). Thus, an accumulation of dispersing beetles could have been expected on fresh clear-cuts as a result of the beetles staying there for mating and egg-laying. However, the results provide no evidence of such an accumulation because there was neither any significant difference in catches between fresh and old clear-cuts, nor any difference in the seasonal patterns of catches from fresh and old clear-cuts and pine stands. Moreover, the catches on old clear-cuts were not the result of beetles emerging from the breeding material because they were too old (3 years). To conclude, the results obtained indicate that M. sutor moves around in the forest landscape during the whole season.

Figure 3 Seasonal patterns of cumulative trap catches of (A) Monochamus sutor and Monochamus galloprovincialis in 2012 (Experiment 1); (B) M. sutor in different stand types (Experiment 1); (C) M. sutor and M. galloprovincialis in 2013 (Experiment 2); and (D) M. sutor in 2015 (Experiment 3). Data for all treatments are combined and the n-values (number of caught individuals) are provided in the figures.
The flight period of *M. sutor*, as estimated by baited traps, extends from the second half of May until the end of August. Most beetles were caught in June and July. The flight period occurred approximately 1 month later for *M. galloprovincialis* than for *M. sutor*. This may reflect differences in the abundance of the major sources of their respective breeding materials. *Monochamus sutor* reproduce to a large extent in logging residues that are mainly created during the winter and thus are already available in early spring. By contrast, *M. galloprovincialis* may depend more on drought stressed trees or branches, which are more common later in the summer. More beetles were caught in wet than in dry traps, which is in accordance with earlier studies on *Monochamus* species, as well as other groups of bark- and wood-boring beetles (Allison & Redak, 2017). The difference arises from some beetles managing to escape from traps with dry collecting cups.

**Implications for PWN surveys**

When trapping vector beetles in detection and delimiting surveys for PWN, it is important to use traps in the most efficient way possible to maximize catches of *Monochamus*. This is especially important in regions such as Scandinavia where PWD is not expected and where the proportion of vector beetles harbouring PWN may be low (Okland et al., 2010; Schroeder, 2014). For *M. sutor*, traps should be placed on clear-cuts that are fresh or up to several years old. Because production forests dominate in Sweden, and clear-cutting is the dominant harvesting method, there are many places over the wider landscape where trapping in clear-cuts is possible. One additional advantage with trapping in clear-cuts is that the Swedish Forestry Agency has all of the clear-cuts mapped on a nationwide GIS-layer, which can be used to select trapping positions. For *M. galloprovincialis*, there was no difference in catches between clear-cuts and pine stands. Thus, for this species, pine stands can also be used as trapping sites if there is a lack of clear-cuts. An earlier study demonstrated seven-fold higher catches of *M. galloprovincialis* in traps placed in the tree canopy compared with traps at ground level (Foit et al., 2019). *Monochamus* beetles that are to be analyzed for the presence of PWN are generally caught alive in dry traps. However, because considerably higher numbers are caught in wet traps, which also require less frequent monitoring, this method could be a more efficient alternative to dry traps. Nematodes recovered from a wet trap study of *M. galloprovincialis* carrying PWN, using monoethanol glycol in the collecting cup as a preservative, died within 24 h. This resulted in certain morphological characters being altered to such an extent that it hampered their identification (Berkvens et al., 2017). However, identification by molecular techniques was still possible (see also Blatt et al., 2019). The number of *M. sutor* caught will be nine- to 14-fold higher if traps are situated in clear-cuts and wet collecting cups are used, rather than the traps being situated in stands in conjunction with dry collector cups.

The difference in flight period means that, if the vector species is unknown, the trapping period should be extended to cover peaks in flight activity for both species, at least in areas where both species may be present.

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**References**

Allison, J.D. & Redak, R.A. (2017) The impact of trap type and design features on survey and detection of bark and woodboring beetles and their associates: a review and meta-analysis. *Annual Review of Entomology, 62*, 127–146.

Allison, J.D., McKenney, J.L., Millar, J.G., McElfresh, J.S., Mitchell, R.F. & Hanks, L.M. (2012) Response of the woodboring *Monochamus carolinensis* and *Monochamus titillator* (Coleoptera: Cerambycidae) to known cerambycid pheromones in the presence and absence of the host volatile *α*-pinene. *Environmental Entomology, 41*, 1587–1596.

Allison, J., Strom, B., Sweeney, J. & Mayo, P. (2019) Trap deployment along linear transects perpendicular to forest edges: impact on capture of longhorned beetles (Coleoptera: Cerambycidae). *Journal of Pest Science, 92*, 299–308.

Aukema, J.E., Leung, B., Kovacs, K. et al. (2011) Economic impacts of non-native forest insects in the continental United States. *PLoS ONE, 6*, e24587.

Ayres, M.P. & Lombardero, M.J. (2018) Forest pests and their management in the Anthropocene. *Canadian Journal of Forest Research, 48*, 292–301.

Berkvens, N., Waeyenberge, L., Castels, H., et al. (2017) Effects of the wet catching method on the detection of *Bursaphelenchus xylophilus* from trapped longhorn beetle vectors. *Nematology, 19*, 671–680.

Blatt, S., Bishop, C. & Sweeney, B.J. (2017) Incidence of *Monochamus* (Coleoptera: Cerambycidae) species in Nova Scotia, Canada Christmas tree plantations and comparison of panel traps and lures from North America and Europe. *The Canadian Entomologist, 149*, 191–203.

Blatt, S., Bishop, C. & Burgher-McLellan, K. (2019) Incidence of *Bursaphelenchus xylophilus* (Nematoda: Parasitaphelenchidae) in Nova Scotia, Canada Christmas tree plantations and comparison of panel traps and lures from North America and Europe. *The Canadian Entomologist, 151*, 350–364.

Delli, K.J. (2011) Effects of habitat type and trap placement on captures of bark (Coleoptera: Scolytidae) and longhorned (Coleoptera: Cerambycidae) beetles in semichochemical-baited traps. *Journal of Economic Entomology, 104*, 879–888.

Dwinell, D.L. (1997) The pinewood nematode: regulation and mitigation. *Annual Review of Phytopathology, 35*, 153–166.

Ehnström, B. & Axellson, R. (2002) *Insektsgnag i bark och ved*. ArtDatabanken, SLU, Sweden.

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

Foit, J., Cermak, V., Gaar, V., Hradil, K., Novy, V. & Rolincova, P. (2019) New insights into the life history of *Monochamus galloprovincialis* can enhance surveillance strategies for the pine wood nematode. *Journal of Pest Science, 92*, 1203–1215.

Fuente, B., Saura, S. & Beck, P.S.A. (2018) Predicting the spread of an invasive tree pest: the pine wood nematode in Southern Europe. *Journal of Applied Ecology, 55*, 2374–2385.
Hanks, L.M. & Millar, J.G. (2016) Sex and aggregation-sex pheromones of cerambycid beetles: basic science and practical applications. *Journal of Chemical Ecology*, 42, 631–654.
Liebhold, A.M. (2012) Forest pest management in a changing world. *International Journal of Pest Management*, 58, 289–295.
Liebhold, A.M., Berce, I., Brockenhoff, E.G. et al. (2016) Eradication of invading insect populations: from concept to applications. *Annual Review of Entomology*, 61, 335–352.
Limit, 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. *Anziger für Schädlingskunde, Pflanzenschutz und Umweltschutz*, 62, 53–54.
Mamiya, Y. (1988) History of pine wilt disease in Japan. *Journal of Nematology*, 20, 219–226.
Mota, M., Braasch, H., Bravo, M., Penas, A., Burgermeister, W., Metge, K. & Sousa, E. (1999) First report of *Bursaphelenchus xylophilus* in Portugal and in Europe. *Nematology*, 1, 727–734.
Ökland, B., Skarpaas, O., Schroeder, M.L., Magnusson, C., Lindelöw, Å. & Thunes, K. (2010) Is eradication of the pine wood nematode (*Bursaphelenchus xylophilus*) likely? An evaluation of current contingency plans. *Risk Analysis*, 30, 1424–1439.
Pajares, J.A., Alvarez, G., Ibañez, F., Gallego, D., Hall, D.R. & Farman, D.I. (2010) Identification and field activity of a male-produced pheromone in the pine sawyer beetle, *Monochamus galloprovincialis*. *Journal of Chemical Ecology*, 36, 570–583.
Pajares, J.A., Alvarez, G., Hall, D.R. et al. (2013) 2-(Undecyloxy)-ethanol is a major component of the male-produced aggregation pheromone of *Monochamus sutor*. *Entomologia Experimentalis et Applicata*, 149, 118–127.
Pajares, J.A., Alvarez, G., Hall, D.R. et al. (2017) Attractants for the management of the pine sawyer beetle *Monochamus sutor*, a potential vector of *Bursaphelenchus xylophilus*. *Journal of Applied Entomology*, 141, 97–111.
Rassati, D., Faccoli, M., Petrucco Toffolo, E., Battisti, A. & Marinì, L. (2015) Improving the early detection of alien wood-boring beetles in ports and surrounding forests. *Journal of Applied Ecology*, 52, 50–58.
Ryall, K., Silk, P., Webster, R.P. et al. (2015) Further evidence that monochamol is attractive to *Monochamus* (Coleoptera: Cerambycidae) species, with attraction synergised by host plant volatiles and bark beetle (Coleoptera: Curculionidae) pheromones. *The Canadian Entomologist*, 147, 564–579.
Schröder, T., McNamara, D.G. & Gaar, V. (2009) Guidance on sampling to detect pine wood nematode *Bursaphelenchus xylophilus* in trees, wood and insects. *EPPO Bulletin*, 39, 179–188.
Schroeder, M. (2012) Strategies for detection and delimitation surveys of the pine wood nematode in Sweden. Swedish Board of Agriculture Report 2012:4, Sweden. URL: https://webbutiken.jordbruksverket.se/sv/artiklar/strategies-for-detection-and-delimitation-surveys-of-the-pine-wood-nematode-in-sweden.html.
Schroeder, L.M. (2013) Monitoring of *Ips typographus* and *Pityogenes chalcographus*: influence of trapping site and surrounding landscape on catches. *Agricultural and Forest Entomology*, 15, 113–119.
Schroeder, M. (2014) A strategy for delimitation survey in case of an introduction of the pine wood nematode in Sweden. Swedish Board of Agriculture Report 2014:25, Sweden. URL: https://webbutiken.jordbruksverket.se/sv/artiklar/ta1425.html.
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.
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 *Monochamus sutor*. *Scandinavian Journal of Forest Research*, 7, 107–112.
Seebens, H., Blackburn, T.M., Dyer, E.E. et al. (2017) No saturation in the accumulation of alien species. *Nature Communications*, 8, 14435.
Strand, T., Lamb, B., Thistle, H., Allwine, E. & Peterson, H. (2009) A simple model for simulation of insect pheromone dispersion within forest canopies. *Ecological Modelling*, 220, 640–656.
Thistle, H.W., Strom, B., Strand, T., Peterson, H.G., Lamb, B.K., Edburg, S. & Allwine, G. (2011) Atmospheric dispersion from a point source in four southern pine thinning scenarios: basic relationships and case studies. *Transactions of the ASABE*, 54, 1219–1236.
Togashi, K. & Shigesada, N. (2006) Spread of the pine wood nematode vectored by the Japanese pine sawyer: modeling and analytical approaches. *Population Ecology*, 48, 271–283.
Tomminen, J. (1993) Development of *Monochamus galloprovincialis* Olivier (Coleoptera, Cerambycidae) in cut trees of young pines (*Pinus sylvestris* L.) and log bolts in southern Finland. *Entomologica Fennica*, 4, 137–142.
Trägårdh, I. (1929) On the injury of the pine-sawyer (*Monochamus sutor*) and its prevention. *Meddelande från Statens Skogsförsöksanstalt*, 25, 171–228. (In Swedish with English summary).
Trumbore, S., Brando, P. & Hartman, H. (2015) Forest health and global climate change. *Science*, 349, 814–818.
Vicente, C., Espada, M., Vieira, P. & Mota, M. (2012) Pine wilt disease: a threat to European forestry. *European Journal of Plant Pathology*, 133, 89–99.
Wallin, H., Schroeder, M. & Kvämmne, T. (2013) A review of the European species of *Monochamus* Dejean, 1821 (Coleoptera, Cerambycidae) – with a description of the genitalia characters. *Norwegian Journal of Entomology*, 60, 11–38.

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