Final Report

Project title (Acronym)
Multi-lure and multi-trap surveillance for invasive tree pests (Multitrap)

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1. Research consortium partners

Coordinator – Partner 1			
Organisation	Fera Science Ltd (Fera)		
Name of Contact (incl. Title)	Dr. Neil Audsley	**Gender**:	M
Job Title	Principal Scientist		
Postal Address	Sand Hutton, York, YO41 1LZ, UK		
E-mail	neil.audsley@fera.co.uk		
Phone	+44 (0)1904 462628		

Partner 2			
Organisation	Austrian Research Centre for Forests (BFW)		
Name of Contact (incl. Title)	Dr. Gernot Hoch	**Gender**:	M
Job Title	Head of Department of Forest Protection		
Postal Address	Seckendorff-Gudent-Weg 8, 1131 Vienna, Austria		
E-mail	gernot.hoch@bfw.gv.at		
Phone	+43 1 87838 1155		

Partner 3			
Organisation	National Institute for Agronomic Research (INRA)		
Name of Contact (incl. Title)	Dr. Alain Roques	**Gender**:	M
Job Title	Research Director		
Postal Address	INRA Zoologie Forestière, 2163 Avenue de la Pomme de Pin, 45075 ORLEANS Cedex 2, France		
E-mail	alain.roques@inra.fr		
Phone	+33(0)238417858		

Partner 4			
Organisation	Netherlands Food and Consumer Product Safety Authority (NVWA)		
Name of Contact (incl. Title)	Dr. Antoon Loomans	**Gender**:	M
Postal Address	P.O. Box 9102, 6700 HC Wageningen, the Netherlands		
E-mail	a.j.m.loomans@nvwa.nl		
Phone	+31 622602540		

Partner 5			
Organisation	National Institute for Agronomic and Veterinary Research (INIAV)		
Name of Contact (incl. Title)	Dr. Edmundo Manuel R. De Sousa	**Gender**:	M
Postal Address	Av da Republica, Nova Oeiras, 2780-159 Oeiras, Portugal		
E-mail	Edmundo.sousa@iniav.pt		
Phone	+351 21 4463712		

Partner 6			
Organisation	Canadian Food Inspection Agency (CFIA)		
Name of Contact (incl. Title)	Dr. Troy Kimoto	**Gender**:	M
Postal Address	Canadian Food Inspection Agency, Room # 400, 4321 Still Creek Drive Burnaby, British Columbia, Canada, V5C 6S7		
E-mail	Troy.Kimoto@inspection.gc.ca		
Phone	+1 604 292-5651		

2. Short project report

2.1. Executive Summary

Invasive non-native xylophagous longhorn, bark and jewel beetles are a serious threat to the biosecurity of urban, rural and forest trees, causing long-term damage and tree mortality. This has major impacts on pest and tree management as well as ecosystem services provide by trees. These beetles arrive in various forms of timber including logs, lumber, wood packaging, pallets and live trees for planting. Hence, early detection at or close to points of entry is therefore of paramount importance for the implementation and success of eradicating an invasive species.

This project aimed to advance previous studies (Rassati *et al*., 2014; 2015) that demonstrated multi-funnel traps baited with multi-lures could be used to monitor for invasive beetles at points of entry of imported wood, but focusing primarily on longhorn beetles (Cerambycidae).

The traps and lures currently available for surveillance of invasive xylophagous beetles were reviewed (Down and Audsley, 2017) and were used together with work conducted by INRA (Roques *et al*., 2017) to select lures for testing at 21 ports of entry and 22 forest sites.

This study determined that, using black cross-vane or multi-funnel traps in a parallel set-up across the partner countries, the optimal detection strategy is to use pheromone blends in combination with the host plant volatiles, ethanol and α-pinene. This maximises the taxonomic diversity of beetles captured, particularly Cerambycidae and minimises the number of traps and lures required. Over 80 species of Cerambycidae were captured in both years (2017 and 2018) of study. Such traps and lures are not suitable for Buprestidae.

A standard protocol was produced that should be followed so that surveillance can be standardised and consistent and could contribute towards compliance with community regulations on national surveys for European quarantine pests.

Although the cost-effectiveness of individual trapping programmes will always have to be evaluated on a case by case basis, there are potential benefits from replacing single-lure trapping programmes with combined multi-lure programmes for early detection. Including multi-lures in a single trap reduces the number of traps required, effort of deployment and servicing, and increases the number of different target species captured, thereby increasing trapping efficacy and reducing costs compared to multiple traps baited with single lures. Trap density is also an important success parameter for early detection, which in turn increases the probability of successful eradication thereby reducing costly pest damages.

2.2. Project aims

Invasive non-native xylophagous insects, in particular, wood boring beetles belonging to the Cerambycidae (long horn beetles), Buprestidae (jewel beetles) and the Scolytinae (bark beetles), a sub family of Curculionidae (the true weevils), represent a serious threat to the biosecurity of urban, rural and forest trees. Such pests cause long-term damage and tree mortality, which impacts heavily on associated costs of pest and tree management and ecosystem services provided by trees.

These beetles can enter into a country in various forms of timber such as logs, lumber, wood packaging, pallets as well as live trees for planting (Rassati *et al*., 2014). Early detection at or close to points of entry is therefore of paramount importance for the implementation and success of eradicating an invasive species (Pluess *et al*., 2012; Rassati *et al*., 2014).

Rassati *et al*. (2014; 2015) compared single lures versus blends of lures and multi-funnel versus cross-vane traps to monitor bark beetles at Italian seaports. These authors report that the number of species captured using multi component lures was equal to the sum of single lures with no evidence of negative interference. The two trap designs also performed equally well, but multi-funnel traps were found to be more robust at seaports. They concluded that multi-funnel traps baited with multi-lures could be used to monitor for invasive beetles at points of entry of imported wood. The primary aim of the Euphresco project 2015-F-175 'Multi-lure and multi-trap surveillance for invasive tree pests' was to extend the multi-species surveillance techniques for alien wood-boring beetles at Italian ports developed by Rassati *et al.* (2014, 2015), with a special focus on Cerambycidae. The objectives were:

a) To determine what traps and lures are already available, including host volatile lures, pheromone lures.

b) To evaluate the efficiencies of different lures / traps for each invasive species and whether lures can attract more than one invasive species.

c) To determine how to efficiently monitor for multiple pest species using multiplex trapping.

d) To provide a cost/benefit analysis of multiplex (multi-trap, multi-lure lures) detection of multiple species versus a more targeted approach to individual species.

e) To identify the constraints on multiplex trapping of invasive species at identified high risk sites (e.g. access, security, suitable locations etc.).

2.3. Description of main activities

2.3.1. Review of traps and lures

A review of currently available traps and lures for invasive xylophagous coleopteran pests of trees was produced and submitted at the end of year 1. The deliverable is available in Appendix I.

2.3.2. Trapping at ports and woodland

Based on this information from the literature review and previous work carried out by project partner INRA (Roques *et al*., 2017), a joint experiment was carried out in project countries. Different combinations of pheromones and kairomones for Cerambycidae were tested in ports (high risk areas for the introduction), both on the site as well as in adjacent forests, and in forests with no ports of entry in their vicinity. Because we could only expect random arrivals of non-native species in ports, trappings in forests appeared necessary in order to assess the attractiveness of the lures for the targeted xylophagous groups.

2.3.2.1. Sites

Trappings were carried out across 5 countries; Austria, France, The Netherlands, Portugal, United Kingdom (figure 1).

22 forested sites were selected to compare trap efficacy. Forest sites contained mixed species including pine (*Pinus sylvestris, P. pinastre, P. uncinata*, *P. nigra*) with various levels of broad-leaf species; Beech (*Fagus sylvatica*), Sycamore (*Acer pseudoplatanus*), Oak (*Quercus robur*, *Q. petraea*, larch (*Larix decidua*).

Ports of entry included maritime ports, airports, trade markets and nurseries. Traps were hung inside and/or outside these sites in neighbouring woodland.

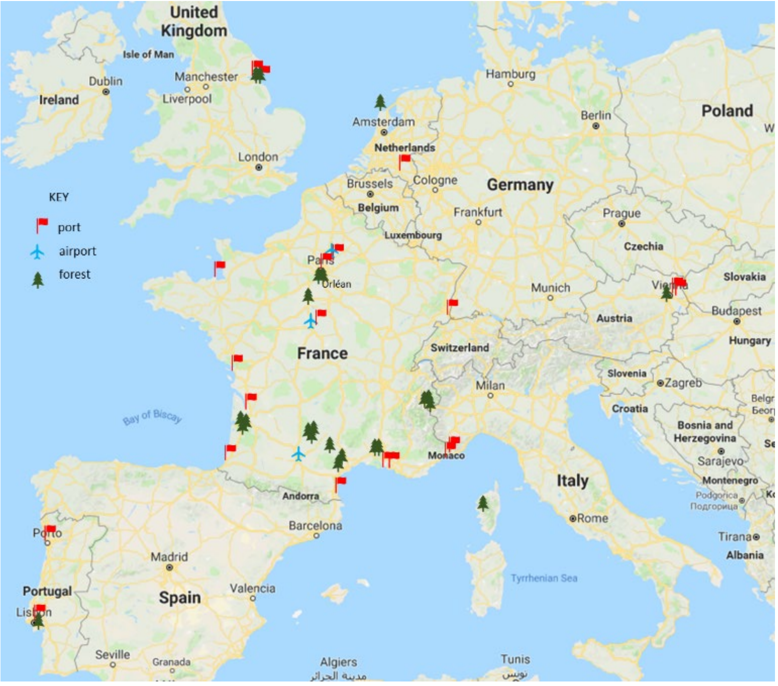

Figure 1. Locations of trapping sites in Austria, France, Portugal, the Netherlands and UK.

2.3.2.2. Traps

Two types of traps were compared: black cross-vane and black multi-funnel (8 funnels) (see Fig. 2) purchased from Chemtica International, Costa Rica. Traps were hung at a height of 2 metres, more than 50 metres apart. Pesticide nets (Storanet, BASF), to kill captured invertebrates, were placed in the white collection beakers located at bottom of traps. One trap type was used at ports, at woodland sites a comparison was made between the two trap types.

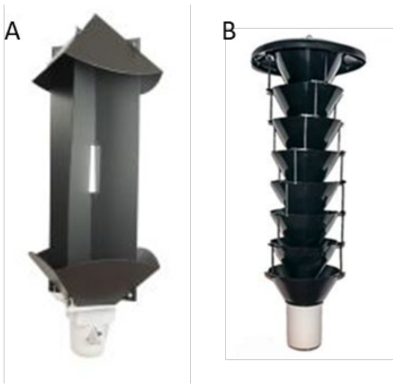

Figure 2. Cross-vane (A) and multi-funnel (B) traps.

2.3.2.3. Lures

Three different lures consisting of blends of cerambycid sex- and sex-aggregation pheromone components were used; kairomones were added in certain treatments (Table 1). All tested compounds are known to present a generic attractiveness at world level for certain genera, tribes of subfamilies of cerambycids, and thus are expected to be capable of attracting non-native species at arrival in ports (Appendix 2; Barbour *et al*., 2011; Hanks *et al*. 2012).

Table 1. Combinations of cerambycid pheromones and kairomones used in this study.

Lure	Pheromones	Kairomones
1+	Fuscumol, fuscumol acetate, geranyl acetone, monochamol	Ethanol, α-pinene
2	3-hydroxyhexan-2-one, prionic acid, 2-methylbutanol, 2R*,3S*-hexanediol	
3	Mixture of lure 1+2	
3+	Mixture of lure 1+2	Ethanol, α-pinene

All pheromones were purchased from ChemTica International, Costa Rica, except for prionic acid that was purchased from AlphaScents USA. The pheromone blends (table 1) were then made at INRA, Orléans. Ethanol and α-pinene were purchased from Sigma-Aldrich.

Chemicals were absorbed on to cotton swabs and placed in sealed plastic bags. Bags were then fastened to the traps. Separate bags with cotton swabs of ethanol and α-pinene were also used on traps with lure 1 (1+), and in 2018 only, traps with lure 3 were compared with (3+) and without (3) ethanol and α-pinene

2.3.2.4. Sampling and invertebrate identification

Samples were collected every 3-weeks, invertebrate were stored in 70% ethanol or dry for identification. Lures and pesticide nets were replaced. A total of 6 collections were made from each trap over an 18-week period.

2.3.3. Standard protocol for trap deployment and dry-sample collection

A standard protocol for the deployment and servicing of multi-lure traps was devised to ensure standard procedures for monitoring for xylophagous beetles in each country (see Appendix 3).

2.3.4. Constraints of multi-plex trapping

The constraints of multi-plex trapping of invasive beetles at high risk sites was assessed (see appendix 4).

2.3.5. Cost-benefit analysis

Semi-structured interviews with project scientists have been carried out to describe the national deployment contexts. In addition, web-based reviews of existing literature on the economics of pheromone trapping, the impact of target pests and plant health legislation, have been conducted to support agent-based modelling for assessing the impact of deployment and control parameters.

2.4. Main results

The main results are presented below:

Large variations in trappings were observed between sites. The number of trapped species and individuals were significantly higher in forest sites compared to ports (figure 3).

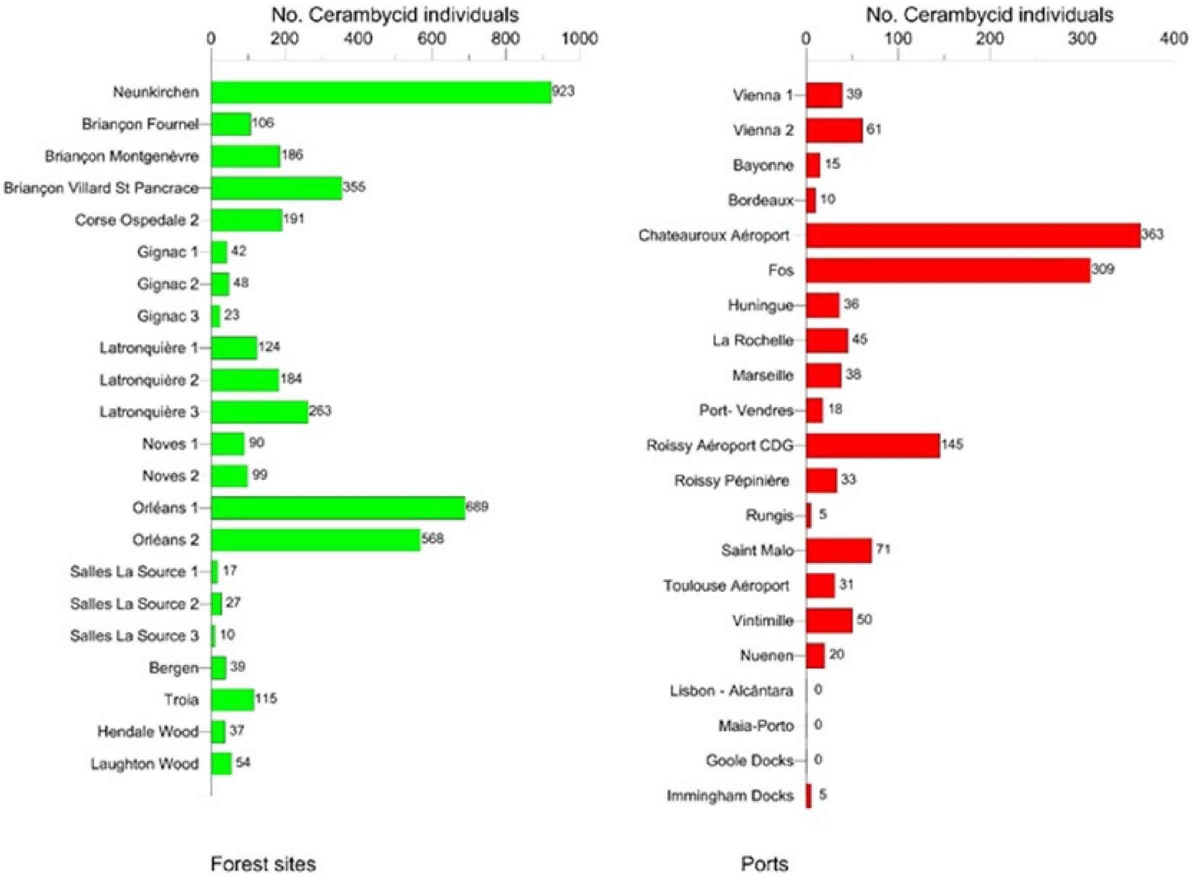

Figure 3. A comparison between the number of individual Cerambycidae captured at forest (green bars) and port (red bars) locations in 2017.

In 2017, 84 cerambycid species were trapped for a total of 5772 specimens; one exotic species, *Xylotrechus stebbingi*, captured in both ports and forests in France (101 specimens). In 2018, 83 cerambycid species captured, 5721 individuals; two exotic species, *Xylotrechus stebbingi* (178 specimens) and one *Cordylomera spinicornis*, were captured in France at ports of entry.
The Cerambycidae captured in 2018 are listed in Appendix 5.

Comparison between traps (forest sites)

In 2017, a comparison between using the same lure was performed on cross-vane and multi-funnel traps. The experiments showed there was no difference in the numbers of species or individuals of Cerambycidae captured.

Comparison between lures

In 2017, the trapping efficiency of lures 1+ and 2 were compared to lure 3+ in ports and forests to determine the most effective attractant (figure 4):

- Significant difference in the number of trapped species between lure for both trap types was observed.
- For both trap types of traps, the sum of captures of lure 1+ and lure 2 was significantly higher than the individual lures, but was not different to the captures of lure 3+ suggesting that there was no significant interference between the pheromones lures.
- For multi-funnel traps, there was no difference between the number of individuals captured by the 3 different lures.
- For cross-vane traps, lures 1+ and 3+ captures were similar, and both were significantly higher than for lure 2.

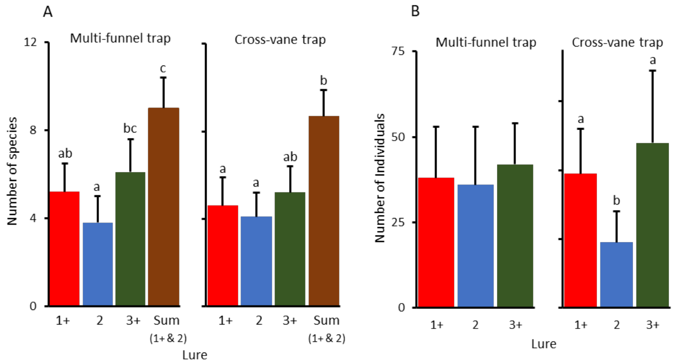

Figure 4. Comparison between the mean number of Cerambycidae species (A) and individuals (B) captured by different lures in multi-funnel and cross-vane traps. Different letters denote significant differences between lures

In 2018, in forests, the trapping efficiency of lures 1+, 2, 3 and 3+ were compared using multi-funnel and cross-vane traps:

- For cross-vane traps, lure 2 was the significantly less effective than lures 1+, 3 and 3+, which were not significantly different to each other (figure 5).
- There was no difference in captures between lures using multi-funnel traps.
- For both trap types, there was no differences between lures in the mean numbers of individuals of Cerambycidae trapped.

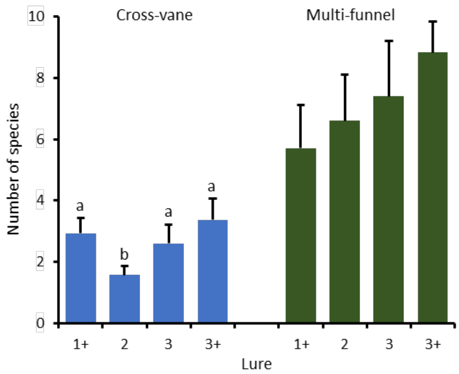

Figure 5. A comparison between the mean number of species captured by different lures in cross-vane and multi-funnel traps in forest locations.

Figure 6 shows a comparison between the efficiency of cross-vane versus multi-funnel traps containing the same lure at a single forest site in 2018 on trapping different xylophagous beetle groups. There was no significant difference between trap types on the number of species of Cerambycidae, Buprestidae and Curculionidae captured, but the total number of bark beetles (Scolytinae) was significantly higher in multi-funnel traps than in cross-vane traps.

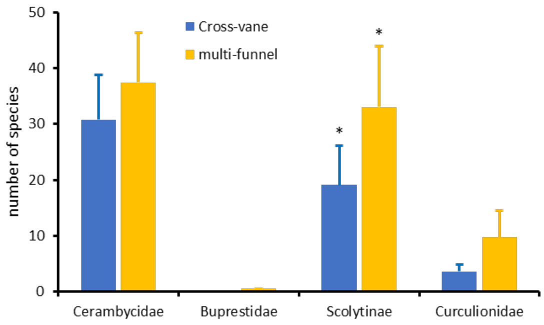

Figure 6. A comparison of the trapping efficiency of the two trap designs for the different groups of xylophagous insects (means ± S.E., n = 23) using the same lures. * indicates significant difference between trap types (P<0.05).

In ports, lure 3 and 3+ were compared using a single trap type (figure 7). No significant difference in the number of species captured per lure. The addition of ethanol and α-pinene to lure 3 significantly increased the total number of individual trapped Cerambycidae

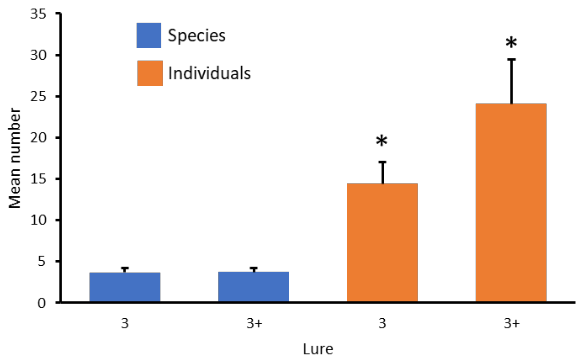

Figure 7. Comparison between lure lures on the mean number of species and individuals captured at ports. * = significant difference between treatments (P = 0.01).

Cost-Benefit Analysis

Within this project, multi-lure trapping systems have been developed for Cerambycidae. Based on semi-structured interviews with project scientists and desk-based reviews of plant health legislation, these systems have been reviewed in the context of monitoring and early detection. Using multi-lures as a tool for early detection, agent-based models have highlighted potential benefits from combining single-lure trapping programmes. This is an important conclusion considering the increased emphasis on national surveys of European quarantine pests.

Semi-structured interviews with project scientists have been carried out to describe the national deployment contexts. In addition, web-based reviews of existing literature on the economics of pheromone trapping, the impact of target pests and plant health legislation, have been conducted to support agent-based modelling for assessing the impact of deployment and control parameters.

In line with findings reported in previous studies, agent-based models have highlighted the benefits of early detection in terms of avoided losses, though the cost-effectiveness of individual trapping systems ultimately depends on the spread behaviour of the pest, its impact on host plants and the management response after detection. Considering the potential deployment of multi-lure traps as monitoring tools for early detection, an important finding is that – above a certain minimum level – trap numbers have a much stronger effect on the time of first detection than trap effectiveness. This implies that (1) interaction effects between multiple lures, reducing the overall sensitivity of the trap, are of limited importance and (2) trapping programmes for different pests should be combined to increase overall trap numbers. Additional costs for the more complex analysis of multi-lure trap contents are expected to be outweighed by benefits from increasing trap numbers by combining trapping programmes. In addition, multi-lure traps offer the potential to detect and identify unknown pests; the ultimate benefit here, however, strongly depends on regulatory response mechanisms. As modelling of unknown unknowns is by definition impossible, only qualitative assessments can be made based on the pest families selected for multi-lure trapping. Looking into the beetle families selected in this project, Cerambycid introductions are a documented risk for the European Union and both Cerambycids and Buprestids have known genus's causing large damages to agriculture and forestry, which are prioritised for surveys by the European Union in 2019/20. It should be mentioned that limited evidence collected through an online portal suggests that currently Cerambycid outbreaks are detected by the general public within 5 years; especially for slow-moving pests this implies reduced additional benefits from earlier detection.
Although the cost-effectiveness of individual trapping programmes will always have to be evaluated on a case by case basis, the work conducted in this project highlights the potential benefits from replacing single-lure trapping programmes with combined multi-lure programmes for early detection. Trap density was found to be an important success parameter for early detection, in turn increasing the probability of successful eradication and reducing costly pest damages. Considering the increased emphasis on national surveys for European quarantine pests, multi-lure trapping systems therefore offer countries an interesting possibility to comply with community regulation without compromising eradication success through low density trapping programmes.
The cost of an individual trap is approximately 55 € (including shipping), and the lure blends are around 11 €/trap/lure change, about 125 €/trap/year for a complete survey period. Including multi-lures in a single trap reduces the number of traps required, effort of deployment and servicing, and increases the number of different target species captured, thereby increasing trapping efficacy and reducing costs compared to multiple traps baited with single lures.

2.5. Conclusions and recommendations to policy makers

Early detection of invasive xylophagous beetles at points-of-entry is a major challenge for regulatory agencies.
The optimal detection strategy is to use pheromone blends in combination with the host plant volatiles, ethanol and α-pinene. The advantage of the deployment of multi-lure traps, containing pheromone blends and host volatile blends, compared to single lure traps are:

- It maximises the taxonomic diversity of beetles, particularly Cerambycidae. Over 80 different Cerambycidae species were captured in this study (see appendix 5).

- It minimises the number of traps and lures required.

In contrast, the absence of buprestids in captures is a major problem showing this particular combination of lure blends and black traps are not suitable for this group of beetles.
Standard protocols (see appendix 3) should be followed so that surveillance can be standardised and consistent across all participating organisations and countries.

The constraints of trapping should be considered (see Appendix 4).
Considering the increased emphasis on national surveys for European quarantine pests, multi-lure trapping systems offer countries an interesting possibility to comply with community regulation without compromising eradication success through low density trapping programmes.

2.6. Benefits from trans-national cooperation

Cooperation in the Euphresco consortium provided the means to carry out a large trans-national experiment to test the multi-lure approach.
The practical use of multi-trap approach was conducted in different countries, in a number of very different ports, ecosystems, *etc*.
The results of the MULTITRAP project are presently being used to develop further trapping experiments for early detection of non-native xylophagous species at arrival, which also includes buprestids in the target groups, within the Horizon 2020 project "HOMED" (HOlistic Management of Emerging forest pests and Diseases).

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3. Publications

3.1. Article(s) for publication in the EPPO Bulletin
None.

3.2. Article for publication in the EPPO Reporting Service
None.

3.3. Article(s) for publication in other journals
- Down RE, Audsley N. (2017) Review of currently available traps and lures for invasive xylophagous coleopteran pests of trees. Open access available via authors.
- Fan JT, Denux O, Courtin C, Bernard A, Javal M, Millar JG, Hanks LM, Roques A (2019). Multi-component blends for trapping native and exotic longhorn beetles at potential points-of-entry and in forests. J. Pest Sci. 92: 281-296. https://doi.org/10.1007/s10340-018-0997-61.

4. Open Euphresco data

None.

Appendix 1. Review of currently available traps and lures for invasive xylophagous coleopteran pests of trees

Introduction

Invasive non-native species of insects cost forestry billions of euros every year. The development and deployment of early detection (screening) methods is therefore of paramount importance, offering the best chance of eradicating the pest by enabling rapid response systems to be implemented (Pleuss *et al.*, 2012; Rassati *et al.*, 2014). In particular, wood boring beetles belonging to the Cerambycidae, Buprestidae and Curculionidae (subfamily Scolytinae) families represent a serious threat to biosecurity in all forested countries (Brockerhoff *et al.*, 2006b). These species can arrive through fresh timber and trees for planting (Haack *et al.*, 2010; Liebhold *et al.*, 2012), however, the most likely route of entry for wood boring insects is via wood packaging material (crating, dunnage and pallets), logs and lumber (Brockerhoff *et al.*, 2006a; Liebhold *et al.*, 2012; Rassati *et al.*, 2014) and this is confirmed by inspection data from the USA, Australia and New Zealand (Stanaway *et al.* 2001; Haack 2006; Brockerhoff *et al.*, 2006a). As such, sea ports and other points of cargo entry/storage facilities are the most likely points of entry into a country for these species due to the shipment of large amounts of cargo packaged in wooden crates and pallets.

Early detection usually involves specific inspections and surveillances activated by national plant protection organisations, co-ordinated by international bodies such as the International Plant Protection Convention (IPPC) and the European and Mediterranean Plant Protection Organization (EPPO). More recently, countries such as USA, Canada, Australia, New Zealand and Italy are developing, or have implemented, trapping and sampling strategies to enhance detection, and these studies can provide crucial information about the entry and potential establishment of a new organism (Brockerhoff *et al.*, 2006b; Rabaglia *et al.*, 2008; Wylie *et al.*, 2008; Rassati *et al.*, 2014). However, if trapping devices are to provide effective surveillance, they must be reliable at low population densities (Liebhold and Tobin, 2008).

The efficiency of a trap depends on the design of the trap itself and the attractiveness of the lures used. Monitoring programmes that require information on population density and phenology of specific target species usually use species specific lures. However, surveillance programmes for alien species would ideally target multiple species, often from different families, and it would be difficult to predict which species may arrive (Rassati *et al.*, 2014). This can become costly if individual traps baited with specific lures are used, hence the need for effective traps simultaneously baited with a combination of generic blends and specific attractants (Schwalbe and Mastro 1988; Brockerhoff *et al.*, 2006b; Wong *et al.*, 2012). The use of multi-lure traps reduces the number of traps necessary, therefore reducing the cost of trap materials and manpower for the time involved in checking traps; it also reduces problems associated with finding safe and suitable places to hang the traps within the grounds of the site (Schwalbe and Mastro 1988). However, lure combinations need to be chosen carefully as certain combinations can have negative effects on trapping efficiency.

This review reports on, and discusses, the monitoring and surveillance strategies currently deployed for high-risk, high-threat, wood-boring coleopteran species belonging to the

Ceramycidae (in particular Asian (ALB) and Citrus longhorned beetles (CLB), (*Anoplophora glabripennis* (Motschulsky) and *Anoplophora chinensis* (Forster), respectively)), Curculionidae subfamily Scolytinae (in particular *Ips* species of bark beetles) and Buprestidae (in particular Emerald ash borer, *Agrilus planipennis* Fairmaire) families. This review details scientific studies on the elucidation of pheromone components, host plant volatiles and kairomones, known to act as attractants to these insect species, and their effectiveness when used as baits in trapping studies. Currently available traps and lures are reported upon, and the use of various trap and lure combinations to attract multiple species is discussed.

Trap designs

The most common trap designs currently in use for wood-boring beetles are the cross-vane trap, the multi-funnel trap and the German slot trap (Rassati *et al.*, 2014). Multi-funnel traps are currently the most frequently used trap design for early detection programmes including within goods warehouses of several western U.S. ports (Rabaglia *et al.*, 2008; Rassati *et al.*, 2014). It has previously been recommended that traps with a vertical black shape imitating a prominent stem silhouette should be used for catching Cerambycidae and Buprestidae species (De Groot and Nott, 2001, 2003). Trap designs and colours are discussed in more detail in the following sections.

Host plant volatiles

Attraction to plant volatiles has been exploited for pest management and in monitoring traps, either alone or in combination with insect pheromones for some time (Allison *et al.*, 2004; Sweeney *et al.*, 2004; Ibeas *et al.*, 2007; Miller 2006). Current surveillance protocols for wood-boring beetles often use generic blends of kairomones (e.g. (—)-α-pinene and ethanol), which mimic the cocktail of volatiles emitted by stressed or dying trees (Brockerhoff *et al.*, 2006b; Rassati *et al.*, 2014). The ethanol and (—)-α-pinene combination is attractive to numerous species of bark and ambrosia beetles (Miller and Rabaglia, 2009). However, whilst (—)-α-pinene is very effective at attracting beetles known to infest conifer species, it has been shown to repel some species that attack broadleaved species of trees (e.g. the ambrosia beetle *Anisandrus dispar* (F.)) (Schroeder and Lindelöw, 1989). Host plant volatiles are often complemented with kairomones such as bark beetle attractants (e.g. ipsenol and ipsdienol) to increase trapping efficiency and provide attractancy to some cerambycid and buprestid species (Miller *et al.*, 2011). The use of plant volatiles is discussed in more detail in the following sections, as more often than not the lures used will include a plant volatile attractant alone or in combination with other kairomones or pheromones.

Trapping of Scolytinae: Spruce bark beetle, *Ips typographus*

The spruce bark beetle, *Ips typographus* (L.) is one of the most destructive European forest pests. Control strategies include the use of several types of baited traps or trap-trees in order to catch as many flying beetles as possible to reduce the population density and risk of an outbreak (Faccoli and Stergulc, 2008). Laboratory studies have identified a male aggregation pheromone from spruce bark beetle and suggested that it could have numerous components including *cis*-verbenol, *trans*-verbenol, ipsenol, ipsdienol, 2-methyl-3-buten-2-ol, myrtenol, *trans*-myrtanol, 2-phenylethanol and verbenone. Ipsenol, ipsdienol, *cis*-verbenol and *trans*-verbenol were initially thought to be common to all *Ips* species (Vité *et al.*, 1972; Schlyter *et al.*, 1987a) although subsequent studies indicate that this may not be the case (Miller *et al.*, 1991). The identification of these components led to the development of lures such as Ipslure®, Typolure II (which both contain 2-methyl-3-buten-2-ol, *cis*-verbenol and ipsdienol albeit in different ratios), Typolure I and Pheroprax® (which both lack the ipsdienol component) (Schlyter *et al.*, 1987a). Subsequent work has identified 2-methyl-3-buten-2-ol and *cis*-verbenol as the essential components of the *I. typographus* aggregation pheromone (Schlyter *et al.*, 1987a) whereas ipsdienol and *E*-myrcenol are reported to be essential pheromone components for the double-spined spruce bark beetle, *Ips duplicatus* (Byers *et al.*, 1990). Small amounts of ipsdienol combined with 2-methyl-3-buten-2-ol and *cis*-verbenol has been demonstrated to increase trap catch of *I. typographus* where as larger amounts of ipsdienol and ipsenol decrease trap catch (Schlyter *et al.*, 1987b). This is in contrast to studies with the double-spined bark beetle, *Ips duplicatus*, which was only found to be attracted to combinations of pheromone components that included ipsdienol (reported in Schlyter *et al.*, 1987a). The spruce bark beetle also responds to monoterpenes such as (—)-α-pinene produced by its host as well as to verbenol (Vité *et al.*, 1972).

Pheromone traps designed to protect against this species were introduced in the late 1970s, replacing trap trees that had been in use for 200 years prior to trap development (Zahradník and Zahradníková, 2015). Flight (barrier), entering (pipe) and landing (sticky) trap designs including, window traps and cross-vane traps have all been used (Weslien and Bylund, 1988; Zahradník and Zahradníková, 2015). Publications indicate that flat funnel traps are more effective at catching *I. typographus* than cylinder traps, both in Europe and Japan (Ozaki *et al.*, 1991). Ozaki *et al.* (1991) demonstrated that this was the case with a Japanese subspecies of this beetle when these two trap designs were baited with Ipslure® (a pheromone lure consisting of methylbutenol, *cis*-verbenol and ipsdienol; Borregard Ind. Ltd., Norway). Weslien and Bylund (1988) indicate that flight barrier traps are more efficient at capturing spruce bark beetle than traps that depend on a beetle landing upon them or a beetle entering a pheromone baited trap (proportion of males caught with these types of traps during the first six days of the flight season are 41%, 29% and 18%, respectively. The influence of trap colour has also been investigated, and it has been reported that black drainpipe traps baited with pheromones were better at catching *I. typographus* than red, green, yellow and whites equivalents (Dubbel *et al.* 1985). These authors demonstrated that white flight barrier traps (flatfunnel) baited with either Linoprax® (for attracting the striped ambrosia beetle, *Trypodendron lineatum* (Olivier)) or Pheroprax® (for attracting *I. typopgraphus*) caught significantly fewer numbers of these species than black or clear traps. No significant differences were observed between the catches of black, green, grey and redbrown traps although the black traps tended to catch higher numbers. Losses of beneficial predators and parasitoids tended to be minimised with darker coloured traps and therefore these authors concluded that black flight traps are preferential for trapping these species, and have the additional benefits that they are less conspicuous (Dubbel *et al.* 1985).

The development of mass trapping programmes to detect ambrosia beetles (which attack dying and dead trees) at timber yards has been underway since the 1980s and 1990s (Babuder *et al.*, 1996). In 1996, Babuder *et al.* published a research article on the selectivity of synthetic aggregation pheromones for the control of bark beetles in a Slovakian timber storage yard; in particular they were monitoring for an ambrosia beetle, *T. lineatum*, and the spruce bark beetle. Once again the two commercially available aggregation pheromones, Linoprax® and

Pheroprax® (produced by Celamerck/Shell Agrar Company, Ingelheim am Rhein, Germany) were used in this study, to bait Theysohn black flight barrier traps. Theysohn flight barrier traps were used because they are reported to be more effective against these two species than other types of traps (Babuder *et al.*, 1996). Traps were individually baited with one of the two pheromones, and placed in groups around the timber yard (each group consisting of a Linoprax® baited trap, a Pheroprax® baited trap and a control (unbaited) trap). These authors report that a total of 24,349 insects were caught in five Linoprax® baited traps; 78.5% were *T. lineatum*, 19.9% were *I. typographus* and 1.6% were other beetles (Babuder *et al.*, 1996). In comparison the five Pheroprax® baited traps caugh 22,815 insects, of which 92.8% were *I. typographus*, 5.8% were *T. lineatum* and 1.4% of them were other species, indicating that Pheroprax® is more selective towards *I. typographus* than Linoprax® is for *T. lineatum* (Babuder *et al.*, 1996). The unbaited traps caught 3,429 insects (52.5% were *I. typographus*, 38.4% *T. lineatum* and 10.1% were other species of beetle). A large proportion (51.7%) of the other species caught were the six-toothed spruce bark beetle *Pityogenes chalcographus* (L.). More males than females were caught by both baits (1 : 0.4 male : female ratio), probably because female beetles require additional host odour stimuli for maximum attraction (Babuder *et al.*, 1996). Weslien and Bylund (1988) also suggest that the sex ratio of *I. typographus* can be influenced by how far advanced the flight season is.

Traps containing lures of host volatiles such as ethanol and (—)-α-pinene, combined with *Ips* spp. pheromones have been used in surveillance programmes in the United States and Canada for over a decade (Rabaglia *et al.*, 2008;) and are relatively successful at detecting exotic Scolytinae. Eight Scolytinae species (four bark beetles and four ambrosia beetles) were first detected in the U.S.A. as part of formal early detection programmes that used flight-intercept traps baited with ethanol, (—)-α-pinene and ipsdienol (Haack, 2006). The trapping of multiple Scolytinae species either within surveillance programmes, the development of surveillance programmes, or experimental studies investigating by catches of current trapping methods and/or the use of multiple pheromone blends for attracting multiple species is discussed in more detail later in this review.

Trapping of Buprestidae: Emerald ash borer, *Agrilus planipennis*

Emerald ash borer is one of the most destructive insect pests affecting ash species of the genus *Fraxinus*. Since the first discovery of this invasive pest in 2002 in Michigan, USA, the beetle has been responsible for the death of tens of millions of ash trees and hundreds of millions of dollars of economic losses in the U.S. (Kovacs, 2010; Emerald Ash Borer info, 2014). Visual surveying is difficult. During the early stages of attack, the D-shaped exit holes tend to be found only in the upper canopy, whilst the other more visible symptoms such as bark cracks, woodpecker attacks, canopy dieback and epicormic branching do not become apparent until a tree is under heavy attack (Crook and Mastro, 2010; Herms and McCullough, 2014).

Due to the aggressive and destructive nature of this pest, early detection is crucial, and it is thought that a better understanding of the behaviour and chemical ecology of the adult beetle would help to develop effective detection systems (Silk *et al.*, 2011). Progress towards the development of an effective trapping system for emerald ash borer has been reviewed (Crook and Mastro, 2010; Silk and Ryall, 2015). Indeed, one of the primary goals of the U.S.

Department of Agriculture-Animal and Plant Health Inspection Service-Plant Protection and Quarantine (USDA-APHIS-PPQ) Emerald Ash Borer Cooperative Project has been to develop an effective and sensitive monitoring system that is able to detect low-density populations of *A. planipennis* when no visible symptoms of attack are apparent on trees. Many studies have been conducted to establish the most effective trap type, colour and lure for trapping *A. planipennis*, however these studies do not yield consistent results (Crook and Maestro 2010) and the results can be difficult to compare. Detection and sampling of emerald ash borer infestations has also been reviewed by Ryall (2015).

Crook *et al.* (2009) indicated from their studies that green traps (540 - 550 nm wavelength), within the mid-canopy would be the most effective trap for detecting *A. planipennis*, perhaps using a lighter green (540 – 550 nm, 64% reflectance) earlier in the season. Likewise, Francese *et al.* (2010) also concluded that the optimal colour for trapping *A. planipennis* was green (530-540 nm wavelength) in the mid-range (22-67%) of reflectance (brightness); 49% reflectance (i.e. a darker green) was more effective than 67% reflectance. However, purple traps (especially the new Sabic purple) have also been found to be attractive to *A. planipennis* adults (Marshall *et al.*, 2010; McCullough *et al.*, 2011; Poland *et al.*, 2011; Francese *et al.*, 2013a), especially the females (Crook *et al.*, 2009; Francese *et al.*, 2008), and especially in areas where *A. planipennis* population densities are low. This is thought to be because electro-retinogram studies suggest that mated females, but not males, are sensitive to red wavelengths (640-650 and 670 nm) (Crook *et al.*, 2009). Both purple and green prism traps are reported to be more effective at catching *A. planipennis* when deployed at a height of 13 m, within the tree canopy, than when deployed at 1.5 m (Crook *et al.*, 2008, 2009).

Buprestidae generally do not respond to host volatile lures consisting of monoterpenes and ethanol (Chenier *et al.*, 1989). Instead, *A. planipennis* is attracted to bark and foliage volatiles from ash (reviewed by Crook and Mastro, 2010), including sesquiterpenes emitted from stressed trees. The active compounds within the ash tree bark volatile have been identified as α-cubebene, α-copaene, 7-*epi*-sequithujene, E- β-caryophyllene, α-humulene (also known as α-caryophyllene), and eremophilene (Crook *et al.*, 2008; Cossé *et al.*, 2008). An oil distillate (Phoebe oil) from the Brazilian walnut, *Phoebe porosa* Nees & Mart (Lauraceae) contains all six of these compounds. Five of the six compounds (α-cubebene, α-copaene, E- β-caryophyllene, α-humulene and eremophilene) are also found in Manuka oil, the oil distillate from the New Zealand manuka tea tree, *Leptospermum scoparium* J.R. Forst & G. Forst (Myrtaceae) (Crook and Mastro, 2010). Both these oils attract both male and female adult *A. planipennis* in field trapping studies, with Phoebe oil being the more effective, presumably because it contains 7-*epi*-sequithujene, which is lacking in Manuka oil (Crook *et al.*, 2008). However, whilst Manuka oil is commercially available, Phoebe oil currently is not (Crook *et al.*, 2014).

A number of components have been identified in ash leaf volatiles, emitted by plants damaged by feeding beetles, and these compounds have been shown to be attractive to adult *A. planipennis* in laboratory studies (Rodriguez-Saona *et al.*, 2006). These compounds include hexanal, (*E*)-2-hexanal, (*Z*)-3-hexen-1-ol, 3-methyl-butlaldoxime, 2-methyl-butylaldoxime and hexyl acetate (which males have a greater response to), linalool (which females have a greater response to), (*Z*)-3-hexen-1-yl acetate, (*E*)-β-ocimene, 4,8,-dimethyl-1,3,7-nonatriene and

E,*E*,-α-farnesene (Rodriguez-Saona *et al.*, 2006). Crook *et al.* (2014) report that subsequent investigations (Grant *et al.*, 2010, 2011) suggest that one of these components, (3Z)-hexenol (also known as (*Z*)-3-hexen-1-ol), was able to increase trap catches, especially of male beetles. However, further work now suggests that (3Z)-hexenol only increases trap efficiencies in field studies when light green prism traps (wavelength 540 nm, 64% reflectance) are used; when the improved darker green (540 nm wavelength, 49% reflectance) Sabic prism traps are used, the addition of (3Z)-hexenol does not improve trap efficiency (Crook *et al.*, 2012, 2014). In addition, Crook *et al.* (2012) indicated that bark sequiterpene volatiles (Manuka oil) may not be synergistic to (3Z)-hexenol when used on green traps. Combining some of the other green leaf volatiles to (3Z)-hexenol does not appear to further enhance trap catches of *A. planipennis* (de Groot *et al.*, 2008; Grant *et al.*, 2010). Francese *et al.* (2013a) report on a large scale study of four trap designs (standard "Program used" purple prism traps, Sabic purple prism traps, Sabic green prism traps and green multifunnel traps (coated with Rain-X); all traps were baited with a blend of Manuka oil (50 mg/d) and (3Z)-hexenol (50 mg/d) to act as a lure. The Sabic purple prism trap had the highest detection rate (86%; detection rate defined as at least one catch on a trap over the course of the season, or not), followed by the standard purple prism trap (73%), the Sabic green prism (66%) and lastly the green multifunnel trap (58%).

In addition to plant volatiles, some work has also been performed to identify possible *A. planipennis* pheromones. In 2007, Bartelt *et al.* reported on the discovery of a macrocyclic lactone, (3Z)-dodecen-12-olide (also known as (3Z)-lactone), which was found to be approximately ten times more abundant in females; the first such pheromone to be identified within the Buprestidae family. At the time of identification it was deemed not to be a typical sex pheromone because it was detected from both sexes, and because the highest amounts were detected in beetles two to four days after emergence when the beetles are still sexually immature; an aggregation function was deemed possible (Bartelt *et al.*, 2007). A (3Z)-lactone pheromone is now commercially available via Sylvar Technologies, Fredericton, NB, Canada (Ryall *et al.*, 2013). There is also some evidence to suggest that females may produce a cuticular hydrocarbon contact sex pheromone, with 3-methyltricosane (Lelito *et al.*, 2009) and 9-methylpentacosane (Silk *et al.*, 2009) identified as components, however, these require further investigation (Silk and Ryall, 2015).

Crook *et al.* (2014) published the results of a study comparing multifunnel traps, prism traps and lure types at varying population densities as detection tools for *A. planipennis*. These authors used two trap designs: Sabic purple prism traps (420 nm, 21.7% reflectance and 670 nm, 13.6 % reflectance; Great Lakes IPM, Vestaburg, MI) and green multifunnel (12 unit) traps (530 nm, 57% reflectance; Chemtica Internacional, San Jose, Costa Rica). Each of the two traps was baited with one of two lures; either Manuka oil (50 mg/d) and (3Z)-hexenol (50 mg/d) or (3Z)-hexenol (50 mg/d) and (3Z)-lactone (2 µg/d). The outer surfaces of the prism traps were coated with Tanglefoot glue (brushable formulation; Contech, Grand Rapids, MI) and green multifunnel traps were coated with fluon (Insect-A-Slip Insect barrier; Bioquip products, Rancho Dominguez, CA). Study sites were selected along or near the edges of the current emerald ash borer infestation across nine U.S. states. Traps were hung at a height of 5-8 m in the lower canopy. These authors found that there was a significant effect of trap type on catch, with the green multifunnel traps catching more *A. planipennis* beetles than the purple prism traps, however, the purple prism traps provided equal beetle detection rates in areas of low beetle density compared with the green multifunnel traps. The type of lure had no significant effect on trap catch, with the two lure combinations providing similar rates of detection. Crook *et al.* (2014) therefore concluded that when large-scale surveys for *A. planipennis* were required with traps hanging just below the canopy level in areas of low population density, green or purple fluon-coated traps would be equally effective irrespective of the lure combination used.

Recent work by Silk *et al.* (2015) has shown that a synthetic analogue of the (3Z)-lactone pheromone is also capable of attracting male *A. planipennis* and is therefore likely to provide a cheaper lure option due to easier production and reduced synthesis costs (Ryall *et al.*, 2015). When combined with (3Z)-hexenol, (3Z)-lactone can significantly increase trap catches, particularly of male beetles (Silk *et al.*, 2011; Ryall *et al.*, 2012, 2013) but this may well be dependent on a number of factors including the dose of (3Z)-lactone, the type of trap used, the placement of traps on the same tree versus adjacent trees, placement of traps with regard to aspect (i.e. southern versus northern aspect of the crown), as well as the siting of the trap within the canopy of the ash tree as opposed to hanging below the canopy (Ryall, 2015; Ryall *et al.*, 2015). Field experiments by Silk *et al.* (2011) concluded that combining the pheromone component with either green leaf volatiles or Phoebe oil did not affect the number of catches when sticky purple prism traps were used, however, when they deployed green prism traps in the canopy of ash trees a combination of the pheromone component and (3Z)-hexenol significantly increased the number of males caught in the traps. Indeed, after a study conducted in Canada, which included five different field trapping experiments, Ryall *et al.* (2015) were able to conclude from their investigations that optimal set-up for detection programmes for *A. planipennis* was the deployment of dark green (540 nm wavelength, 49% reflectance; Synergy Semiochemicals Corp., Burnaby, BC) sticky traps baited with 3.0 mg (3Z)-lactone + (3Z)-hexenol hanging in the south aspect of the mid tree canopy. Green sticky prism traps are thought to capture more species and specimens of Agrilus than purple traps, regardless of lure, except for the beech splendour beetle, *Agrilus viridis* (L.), which were caught in higher numbers on purple traps with cubeb oil as the lure (Troy Kimoto, CFIA pers. comm.). Therefore from the point of view of detecting multiple *Agrilus* species, green sticky prism traps may be the better option.

Despite the number of studies investigating the efficacy of different trap types and lures for surveying *A. planipennis*, very few have been performed at sites with very low population densities. However, optimal trap-lure combinations for very low population densities are essential for effective early detection of this species. Purple prism traps are reported to be more effective than their green counterparts at low beetle densities (Marshall *et al.*, 2010; Francese *et al.*, 2013a). In 2013 Ryall *et al.* report on field trials specifically designed to test the ability of green baited traps to reliably detect low levels of *A. planipennis* infestation. These authors used sticky green prism traps (Synergy Semiochemicals, Burnaby, BC, Canada) suspended in the mid-crown of ash trees. During their first experiment, the authors baited the traps with the leaf volatile (3Z)-hexenol, to establish detection rates over a range of larval densities, and the relationship between mean trap capture with these traps and infestation density within the surrounding area. Results showed that these traps detected at least one adult *A. planipennis* in 55.3% of the plots categorised as 'nil-low' density and in 100% of plots within the moderate to high categories. Consistent results between trapping and branch sampling were observed in approximately 73% of the plots: 19.5% of the plots were deemed to be uninfested by both methods and 53.3% declared infested by both methods. The remaining 27% of the plots gave inconsistent results with traps failing to detect known infestations in 8% and branch sampling failing to detect infestations in 19% of plots where *A. planipennis* were successfully trapped (Ryall *et al.*, 2013). In a second experiment performed by Ryall *et al.* (2013), the authors baited the traps with the (3Z)-lactone pheromone and/or (3Z)-hexenol in plots identified as nil-low population density as determined by branch sampling. Traps baited with both compounds had a detection rate of 88% compared with 60% for the traps baited with (3Z)-hexenol alone. Specifically, male catch was significantly increased with the addition of (3Z)-lactone to the bait, while the numbers of females caught by the two different lures was similar. These authors concluded by recommending the use of dark green sticky prism traps baited with both (3Z)-hexenol and (3Z)-lactone for early detection of *A. planipennis*. They also suggest that further research is necessary, particularly with regard to identifying volatiles that are attractive to female beetles in order to maximise detection of virgin and/or mated females in new infestation areas (Ryall *et al.*, 2013).

Some studies (McCullough *et al.*, 2011, Poland *et al.*, 2011; Poland and McCullough, 2014) would indicate that double-decker traps are more effective than canopy (prism) traps in areas of low infestation. Field studies by Poland *et al.* (2011) at sites ranging from very low to heavy *A. planipennis* infestations concluded that 3 m tall double-decker traps with either purple or green prisms attached near the top, and baited with green leaf volatiles and Manuka oil, captured more adults than similar but taller (6m) tower traps, and both green and prism traps hung in the tree canopy. McCullough *et al.* (2011) demonstrated that purple double decker traps, baited with a blend of ash leaf volatiles, Manuka oil and ethanol had a far higher detection rate compared with similarly baited green double decker traps or purple prism canopy traps baited with Manuka oil. More recently Poland and McCullough (2014) reported on field trials comparing different trap designs (canopy or double decker traps with two prisms attached to the pipe), colours (purple or green) and host volatile baits ((3Z)-hexenol combined with an 80:20 blend of Manuka and Phoebe oils or (3Z)-hexenol combined with Manuka oil). Infestation levels of *A. planipennis* at their field sites ranged from low through to high. Their results confirmed that the effectiveness of the trap designs was influenced by the infestation level of the trapping area. Where heavy infestations were present, all trap design/colour/bait combinations attracted high numbers of beetles. However, at sites with low *A. planipennis* populations, the purple double decker traps were consistently more effective than the green canopy traps in terms of the number of adults caught, while overall, double-decker traps faired better than canopy traps and purple traps were more attractive than green traps (Poland *et al.*, 2011; Poland and McCullough, 2014). This was also borne out with the detection rates (number of traps that caught one versus one or more beetles): a 100% rate of detection was observed for both purple and green double decker traps compared with 82% for purple canopy traps and 64% for green canopy traps (Poland and McCullough, 2014).

Large-scale operational detection surveys for *A. planipennis* within the U.S. since 2008 have used purple prism traps suspended in the canopy of ash trees and baited with Manuka oil and (3Z)-hexenol (Poland and McCullough, 2014; Emerald Ash Borer info, 2014; Herms and McCullough, 2014). In Canada, however, surveys are currently conducted with green sticky traps baited with (3Z)-hexenol (Ryall, 2015). Prism traps are favoured because of their ease of installation, however, they do have disadvantages (see Table 1; Ryall, 2015) and it is acknowledged that double decker traps (essentially two prism traps attached to a 3 m tall PVC pipe) may provide better rates of detection in areas of low *A. planipennis* density. Double decker traps are possibly more effective at low infestation levels because of their larger surface area, and because the free-standing design means they are very visible, can be positioned in full sun (taking advantage of the beetle preference for full sun), and provide a distinct point source of the lure without it being masked by volatiles emitted from host trees within the canopy (Mc Cullough *et al.*, 2011; Poland *et al.*, 2011; Poland and McCullough, 2014; Herms and McCullough, 2014; Ryall, 2015). Whilst double decker traps are relatively simple to deploy, needing approximately the same time to set up as canopy traps, they are more costly because they require two panels as well as a PVC pipe and T-posts (Poland and McCullough, 2014). However, these authors argue that the costs associated with “false negative trap data” can be substantial, as failing to detect the presence of *A. planipennis* delays implementation of quarantine procedures and fails to protect the trees in the surrounding landscapes.The use of multifunnel traps has also been evaluated (Francese *et al.*, 2011, 2013a, 2013b). Coating traps with a formulation that increases slipperiness also greatly enhances the numbers of beetles caught, as demonstrated by the use of Rain-X-coated traps (Francese *et al.*, 2011), which caught significantly more beetles than untreated traps but did not catch anymore than (Tangle-Trap) painted traps, and Fluon-coated traps (Francese *et al.*, 2013b); Fluon appears to be the more effective coating.

Poland *et al.* (2011) also discuss the advantages and disadvantages of double-decker traps versus canopy traps. They suggest that whilst canopy traps are relatively inexpensive, they can sustain damage in storms and high winds; 20% of canopy traps were damaged in one incidence of bad weather compared to 3.8% of the double-decker traps. The placement of canopy traps can be difficult depending on the terrain and tree density. In addition, because they are placed within the tree canopy they may sometimes need to be cleaned and the stickness (Pestick) re-applied as leaves and other debris from the trees can stick to the traps (Poland *et al.*, 2011).

Since the literature contains numerous conflicting comparisons of different trap designs, placements and lures, authors have concluded that survey protocols should perhaps include a mix of trap types and the use of girdled trees. For instance, canopy traps may be more appropriate for systematic sampling across large areas whereas double-decker traps used in conjunction with girdled detection trees and winter/early spring time visual surveys for trees with woodpecker damage, may be more appropriate for high risk sites (Poland *et al.*, 2011; Poland and McCullough, 2014).

Table 1. The advantages and disadvantages of traps that have been tested for emerald ash borer monitoring/detection, as determined by Ryall (2015).

Trap type	Trap description	Advantages	Disadvantages
Sticky prism canopy traps	Baited with host volatiles,	Non-destructive.	Require at least two site visits.

	pheromones or a combination of both.	Easy to use, with minimal training.	Insect specimens must be cleaned. Not re-useable. Possibly have a high false negative rate (although this is unknown). Can only be used during the short adult flight period. Host volatiles and/or pheromone combinations are still being optimised.
Double decker traps	Two sticky prism traps used at ground level and baited with host volatiles.	Similar advantages to the sticky prism traps with the addition that they may provide a higher detection rate.	Similar disadvantages to the sticky prism traps. In addition, more resources are required per trap e.g. T-post, PVC pipe. Require a ground location for deployment. Requires tall poles to set up the traps. Potentially prone to vandalism.
Funnel traps	Reuseable multifunnel traps	Non-destructive. Clean samples. Re-useable.	Difficult to set up. Need to be stored during the off-season. The initial cost is more expensive. Colour and lure combinations are still being optimised.

To summarise:

1. Extensive literature exits on trap designs, colours, placement, and lures used for detecting emerald ash borer, often with conflicting conclusions.
2. Based on current knowledge it is thought that the optimal trap for emerald ash borer detection programmes is the dark green sticky traps (540 nm wavelength, 49% reflectance; Synergy Semiochemicals Corp., Burnaby, BC) baited with 3.0 mg (3Z)-lactone + (3Z)-hexenol hanging in the south aspect of the mid tree canopy (Ryall *et al.*, 2015).
3. Purple prism traps baited with bark sequiterpenes may provide a suitable alternative (Ryall (2015).
4. There is evidence to suggest that at very low population densities, double decker traps (essentially two prism traps attached to a T-post at the top of a PVC pipe) may be more effective at trapping emerald ash borer.

Trapping of Cerambycidae

Flight Intercept traps such as funnel traps and cross-vane panel traps are the most effective traps available for capturing cerambycid beetles as they mimic the vertical silhouette of tree trunks (Graham *et al.*, 2010; Hanks and Millar, 2016). It is important that all surfaces are fluon-coated so that the beetles immediately fall into the collection bucket and cannot walk out again (Hanks and Millar, 2016). Surveillance and monitoring programmes have tended to use traps that are baited with (—)-α-pinene and ethanol plant volatiles. These volatiles are attractive to conifer feeders but are much less effective, or even completely ineffective, at trapping species that attack deciduous trees, as such these lures only tend to attract a few cerambycid species in large numbers (Schroeder and Lindelöw, 1989; Wong *et al.*, 2012; Hanks and Millar, 2016). More recently, lures have consisted of a combination of host tree volatiles and a cerambycid pheromone component, often one that is not specific but rather is attractive for several species (Gernot Hoch, pers. comm); lure combinations are discussed in more detail in other sections of this review (see sections on By catch studies and trapping of multiple species, and multiple pheromone blends). Research to date on the chemical ecology of, and lure attractancy towards, numerous cerambycid species have revealed a huge repertoire of compounds that can either attract, repel or deter, and include kairomones (such as plant volatiles, smoke volatiles and bark beetle pheromones), long and short range pheromones, defensive compounds and oviposition stimulants (Allison *et al.*, 2004; Hanks and Millar, 2016). It is thought likely that female cerambycid beetles use a combination of male-produced pheromones and plant volatiles to locate a mate; firstly both male and female adults are attracted to larval host plants by plant volatiles, then the females are attracted to the males over shorter distances by male-produced pheromones and finally, males recognise females by female-produced contact pheromones (Ginzel & Hanks, 2005). Allison *et al.* (2004) suggest that attractants are often monoterpenoid or phenolic ester compounds, that the female-produced short-range sex pheromones are likely to be methyl-branched cuticular hydrocarbons, and the male-produced long-range sex pheromones are often α-hydroxy ketones and (α,β)-diols ranging in length from six to ten carbons.

Sawyer beetles (*Monochamus* species)

Monochamus species are vectors of the pine wood nematode (*Bursaphelenchus xylophilus* (Steiner and Buhrer, 1934)) (Akbulut and Stamps, 2012), which is the causal agent of pine wilt disease. The main vector in Europe is *Monochamus galloprovincialis* Olivier. Trapping the vectors provides an important means for monitoring and controlling pine wilt disease.

Halbig (2013) reports that host plant volatiles generally have relatively low attractiveness for sawyer species but are attractive when blended with bark beetle pheromones. A blend of ethanol and (—)-α-pinene alone was less attractive to *M. galloprovincialis* than when combined with *Ips* species pheromones (ipsenol or a blend of ipsenol, ipsdienol, *cis*-verbenol and methylbutenol (Pajares *et al.*, 2004), and that a blend of ethanol, (—)-α-pinene and ipsenol acted synergistically. Similar results have been obtained with other *Monochamus* species (Allison *et al.*, 2003). Subsequent work established that it was the (—)-α-pinene and ipsenol that worked synergistically together, and that the addition of methylbutenol doubled the numbers of male and female beetles trapped (Ibeas *et al.*, 2007). These authors concluded that a blend of (—)-α-pinene, ipsenol and methylbutenol would make a highly effective operational lure for monitoring *M. galloprovincialis* (Allison *et al.*, 2003; Ibeas *et al.*, 2007). The bark beetle repellent, verbenone, further enhanced the attractiveness to this three component blend to female *M. galloprovincialis* (Ibeas *et al.*, 2007).

Males of numerous *Monochamus* species (*M. galloprovincialis*, *M. alternatus*, *M. carolinensis*, *M. titillator*, *M. scutellatus, M. sutor* and *M. notatus* are known to produce a pheromone compound (2-undecyloxy-1-ethanol; known as “Monochamol”), which the females react to (reviewed by Halbig, 2013, and by Hanks and Millar, 2016). Field studies have determined that adding Monochamol to the kairomone blend of (—)-α-pinene, ipsenol and methylbutenol (or combinations of just some of these three kairomones) can significantly increase the attractancy of baits to *Monochamus* species when used in multifunnel traps or panel traps (Pajares *et al.*, 2010; Teale *et al.*, 2011; Allison *et al.*, 2012; Pajares *et al.*, 2016).

As a result of these investigations a variety of lure products combining host volatiles, bark beetle attractants and sawyer beetle pheromone components are now commercially available for trapping *Monochamus* species, as has been summarised by Halbig (2013) (Table 2), and are highly successful in monitoring these insect vectors. They are also considered for mass trapping of *M. galloprovincialis* (Alvarez *et al.*, 2016; Sanchez-Husillos *et al.*, 2015).

Table 2. Commercially available lures currently manufactured for trapping sawyer beetles. Information taken from Halbig, 2013. Ethanol and α-pinene are host volatiles; ipsenol, ipsdienol and 2-methyl-3-butenol-2-ol are bark beetle attractants; 2-undecyloxy-1-ethanol is the *M. galloprovincialis* pheromone compound commonly known as Monochamol.

Target species	**Product**	**Content**	**Produced by**
Monochamus galloprovincialis	MG-Kombi®	Ethanol, α-pinene, Ipsenol, Ipsdienol, Methylbutenol	Witasek
Monochamus galloprovincialis	Galloprotect 2D®	Ipsenol, 2-methyl-3-butenol-2-ol, 2-undecyloxy-1-ethanol	SEDQ
	Galloprotect Pack®	Galloprotect 2D®, α-pinene	
Monochamus alternatus	Monalt®	Not specified	Alpha Scents
Longhorn beetles	Monoch®	α –pinene, Ethanol, Ipsenol	

Asian longhorned beetle (ALB), *Anoplophora glabripennis*, and Citrus longhorned beetle (CLB), *Anoplophora chinensis*

The Asian longhorned beetle is a native of China, primarily causing damage to poplar trees grown for timber in plantations. As such, it poses a significant threat to the 6.67 million hectares of poplar plantations in China and is estimated to cause annual losses of US$1.5 billion (Hu *et al.*, 2009; Nehme *et al.*, 2014). The beetle was first reported outside of Asia in the U.S.A. (New York) in 1996 (EPPO, RSe 1996/214). Since 1996, it has been found in other areas of North America (USDA-APHIS, 2014a; EPPO, Rse 2008/157) and Canada (*Hu et al.*, 2009) with the largest infestation discovered in Worcester, Massachusetts in 2008 (Nehme *et al.*, 2014). The beetle has also invaded several countries in Europe, including Austria (2001), France (2003), Germany (2004), Italy (2007) (Haack *et al.*, 2010) and the U.K. (discovery of an established population in 2012; Straw *et al.*,2016), and has been intercepted in other countries before it had chance to establish (Hu *et al.*, 2009). This beetle infests numerous hardwood deciduous species (Nowak *et al.*, 2001), including maple, resulting in canopy dieback. It has the potential to alter forested landscape, and threatens many industries including timber, maple syrup, tree nurseries, greenhouses and tourism, causing considerable economic loss, in the U.S.A. and European countries where it has invaded (Nehme *et al.*, 2010). In addition, trees can be weakened by the insect tunnelling; this results in falling limbs and trees, creating hazards for people and property alike (Nowak *et al.*, 2001). The estimated potential impact of Asian longhorned beetle if all urban areas of the U.S.A. became infested would be 35% loss of canopy cover, loss of 30% of trees (1.2 billion trees) with a compensatory value of $669 billion (Nowak *et al.*, 2001; USDA-APHIS-PPQ, 2011).

The Citrus longhorned beetle is also native to East Asia and polyphagous in nature. It has invaded and established itself in several European countries (France, Italy and the Netherlands) and is predicted to cause major economic and environmental damage if it is not successfully eradicated (Haack *et al.*, 2010; Hansen *et al.*, 2015). Although eradicated in France (*Haack et al.*, 2010), it is now widespread in the Lombardia region of Italy, having first been detected in 2000 in the Milan area (Herard *et al.*, 2009).

At the time of the Haack *et al.* (2010) publication, no long range pheromones had been reported for Asian or citrus longhorned beetles, however, short range pheromones had been identified and the role of plant volatiles in attracting these species was under consideration. In 2002, Zhang *et al.* identified a male-produced pheromone in *A. glabripennis*, which was found to consist of a blend of two dialkylethers: the alcohol 4-(*n*-heptyloxy)butan-1-ol and the aldehyde 4-(*n*-heptyloxy)butanal. The alcohol is structurally very similar to the male-produced pheromone (2-(undecyloxy)ethanol) of the *Monochamus* species (Hanks and Millar, 2016). In 2014, a third component of *A. glabripennis* male-produced pheromone was reported ((3*E*,6*E*)-α-farnesene; Crook *et al.*, 2014b). Laboratory tests showed that both sexes were attracted to this component, and that when it was combined with each of the dialkylethers more beetles were attracted than to either of the dialkylethers alone. More recently, the same two dialkylethers were identified in a volatile pheromone produced by male *A. chinensis* (Hansen *et al.*, 2015). Field studies (using flight intercept panel traps (IPM Technologies, Portland, OR, USA) indicated that both sexes of *A. chinensis* were equally attracted to traps baited with 4-(*n*-heptyloxy)butan-1-ol or a 1:1 blend of 4-(*n*-heptyloxy)butan-1-ol and 4-(*n*-heptyloxy)butanal, and that these two baits attracted significantly greater numbers of beetles than the control traps and those baited with 4-(*n*-heptyloxy)butanal alone (Hansen *et al.*, 2015). The authors concluded that strictly speaking, 4-(*n*-heptyloxy)butan-1-ol must be an aggregation pheromone as both sexes were attracted to it, however, its primary function was thought to be to bring the two sexes together for mating.

Once male and female ALB are in close proximity, it has been suggested that the female produces a sex trail pheromone consisting of two major components (2-methyldocosane and (*Z*)-9-tricosene) and two minor components ((*Z*)-9-pentacosene and (*Z*)-7-pentacosene), attractive only to males (Hoover *et al.*, 2014), and a contact pheromone consisting of five components ((*Z*)-9-tricosene, (*Z*)-9-pentacosene, (*Z*)-7-pentacosene, (*Z*)-9-heptacosene and (*Z*)-7-heptacosene (Zhang *et al.*, 2003), which allow the males to locate the females and then initiate mating, respectively (Nehme *et al.*, 2014). Further work by Wickham *et al.* (2012) provided evidence suggesting that once the five components identified by Zhang *et al.* (2003) had undergone ozonolysis and photooxidation in the laboratory (simulating abiotic oxidation in the natural environment) they were converted to aldehyde products that were attractive to the males. As a result of their studies, Wickham *et al.* (2012) suggest that rather than following the model proposed by Ginzel and Hanks (2005) (above), the females select host trees and then produce a long range pheromone to attract the males. Evidence for a female-produced contact pheromone has also been reported for the cerambycid *Hedypathes betulinus* (Klug, 1825) (Fonseca and Zarbin, 2009) although the components of the suggested pheromone were not identified.

In 2009, Nehme *et al.* published the results of their laboratory (Y-tube olfactometer tests) and greenhouse studies (using a combination of traps and lures), which ascertained that the male-produced pheromone primarily attracts virgin females when perceived in combination with plant volatiles; females were significantly more attracted to the pheromone than the males but males were more attracted to some plant compounds. Along with two essential oils (Eucalyptus oil and Manuka oil; Manuka oil has previously been shown to be moderately attractive to emerald ash borer (Crook *et al.*, 2008) and *Xyleborus glabratus* Eichhoff (Coleoptera: Scolytinae; Hanula and Sullivan, 2008)), Nehme *et al.* (2009) tested 12 plant volatiles for attractiveness to *A. glabripennis* adults. These included (—)-verbenone , (*E*)-pinocarveol, (*Z*)-3-hexen-1-ol, (—)- linalool, linalool oxide, camphene, delta-3-carene, (*E*)-caryophyllene, myrcene, (±)-2-pentanol, (*Z*)-3-hexenyl acetate, and benzenyl acetate. Both (—)-verbenone and (*E*)-pinocarveol are known to be attractants to the old-house borer, *Hylotrupes bajulus* (L) (Coleoptera: Cerambycidae) (along with (+)-α-pinene and (+)-terpinen-4-ol; Reddy *et al.*, 2005) and (—)-verbenone is known to increase the attractiveness of α-pinene, ipsenol and methylbutenol to female *M. galloprovincialis* (Ibeas *et al.*, 2007). The remaining volatiles tested are produced either by healthy or stressed *Acer mono* Maxim and *A. negundo* and/or have been shown in other studies to attract *A. glabripennis* and other cerambycid adults (Chenier *et al.*, 1989; Ping *et al.*, 2001; Nehme *et al.*, 2009). Seven of the 12 plant volatiles tested elicited a > 50% response in virgin males whereas only four of them attracted > 50% females during the Y-olfactometer tests. Manuka oil and Eucalyptus oil had no effect. The volatiles δ-3-carene and (*E*)-caryophyllene were significantly more attractive to males than females. (*Z*)-3-hexenyl acetate and myrcene were found to be repellent to males, and camphene was repellent towards females (Nehme *et al.*, 2009). (Z)-3-hexenyl acetate is a stress-induced volatile. Since

A. glabripennis prefers slightly weakened, but not highly stressed hosts, it is perhaps unsurprising that a stress-induced volatile should be repellent (Hanks, 1999).

These same investigators (Nehme *et al.*, 2009) also used their greenhouse studies to identify the best trap design in combination with the best lure. Four trap designs were tested: the intercept panel trap (APTIV, Portland, OR), a circle trunk trap (curculio trap; Great Lakes Integrated Pest Management, Vestaburg, MI), the Lindgren funnel trap (12 funnel size; Contech, Delta, Canada) and a screen sleeve trap designed by V. Mastro and D. Lance (USDA-APHIS-PPQ, Otis, MA) specifically for *A. glabripennis* after the limited success of commonly available traps. Nehme *et al.*, (2009) report that when different trap designs without lures were tested, the screen sleeve trap was the most effective at capturing *A. glabripennis* beetles, but the majority of trapping involving the use of lures is performed with intercept panel traps. The Nehme *et al.* (2009) greenhouse study indicated that the efficacies of the panel traps and screen sleeve traps differed according to the lure used. Screen sleeve traps baited with linalool caught the highest number of beetles per week whereas the panel traps baited with linalool alone did not catch any beetles. Intercept panel traps were more effective when baited with (Z)-3-hexen-1-ol, catching on average twice as many beetles as the screen sleeve traps baited with this plant volatile. The addition of the male-produced pheromone blend to the (Z)-3-hexen-1-ol bait resulted in higher numbers of trapped beetles, significantly improving the efficacy of the screen sleeve trap compared to the use of either lure alone. Performance of the circle trunk and Lindgren funnel traps was poorer than the screen sleeve traps and Intercept panel traps. However, no combination of trap design and lure caught significantly more beetles than the empty control traps in the greenhouse, indicating very limited success of these combinations of trap designs and lures.

In 2010, Nehme *et al.* published the results of field studies in China evaluating of the use of male-produced pheromone components, and plant volatiles in two traps. The addition of different combinations of plant volatiles was also assessed. During the first field season black Intercept Panel traps (cross-vein panels; APTIV, Portland, OR) were hung in host trees and baited with one of the following treatments: five live males in a cage, five live females in a cage, 10 µg of 4-(*n*-heptyloxy)butan-1-ol, 10 µg of 4-(*n*-heptyloxy)butan-1-al, 10 µg of a 1:1 blend of the two male pheromone components and 10 µg of the pheromone blend with 100 µg each of (—)-linalool and *trans*-pinocarveol (plant volatiles chosen on the basis of preliminary laboratory studies) and were compared with unbaited control traps. In a second study, the use of Intercept panel traps hung on trees was compared with panel traps hung on rows of bamboo poles 20 m away from host trees and screen sleeve “walk-in” traps (handmade and designed by V. Mastro and D. lance (USDA-APHIS-PPQ, Buzzards Bay, MA); Nehme *et al.*, 2010) wrapped around host tree trunks. Five lure treatments were tested against unbaited control traps: 10 µg male –produced pheromone (equal blend of the two components); 100 µg of the plant volatile (—)-linalool; 10 µg male –produced pheromone + 100 µg of (—)-linalool; a mix of plant volatiles (100 µg each of (—)-linalool, (Z)-3-hexen-1-ol, (—)-trans-pinocarveol, linalool oxide and *trans*-caryophyllene; and finally a mix of 10 µg male –produced pheromone + 100 µg each of the five plant volatiles. The choice of plant volatiles used was based on the authors previous Y-olfactometer tests (Nehme *et al.*, 2009).

The results of the Nehme *et al.* (2010) study indicated that Intercept panel traps baited with the male-produced pheromone caught significantly more females than control traps in both years. The alcohol-only portion of the pheromone attracted only female beetles while the aldehyde component did not attract any beetles of either sex. Combining the pheromone blend with the combination of plant volatiles (—)-linalool, (Z)-3-hexen-1-ol, (—)-*trans*-pinocarveol, linalool oxide and *trans*-caryophyllene usually significantly increased catches of females, 85% of which were virgin. The same trend was observed at the sites where the results were not found to be significant. More males were caught in traps baited with plant volatiles than those baited only with the pheromone. Intercept panel traps and screen sleeve traps appeared to be equally successful at trapping *A. glabripennis* in the field but their success was dependent on the lure used. During the second field season, the sleeve traps baited with the male-produced pheromone and (—)-linalool caught the highest number of beetles overall whereas the panel traps had the highest catches when baited with the male-produced pheromone and a mix of the five plant volatiles. The panel traps hung on bamboo poles away from host plants were less effective at capturing beetles than either trap type placed on host trees. The authors suggested that the trap catch data showed promise for use in monitoring programmes in areas where the beetles were at low population densities, such as at points of entry for non-native countries. They concluded that Intercept panel traps baited with the *A. glabripennis* male-produced pheromone, in combination with the plant volatiles (—)-linalool, (Z)-3-hexen-1-ol, (—)-*trans*-pinocarveol, linalool oxide and *trans*-caryophyllene could be considered a promising trap/lure combination for monitoring Asian longhorned beetle, and that screen sleeve traps baited with the pheromone combined with (—)-linalool would provide a potential alternative (Nehme *et al.*, 2010). However, Wickham *et al.* (2012) point out that although the results of the Nehme *et al.* (2010) study were siginificantly different, beetle attraction to the traps was still limited. Nehme *et al.* (2010) do point out that differences in host tree composition (amongst other things) in invaded countries were likely to affect beetle behaviour, and attractiveness to specific plant volatiles, and may therefore need to be tested and adjusted for use in countries other than China. It is also likely that trapping results for Asian longhorned beetle are dependent on the population dynamics at each individual site, and this should therefore be taken into consideration (Alain Roques pers. comm.).

In 2014, Nehme *et al.* reported on the development, deployment and evaluation of trapping systems for *A. glabripennis* in the United States, building on the previous work described above. From 2009-2012 they deployed traps throughout the Worcester area of the United States, where there was (and still is) a large outbreak of Asian longhorned beetle. They evaluated a number of lures. Since the trapping area was under federal and state quarantine, and following a USDA-APHIS eradication programme, it is important to note that the authors expected the number of trapped beetles to decrease over time as beetle-infested trees were removed.

During this study, Nehme *et al.* (2014) report that Intercept panel traps (forestry panel traps; Alpha Scents, Syracuse, NY) were used; during the final year damaged traps were replaced with woodborer panel traps (ChemTica Internacional S.A., Heredia, Costa Rica). The surface of the traps was modified to increase their slipperiness, and therefore enhance beetle catch, in the following ways: coating with Rain-X (ITW Global Brands, Houston, TX) in 2009; coating with a mixture of Fluon (Northern Products Inc., Dudley, MA) and 5% India ink (to retain the black colour of the trap) in 2010; and coating with a 10% vol:vol diluted Fluon solution in 2011-2012 (the India ink was omitted because the diluted Fluon solution did not alter the trap colour). The switch to fluon was made because reports suggested that the use of Fluon increased trap catches of cerambycids by 14% when compared with Rain-X (Graham *et al.*, 2010). Traps were suspended from tree limbs approximately 5m above the ground ensuring that they did not come into contact with foliage and other tree limbs. Susceptible open-growing trees or trees on the forest edge were selected for trapping so that the beetles could easily fly into the traps (Nehme *et al.*, 2014). Over the course of the four year study, the author's deployed a large number of traps: 82 traps across the regulated area (2009); 40 traps during 2010; 500 traps in areas where infested trees had previously been detected and removed as well as in unsurveyed areas (2011); 391 traps in areas near recent infested tree finds, areas between the previous year's transects, and areas not yet surveyed (2012). The lure formulations and emitters used during this study were obtained either from ChemTica (ChemTica Internacional S.A., Heredia, Costa Rica) or Synergy (Synergy Semiochemicals Corp., Burnaby, British Columbia, Canada). The lures themselves consisted of various mixtures of the plant volatiles linalool, linalool oxide, *cis*-3-hexen-1-ol, *trans*-pinocarveol, δ-3-carene and *trans*-caryophyllene presented with or without the male-produced pheromone. In 2012, *trans*-pinocarveol was omitted following the results obtained from the 2009-2010 trapping and laboratory studies by the authors. A total of 17 different lure combinations were tested during the course of the study (Nehme *et al.*, 2014).

During the four years of the Nehme *et al.* (2014) study, a total of 45 Asian longhorned beetles were captured in 40 individual traps baited with the lures (in various combinations) whilst no beetles were caught in the blank control lure traps. The relative efficacy of the individual lures could not be statistically compared as the numbers of beetles caught were too small, however the authors were able to analyse the data in such a way as to observe a trend towards a combination of the beetle pheromone and plant volatiles providing the greatest attractancy. The authors point to other ongoing work (Nehme *et al.*, 2010; Meng *et al.*, 2014), including in areas with greater beetle density in China, to identify potential differences in the efficacy of these particular lures. The number of beetles trapped over time decreased as expected due to the eradication measures in force in the regulated area. However, while the total number of beetles found each year decreased, the proportion of beetles found via the trapping study increased. In some instances the traps resulted in the detection of some undiscovered beetle infestations in areas that had not yet been surveyed (Nehme *et al.*, 2014).

As a result of these studies, entomologists from the U.S. Forest Service's Northern Research Station and the Pennsylvania State University have developed a pheromone trap that is being tested in the field in Worcester, MA. (U.S. Forest Service, 2012).

During the ANOPLORISK-II project (funded by the Euphresco Network for phytosanitary research coordination), traps and lures developed in North America for Asian longhorned beetle were tested in outbreak areas of the UK (Paddock Wood (Kent)) and Austria (Gallspach) (ANOPLORISK-II, 2015). Teflon coated cross-vane traps (ChemTica), surface treated with Fluon, and baited with a lure consisting of 4-(n-heptyloxy)butanal and 4-(n-heptloxy)butan-1-ol, along with linalool, (Z)-3-hexen-1-ol and *trans*-caryophyllene were used. In the UK, 18 traps were deployed but no ALB were caught; this was also the case in previous years (2012 and

2013) during similar trap deployments. All the traps contained catches of other arthropods, including at least 18 species of Coleoptera but none were Cerambycidae (or Buprestidae or Scolytinae). In Austria during 2014, 20 traps were used with no ALB catches, and 27 traps were deployed in 2015 with just one female ALB caught. The presence of this one trapped beetle demonstrated the feasibility of trapping in areas with low population levels as after receiving the trap report, inspectors surveyed the area around the trap and detected an emergence hole and an additional dead insect in a tree that had been inspected (and hence overlooked) in 2014 (ANOPLORISK-II, 2015). In addition, during the 2015 trapping season three specimens of two other cerambycid species (*Phymatodes testaceus* and *Leptura rubra*) were caught. The low numbers of ALB caught were not unexpected when compared with the experiences of North America (see work by Nehme *et al.*, 2014). In addition, eradication measures were in place at both outbreak sites and the number of infested trees was low compared with the Worcester, U.S. site so ALB populations were expected to be low or absent (ANOPLORISK-II, 2015).

In addition to trapping at these two outbreak sites, the ANOPLORISK-II project deployed traps for both Asian longhorned beetle and *Monochamus* spp. around two major stone importers in Austria considered to be high risk sites for introduction of these invasive species (ANOPLORISK-II, 2015). Neither of these sites were located near pine forests. The traps for *Monachamus* spp. consisted of Teflon-coated multifunnel traps (Econex SL, Murcia, Spain) baited with Galloprotect-2D (SEDQ, Barcelona, Spain). In 2015, α-pinene was added to increase the attractancy for other woodborers of coniferous hosts. No Asian longhorned beetles were caught however, the *Monchamus* lure resulted in the trapping of four *M. galloprovincialis* (using five traps). In addition the *Monchamus* lure trapped 15 other cerambycid species (one of which was a non-native) (see below).

The ANOPLORISK-II final report suggested that the current ALB lure (a blend of male-produced pheromone and plant volatiles of broad leaved trees) does not represent the full signal needed to attract adult beetles. This opinion is also voiced by Wickham *et al.* (2012), who advise that a multicomponent trap is required, combining the semiochemicals from the multiple steps in the beetle's mating sequence.

To summarise:

1. Flight intercept traps such as funnel traps and cross-vane panel traps are the most effective for catching cerambycids (Graham *et al.*, 2010; Hank and Millar, 2016).
2. Trap surfaces must be coated in fluon to ensure the beetles immediately fall into the collection bucket and cannot walk out again (Hanks and Millar, 2016).
3. α-pinene and ethanol are not necessarily effective at trapping cerambycids as they are attractive to conifer feeders rather than species that attack deciduous trees (Schroeder and Lindelöw, 1989; Wong *et al.*, 2012; Hanks and Millar, 2016).
4. Large scale trapping to monitor pine sawyer beetles is deployed in areas of Europe in order to control pine wilt disease. A lure consisting of the host plant volatile α-pinene plus the bark beetle pheromones ipsenol and methylbutenol make a highly effective operational lure for monitoring *M. galloprovincialis* (Allison *et al.*, 2003; Ibeas *et al.*, 2007). The addition of Monochamol (2-undecyloxyl-1-ethanol; a male pheromone

component) further increases attractancy (Pajares *et al.*, 2010; Teale *et al.*, 2011; Allison *et al.*, 2012).

5. A male produced short range pheromone composed of two components (4-(n-heptyloxy)butan-1-ol and 4-(n-heptyloxy)butan-1-al) has been identified in Asian longhorned beetle and citrus longhorned beetle.
6. Black intercept panel traps baited with the broad-leaved plant volatiles (Z)-3-hexen-1-ol, (—)-linalool, linalool oxide and *trans*-carophyllene, and the male-produced pheromone blend can be considered a promising trap/lure combination for Asian longhorned beetle and have been tested in outbreak areas in the U.S. (Nehme *et al.*, 2010) and have been developed and tested in U.S. outbreak areas.
7. Cross-vane traps surface treated with Fluon and baited with the male pheromone blend and the plant volatiles (Z)-3-hexen-1-ol, (—)-linalool, linalool oxide and *trans*-carophyllene are currently deployed in European outbreak areas (ANOPLORISK-II, 2015).
8. However, the currently available traps for Asian longhorned beetle still have limited attractancy, with the lure likely to be missing a component(s) required to improve efficacy (Wickham *et al.*, 2012; ANOPLORISK-II, 2015). Currently available data on the trapping of Asian longhorned beetle in the U.S. and China needs to be treated with caution as the results obtained are possibly dependent on the population dynamics at each particular study site (Alain Roques pers. comm.) and therefore may not necessarily reflect the outcome of trapping at other sites.
9. A huge repertoire of compounds that can either attract, repel or deter, and include kairomones (such as plant volatiles, smoke volatiles and bark beetle pheromones), long and short range pheromones, defensive compounds and oviposition stimulants have been identified in cerambycid beetles (Allison *et al.*, 2004; Hanks and Millar, 2016).

Development of trap-based surveillance programmes

Ports, airports and other points of entry for international cargo, as well as storage facilities for such cargo, are seen as high risk sites for entry of invasive wood-boring beetles. The surrounding areas, forested and urban (which can provide a large number of native and exotic host plants), may provide suitable host trees for establishment of any invading species as most invading species emerging from packaging materials would fly away from the point of entry in search of suitable hosts (Bashford 2012; Rassati *et al.*, 2015a). Therefore it is important that traps are placed in the surrounding areas to increase the detection of alien species (Rassati *et al.*, 2015a). In addition, it should be pointed out that there are inherent limits to early point of entry trapping programmes, notably that only adult insects are detected by traps. This means that if a beetle is at an immature stage of its life cycle when it arrives in the country, it is highly likely to be moved away from the point of entry during transportation of the commodity and end up in other locations, including disposal sites where wood packaging material is discarded (Alain Roques pers. comm). This has also been suggested by Rassati *et al.* (2015b) and surveillance programmes at wood packaging disposal sites are currently under investigation by these authors. Brockerhoff *et al.*, (2006b) stressed that when monitoring for particularly unwanted alien species, the best approach for their interception should be based on traps baited with their specific attractants if the composition of their pheromones and other attractants are known. Sex and aggregation-sex pheromones for more than 100 cerambycid species are now known and summarised by Hanks and Millar (2016). Various surveillance strategies are either in place or under development as detailed in the sections below.

United States of America

In 2001, the U.S. Forest Service department of the USDA, through the establishment of an Exotic Pest Rapid Detection Team, implemented a pilot study investigating the early detection of non-native bark and ambrosia beetles (Rabaglia *et al.*, 2008). The aim of this project was to develop a rapid detection system for these pests such that a fully operational, national detection programme could be implemented (Rabaglia *et al.*, 2008). Using data on the frequency of past interceptions, the severity of the threat that they pose, and their ability to establish in the U.S., ten target species (*Orthotomicus erosus*, *Ips sexdentatus*, *Tomicus minor*, *Hylurgops palliatus*, *Trypodendron domesticum*, *Pityogenes chalcographus*, *Ips typographus*, *Tomicus piniperda*, *Hylurgus ligniperda* and *Xyleborus* species) were selected. However, the investigators did not want to overlook any other potentially damaging species so all the bark and ambrosia beetles caught in the traps were identified. During the five years of the study, protocols were tested and adapted across 22 States and more than 300 trapping sites. Lindgren funnel traps and lures that have previously been shown to attract and capture bark beetles were chosen as follows. During the first year (2001), traps were placed within (or very near to) ports, airports and other points of entry for international cargo. Four specific chemical lures were used 1) a bark beetle lure (methyl butenol + *cis*-verbenol + ipsdienol; target species: *I. typographus*, *I. sexdentatus*, *O. erosus*, *H. ligniperda*); 2) α-pinene + ethanol (host volatile; target species: *Tomicus* spp., *H. palliatus*, *H. ligniperda*); 3) ethanol (target species: *Xyleborus* spp., *T. domesticum*) and 4) Chalcoprax® (chalcogran; target species: *P. chalcographus*). The results from 2001 demonstrated that the protocols that were used worked well, confirming that trap sites were suitably identified, the traps and lures used were effective, and the taxonomists were accurately identifying the beetles caught (Rabaglia *et al.*, 2008). In 2002, more trap sites were used (still concentrating on points of entry). In 2003, the Chalcoprax® lure was omitted from the study. Other trapping sites were targeted as the APHIS Cooperative Agriculture Pest Survey (CAPS) was targeting ports, airports, warehouses and distribution centres. In order that the two studies complemented each other, the pilot study turned its attention to wooded areas near high-risk solid wood packaging material “endpoints” such as wood recycling locations, dunnage piles, and factories, warehouses and distribution centres where wood was stored outside. No significant changes were made to the protocols during 2004, however, in 2005 trained pre-screeners were used to sort out the common species trapped before sending the remaining samples to the taxonomist. This was instigated because it had become clear by the end of the previous year that the rate limiting step was the number of samples that three professional taxonomists could process in an acceptable timescale (Rabaglia *et al.*, 2008).

During the five year pilot study, more than 250,000 specimens were identified, representing 162 scolytid species. One hundred and thirty three of these species were native to the U.S.A., 24 were established non-native species but 19 of these detections represented new State records indicating an extension of the species’ range (Rabaglia *et al.*, 2008). The five most numerous species found were all established non-native species. Finally, five new invasive species (*Hylurgops palliatus*, *Xyleborus similis*, *Xyleborus glabratus*, *Xyleborus seriatus* and *Scolytus schevyrewi*) were identified. This meant that delimitation trapping surveys were commenced for these species, with the pilot study protocols, lures and site choices adjusted to reflect the needs of these individual surveys (Rabaglia *et al.*, 2008).

As a result of this pilot study, the protocols used have been refined and implementation strategies further developed. They are now being used in the national implementation of the Early Detection and Rapid Response programme for non-native bark beetles, which began in 2007 (Rabaglia *et al.*, 2008). At the time of publication (2008), approximately one third of the country (15-18 states) was to be surveyed each year for non-native bark and ambrosia beetles. Traps containing lures of the host volatiles ethanol and α-pinene, combined with *Ips* species pheromones, have been used in surveillance programmes in the U.S. and Canada for over a decade now (Rabaglia *et al.*, 2008), and are relatively successful at detecting Scolytinae but do not successfully detect cerambycid and buprestid species.

Detection of Asian longhorned beetles consists of intensive surveying for infested trees, which is highly labour intensive. Visual inspection from ground level, using binoculars, concentrates on looking for signs such as adult emergence holes, oviposition scars , sap flow, larval frass, feeding injury and branch dieback in all potential host trees in potentially infested areas (Hu *et al.*, 2009; Haack *et al.*, 2010; USDA-APHIS, 2013b). However, inspecting from ground level is not reliable (thought to be only 30% effective; USDA-APHIS, 2013b), especially for large trees. Detection rates can be improved with the use of hydraulic lifts acting as a platform, but the most efficient detection method used in the U.S.A. is the use of trained tree climbers looking for signs of the beetles within the tree canopies (60-75% effective; USDA-APHIS, 2013b); however, this is also the most costly method (Hu *et al.*, 2009; Haack *et al.*, 2010). The potential use of traps and semiochemical lures as a means of detecting Asian longhorned beetle has been under investigation in the U.S. and China, focussing on the pheromones that they produce and the plant volatiles that they are likely to find attractive, and is detailed above. Research towards the development of traps and lures for Emerald ash borer has been discussed in previous sections.

Canada

The Canadian Food Inspection Agency (CFIA) is responsible for conducting surveys for invasive bark and wood-boring beetles. These surveys include rearing from logs, visual surveys and the use of traps baited with semiochemical lures rearing from logs and visual surveys (Troy Kimoto, CFIA pers. comm.).

The log rearing programme, developed in connection with the Canadian Forest Service (CFS), involves the removal of logs obtained during municipal hazard tree removal, and securely transports them to facilities where they can be monitored for signs of insect activity and emergence. This method is used to increase the likelihood of detecting exotic species that do not respond to the lures currently used in national trapping surveys or are not known to use semiochemicals for mate location (Troy Kimoto, CFIA pers. comm.).

With regard to surveys for Asian and citrus longhorned beetles, the CFIA deploys a visual inspection programme as the number of traps that would be needed to cover the number of sites visually surveyed would be too costly, and the current lures available for these species are not deemed to be highly effective. A systematic, triangular grid-based survey method (developed in conjunction with Jean Turgeon of CFS) is deployed, placed over a city's boundary, with the points spaced at 1301 m intervals. At each grid point, the inspectors assess 30 trees (concentrating on maple followed by willow, poplar and birch), looking for signs of infestation such as exit holes, adult beetles, frass and egg laying sites, using binoculars if necessary. Surveys are performed in the autumn and winter when the inspection teams are less busy, and once the trees have lost their leaves, making inspections easier (Troy Kimoto, CFIA pers. comm.). Asian longhorned beetle is now under eradication in Canada as no infested trees are currently present (Troy Kimoto, CFIA pers. comm.).

Surveys by the CFIA for Emerald ash borer are conducted using sticky green prism traps (Synergy Semiochemical Corp. or Sylvar Technologies Inc. (Fredericton, NB, Canada); tree limb hook and trap spreaders are purchased from MidWest Wire Products LLC (Sturgeon Bay, WI, USA). The lures used include the green leaf plant volatile (Z)-3-hexen-1-ol (in operation since 2010) and the female-produced aggregation pheromone (3Z)-dodecen-12-olide (also known as (3Z)-lactone) has also been included since 2012. The CFIA is concerned about other *Agrilus* species that have not yet invaded Canada; effective traps and lures for these are currently under development for use in national surveys (Troy Kimoto, CFIA pers. comm.).

The brown spruce longhorn beetle, *Tetropium fuscum*, is surveyed using IPM intercept panel traps baited with ultra high release (UHR) ethanol (Contech Inc. or Synergy Semiochemical Corp.), UHR spruce blend (Contech Inc.) and E-fuscumol (Sylvar Technologies Inc.), the aggregation pheromone for *T. fuscum* (Troy Kimoto, CFIA pers. comm.).

All other trapping surveys use 12 unit, wet multiple funnel traps (Contech Inc. or Synergy Semiochemical Corp.), hung such that the bottom of the trap is 30 -200 cm above ground and above the understory vegetation to ensure clear "flight lines" for flying insects. The trapping fluid is a mixture of USP/FCC propylene glycol, bitrex and surfactant. Traps are placed at least 25 m apart in high risk areas where solid wood packaging material, firewood and wooden handicrafts are present such as near landfills, green waste facilities and firewood vendors (Troy Kimoto, CFIA pers. comm.).

A number of lures are used with the multiple funnel traps as follows: From 2011 to 2014 inclusive, traps baited with racemic 3-hydroxyhexan-2-one (K6), racemic 3-hydroxyoctan-2-one (K8) (aggregation pheromones for a number of Cerambycinae longhorned beetles; both synthesised by Bedoukian Research Inc. (Danbury, CT, USA)) and UHR ethanol (added to increase the target species to include Scolytinae; Contech) were used by the CFIA in their national invasive wood boring insect survey (lures were deployed in three separate release devises). This combination is known to attract derambycid and scolytinid species, and whilst in use by the CFIA they detected a cerambycinae longhorned beetle native to eastern Canada in western Canada and also intercepted two specimens of a Sri Lankan/Indian cerambycine beetle (Troy Kimoto, CFIA pers. comm.). The lures K6 and K8 have since been superseded with combinations of (1) *E*-fuscumol, *E*-fuscumol acetate (synthesised by Bedoukian Research Inc. and placed in separate polyethylene bubble caps by Contech Inc.) and UHR ethanol, and (2) monochamol, racemic ipsenol, UHR ethanol and UHR (95/5±)-alpha-pinene (separate release devices previously from Contech Inc but currently from Synergy Semiochemical Corp.), respectively. The *E*-fuscumol/*E*-fuscumol acetate/UHR ethanol combination is currently in use in conjunction with *Monochamus* lures and is specifically used to target non-native longhorned beetles and Scolytinae that attack both gymnosperms and angiosperms. The latter combination of monochamol/racemic ipsenol/UHR ethanol/UHR (95/5±)-alpha-pinene is currently in use to target non-native *Monochamus* species that attack conifers and captures a wide range of wood-boring insects (Troy Kimoto, CFIA pers. comm.).

Additional lures include UHR ethanol plus UHR (95/5±)-alpha-pinene (in separate release devices; purchased from ConTech Inc. or Synergy Semiochemical Corp.), in use since at least 2003 until 2014, and known to capture a wide range of bark and wood boring beetles. It was used to target non-native wood-boring insects from the Buprestidae and Cerambycidae families along with Scolytinae. It is currently used as a component of the "*Monochamus* lure set". An exotic bark beetle lure consisting of three separate components (racemic ipsdienol, *cis*-verbenol and 2-methyl-3-buten-2-ol; all from ConTech Inc.) was used between 2002 and 2011 by the CFIA and is particularly good at capturing many species of Scolytinae, including ambrosia beetles. Ethanol (UHR) was also in use between 2002 to 2011, and mimics a stressed tree. Therefore it was used to attract wood borers that target stressed or declining host trees; it is very good at capturing ambrosia beetles. Indeed, between 2002 and 2011, UHR ethanol, the exotic bark beetle lure and UHR ethanol + UHR (95/5±)-alpha-pinene were used to together (nine traps per site, three of each trap) to target a wide range of Scolytinae, Buprestidae and Cerambycidae (Troy Kimoto, CFIA pers. comm.).

In order to detect the pine shoot beetle, *Tomicus piniperda* (L.) (Curculionidae: Scolytinae), 12 unit wet multiple funnel traps are baited with a three component pine shoot beetle lure consisting of myrtenol, *trans*-verbenol and (95-)-alpha-pinene (Troy Kimoto, CFIA pers. comm.).

New Zealand

In 2006, Brockerhoff *et al.* (2006b) published the results from a national surveillance programme implemented by the Ministry of Agriculture and Forestry in New Zealand, targeting wood-boring and bark beetle species considered to have the potential to become serious pests of conifer plantations and native forests. As well as acting as an early-warning system to detect newly established species, the programme also aimed to test the efficacy of different lures and trap placements. During the course of the general surveillance programme, 580 eight-unit Lindgren-type funnel traps (PheroTech, Delta, BC, Canada) baited with general attractant and/or bark beetle pheromone lures (PheroTech) known to attract a range of high risk Scolytinae and Cerambycidae, namely α-pinene and ethanol, β-pinene and ethanol, frontalin and ethanol or ipsdienol, were positioned around the entire country at sites considered to be high risk (Brockerhoff *et al.*, 2006b). These sites included all the major seaports, international airports, container-unloading sites and forested areas close to the high- risk sites. In excess of 27,000 beetles, of at least 82 species, were caught during the survey, with Scolytinae and Cerambycidae catches accounting for 88% of the catches during the first year and 51% of the catches during the second year (Brockerhoff *et al.*, 2006b). Most of the Scolytinae (99.8%) and Cerambycidae (96.3%) that were caught were introduced species that are known to be established in New Zealand, comprising mostly of *Arhopalus ferus* Mulsant (Cerambycidae), *Hylurgus ligniperda* (F.) (Scolytinae) and *Hylastes ater* (Paykull) (Scolytinae). A full list of the Scolytinae and Cerambycidae species caught during the surveillance can be found in Table 3.

However, no Buprestidae species were caught and neither were any new establishments detected (Brockerhoff *et al.*, 2006b).

Brockerhoff *et al.* (2006b) concluded that baited traps can provide an effective means of monitoring population levels of exotic and native wood-boring and bark beetles in the context of a nationwide surveillance programme. The most efficient lure for attracting beetles associated with conifer trees proved to be plant volatiles (α-pinene + ethanol) rather than species-specific beetle pheromones (Brockerhoff *et al.*, 2006b). However, the authors do suggest that the traps baited with the bark beetle pheromones would likely have been more effective than the plant volatile-only lures at attracting any new establishments of bark beetle species had they been present in the vicinity of the trap as these pheromones are attractive to many of the problematic conifer pests (*Ips*, *Dendroctonus* and *Monochamus* spp.). Overall, as a result of this national surveillance programme in New Zealand, Brockerhoff *et al.* (2006b) do conclude that a trapping programme of this nature, whilst relatively expensive, is likely to improve the chances of detecting new establishments of invasive species early, and hence improve the chances of successful eradication.

However, the trap-based system for surveillance detection developed by Brockerhoff *et al.* (2006b) was discontinued due to a shortage in funding and uncertainty regarding the net benefits, and surveillance programmes currently rely on visual insect and damage detection (Epanchin-Niell *et al.*, 2014). A model for designing cost-efficient surveillance for early detection and control of multiple biological invaders in New Zealand has since been developed by Epanchin-Niell *et al.* (2014) (see below).

Table 3. The wood-boring and bark beetles belonging to the Cerambycidae and Scolytinae families trapped during a national surveillance programme throughout New Zealand from 2002-2004 reported by Brockerhoff *et al.* (2006b). No Buprestidae species were trapped during the survey. [a] depicts non-native (and established) species.

Family	Species
Cerambycidae	*Ambeodontus tristis* (F.)
	Arhopalus ferus (Mulsant)[a]
	Astetholea lepturoides Bates
	Bethelium signiferum (Newman)[a]
	Callidiopsis scutellaris (F.)[a]
	Calliprason pallidus (Pascoe)
	Coptomma variegatum (F.)
	Drototelus elegans (Brookes)
	Hybolasius spp.
	Leptachrous strigipennis Westwood

	Metablax cinctiger (White)
	Navomorpha lineata (F.)
	Oemona hirta (F.)
	Prionoplus reticularis White
	Somatidia spp.
	Stenopotes spp.
	Tetrorea sellata Sharp
	Tetrotea spp.
	Xylotoles gratus Broun
	Xylotoles griseus (F.)
	Xylotoles humeratus Bates
	Xylotoles laetus White
	Xylotoles sp.
	Zorion minutum (F.)
Scolytinae	*Amasa truncata* (Erichson)[a]
	Ambrosiodmus compressus (Lea)[a]
	Chaetoptelius mundulus (Broun)
	Coptodryas eucalyptica (Schedl)[a]
	Cryphalus wapleri Eichhoff[a]
	Hylastes ater (Paykull)[a]
	Hylurgus ligniperda (F.)[a]
	Hypocryphalus spp.
	Pachycotes peregrinus (Chapius)
	Phloeosinus cupressi Hopkins[a]
	Scolytus multistriatus Marsham[a]
	Xyleborinus saxesenii (Ratzeburg)[a]

Europe

In Europe, visual surveying for Asian and citrus longhorned beetles is mostly done from the ground; bucket trucks and tree climbers are occasionally used (Haack *et al.*, 2010). In Austria, traps implemented by the ANOPLORISK-II project are used as an additional tool for surveillance of *A. glabripennis*. Cross traps from ChemTica (Costa Rica) or Witasek (Austria), baited with *A. glabripennis* lure (ChemTica; 2014 and 2015) and Glabriwit (Witasek; 2015 and 2016) have bee used. From 2016 the trapping was continued by the plant protection organization of the federal province (Hoch per. comm.). Trapping for *Monochamus* spp. as part of the *Bursaphelenchus xylophilus* (pine wood nematode) survey is also conducted. Traps are set up in high risk areas (importers of wood or wood packaging material) and operated by the plant protection organization of the federal province. Teflon-coated multifunnel or cross vane traps with extended collector cups for live trapping (ECONEX, Spain) and the lure Galloprotect®-2D (SEDQ, Spain) are used (Hoch per. comm.). Native bark beetles are also monitored by the use of traps in forest sites and operated by foresters, local authorities or BFW. *Ips typographus* and *Pityogenes chalcographus* are both monitored in trap networks covering most of Austra using Theysohn traps, baited with Pheroprax (BASF, Germany) or Ipsowit (Witasek, Austria) and Theysohn traps, baited with Chalcoprax (BASF, Germany) or Chalcowit (Witasek, Austria), respectively. Individual traps are also operated for *Ips sexdentatus, Ips cembrae, Ips duplicates*, and *Ips acuminatus* (Hoch per. comm.). In addition, wood packaging material is subject to import inspections according to the Commission Implementing Decision EU 2015/474 are visually performed by inspectors (Hoch per. comm.).

In 2014, Rassati *et al.* reported upon a pilot study undertaken at four Italian seaports, considered to be high-risk sites for the entry of invasive species. Their study aimed to compare the efficiencies of different lure and trap designs, notably single-lure versus multi-lure traps, cross-vane versus multi-funnel traps, in order to devise a long term monitoring programme. During the three year study, 49 species of wood boring beetles were trapped (totalling 1160 specimens), including six alien species (four Scolytinae (*Ambrosiodmus rubricollis*, *Cyrtogenius luteus*, *Xylosandrus crassiusculus*, *Hypothenemus eruditus*) and two Cerambycidae (*Neoclytus acuminatus*, *Xylotrechus stebbingi*).

The single versus multi-lure traps were tested at two ports using cross-vane traps. In each port, four traps were individually baited with ethanol, (—)-α-pinene, frontalin or an ipsenol/ipsdienol mix and one trap was baited with all four lures together. The number of species trapped in the multi-lure trap was as high as the sum of species trapped by the single-lure traps, suggesting that monitoring could be performed with multi-lure traps (Rassati *et al.*, 2014). No evidence was found for any negative interactions among the tested lures. Cross-vane versus multi-funnel traps were compared at all four ports, with one of each placed at each port. All of these traps were baited with a blend of ethanol, (—)-α-pinene, ipsenol, ipsdienol and 2-methyl-3-buten-2-ol (a replacement for frontalin). The two trap designs performed equally well, however, the multi-funnel trap was found to be more robust to adverse environmental conditions (e.g. high winds) and was easier and quicker to set up within the port (Rassati *et al.*, 2014). As a result of their pilot study these authors suggested that multi-funnel traps baited with different lures should be used for monitoring non-native wood-boring beetle in ports, and that traps should also be placed in the surrounding areas to validate the surveillance programme (Rassati *et al.*, 2014).

In 2015, Rassati *et al.* (2015a) published a further study detailing the improved early detection of alien wood-boring beetles in Italian ports and surrounding forests. The main purpose of this study was to investigate the relationship between the occurrence of alien wood-boring beetles and the annual volume of imported commodities, and secondly, the characteristics of the land surrounding each port in terms of forest cover and composition. Fifteen international Italian ports were chosen depicting a large latitudinal gradient, the widest possible range of data based on volume of solid commodities imported per year, proportion of forest cover in a 10 km radius around each port, and the composition of the forest (conifer versus broadleaf) (Rassati *et al.*, 2015a). Their study utilised 12-unit black multiple-funnel traps (Econex, Murcia, Spain) baited with the generic multi-lure blend previously tested (Rassati *et al.*, 2014), namely (—)-α-pinene, ipsenol, ipsdienol, 2-methyl-3-buten-2-ol and ethanol provided by Contech Enterprises Inc. (Victoria, BC, Canada). Traps were set up both within the port and within a forest site close to the port. The authors classified alien species as those not native to Italy, including those never intercepted before, those previously intercepted but not yet established and species that are non-native but already established (Rassati *et al.*, 2015a). A total of 81 species of wood-boring beetles were collected over the course of the study of which 49 species (40,374 specimens) were Scolytinae, 26 species of Cerambycidae (1,371 specimens) and six species of Buprestidae (8 specimens). As with the Rassati *et al.* (2014) study alien Scolytinae (11 species) and Cerambycidae (3 species) were trapped but no alien Buprestidae species (Table 4).

The Rassati *et al.* (2015a) study showed that alien species richness was positively correlated to the amount of imported commodities at the port, and greater numbers of alien species were found in broadleaf forests surrounding ports compared with conifer forests. The authors concluded that an efficient trapping protocol could greatly increase the likelihood of intercepting alien wood-boring beetles, provided that trapping sites were thoughtfully chosen, and therefore improve the efficacy of early detection.

Table 4. A list of alien wood-boring beetle species trapped inside, and within the surrounding forested areas of ports, as detailed by Rassati *et al.* (2015a). Multi-funnel traps baited with a generic multi-lure blend consisting of (—)-α-pinene, ipsenol, ipsdienol, 2-methyl-3-buten-2-ol and ethanol were used. No alien Buprestidae species were caught.

Family	**Species**	**Previously recorded in Italy**
Scolytinae	*Ambrosiodmus rubricollis* (Eichhoff)	Yes (established)
	Cyrtogenius luteus (Blandford)	Yes (established)
	Gnathotrichus materiarius (Fitch)	Yes (established)
	Hypothenemus eruditus Westwood	Yes (established)
	Xylosandrus crassiusculus (Motschulsky)	Yes (established)
	Xylosandrus germanus (Blandford)	Yes (established)

	Ernoporicus caucasicus (Lindemann)	Yes (not established)
	Liparthrum colchicum Semenov	No
	Pseudothamnurgus scrutator (Pandellè)	No
	Xyleborus ferrugineus (Fabricius)	No
	Xyleborus volvulus (Fabricius)	No
Cerambycidae	*Phoracantha recurva* Newman	Yes (established)
	Xylotrechus stebbingi Gahan	Yes (established)
	Cordylomera spinicornis (Fabricius)	Yes (not established)

A further study by Rassati *et al.* (2015b) investigated the importance of monitoring wood waste landfill in Italy for detecting invasive wood-boring species. This additional study used the same trap designs and lure blend as the 2015a study and compared trap catches at ports and nearby waste landfill sites. The investigators found that the abundance of non-native species was significantly higher in the wood waste landfills sites compared with the ports. An overall total of 74 scolytinid, cerambycid and buprestid species were caught at the sites. Eight non-native species were found; six of these (*A. rubricollis*, *C. luteus*, *G. materiarius*, *H. eruditus*, *X. germanus* and *C. spinicornis*) had been trapped in the 2015a study with *A. rubricollis*, *C. luteus* and *H. eruditus* also caught in the 2014 study. A further two non-native cerambycids (*N. acuminatus* and *X. stebbingi*) were trapped in the 2014 and 2015b studies but not in the 2015a study.

A similar surveillance programme in Lithuania during 2002-2005 is reported by Ostrauskas and Tamutis (2012), whereby trapping was used to monitor for the presence of potentially harmful xylophagous beetles at ports, railway stations and truck control posts where timber and wood were temporarily stored prior to entry or exit into/from Lithuania. Multi-funnel traps (IBL-3, Chemipan Company, Poland) baited with either α-pinene, myrcene or *cis*-verbenol were set in in 10 localities. In total, 807 specimens representing 26 species of Scolytinae were trapped along with 68 specimens representing 17 species of Cerambycidae (Table 5) in seven of the locations. Whilst all the species caught were considered to be native to Europe, two species (*Polygraphus punctifrons* Thom., *Trypodendron laeve* Egg.) have not previously been recorded before in Lithuania (either as a native species or as intercepted species). The most abundant Scolytinae species caught were *I. typographus*, *P. chalcographus* and *T. lineatum* (> 100 specimens); low numbers of the remaining Scolytinae species and cerambycid species were caught. However, no information is provided by these authors as to the efficiencies of the three different lures used.

Table 5. The wood-boring and bark beetles belonging to the Cerambycidae and Scolytinae families trapped during a surveillance programme in Lithuania from 2002-2005 reported by Ostrauskas and Tamutis (2012). [a] depicts species not previously known to or intercepted in Lithuania.

Family (Subfamily)	Species
Cerambycidae	*Acanthocinus aedilis* (L.)
	Anastrangalia reyi (Heyd.)
	Asemum striatum (L.)
	Corymbia rubra (L.)
	Leptura quadrifasciata L.
	Molorchus minor (L.)
	Obrium cantharinum (L.)
	Paracorymbia maculicomis (Deg.)
	Phymatodes testaceus L.
	Pseudovadonia livida (F.)
	Rhagium inquisitor (L.)
	Rhagium mordax (Deg.)
	Spondylis buprestoides (L.)
	Strangalia attenuata (L.)
	Tetropium castaneum (L.)
	Tetropium fuscum (F.)
	Xylotrechus rusticus (L.)
Curculionidae (Scolytinae)	*Crypturgus cinereus* (Hbst.)
	Crypturgus hispidulus Thom.
	Crypturgus pusillus (Gyll.)
	Crypturgus subcribrosus Egg.
	Dryocoetes autographus (Ratz.)
	Hylastes ater (Payk.)
	Hylastes cunicularius Er.
	Hylesinus fraxini (Panz.)
	Hylurgops palliates (Gyll.)
	Ips duplicatus (Sahlb.)

	Ips typographus (L.)
	Orthotomicus laricis (F.)
	Pityogenes chalcographus (L.)
	Pityogenes quadridens (Hart.)
	Pityophthorus pityographus (Ratz.)
	Polygraphus poligraphus (L.)
	Polygraphus punctifrons Thom.[a]
	Polygraphus subopacus Thom.
	Scolytus ratzeburgi Jans.
	Tomicus piniperda (L.)
	Trypodendron domesticum (L.)
	Trypodendron laeve Egg.[a]
	Trypodendron lineatum (Oliv.)
	Trypodendron signatum (F.)
	Trypophloeus granulatus (Ratz.)
	Xyleborinus saxesenii (Ratz.)

Designing cost-efficient surveillance programmes

Epanchin-Niell *et al.* (2014) describe the development of their bioeconomic model relating surveillance intensity (i.e. trap intensity) and invasion size to probabilities of detection and control. These authors considered the surveillance efforts for targeting new populations of multiple pest species in New Zealand. They firstly optimised the model for a single location and single invader and then expanded it to include multiple locations and multiple potential invaders, focussing the surveillance methods on the use of traps baited with insect attractants. The model predicted that for optimal surveillance, just over 10,000 traps should be deployed, every year for 30 years, at a cost of US$54 million. Using this strategy was hypothesised to give a net benefit of US$300 million by reducing total expected control costs and damage by 39% (Epanchin-Niell *et al.*, 2014). However, substantial net benefits (ranging from US$70 million to 227 million) were also observed at suboptimal trapping numbers and the expected costs and damages could be lowered if traps were optimally distributed rather than used at fixed densities. The author's suggest that even low levels of surveillance are worthwhile, and that the intensity of the surveillance could be scaled to available funds, using the model to determine trap numbers and locations in relation to the available funds to design an optimal strategy for the level of funding available.

Bycatch studies and trapping of multiple species

Numerous by-catch data have been reported upon as part of larger studies to establish trapping efficiencies of various trap designs and lures towards species from the three families of xylophagous beetles. This indicates that there is enormous potential for mass trapping of multiple species, and this is currently being researched by giving careful consideration to trap designs and combinations of lures (Hanks, 2012; Wong *et al.*, 2012).

Halbig (2013) reports on by-catches within her study on the attractiveness of insect and host plant volatiles towards longhorned beetles in the genus *Monochamus*. She used ECONEX® multiple funnel traps, coated with Teflon, and baited with one of three different combinations of attractants: Galloprotect 2D®, Galloprotect Pack® (SEDQ) and a third treatment included the addition of smoke volatiles. Nearly 500 *Monochamus* specimens were caught during the study along with numerous bycatches. Species representing at least 25 families of coleopterans were caught, of which 95 specimens belonged to the Cerambycidae and 24 specimens belonged to the Buprestidae; some Scolytinae species were also caught (see Table 6 for full list of Cerambycidae, Buprestidae and Scolytinae species caught during the trapping season).

As part of the Halbig (2013) study, lure attractiveness for the bycatch species was analysed when numbers allowed for statistical analyses to be performed. As a result of these analyses, the author hypothesises that the addition of α-pinene is useful to attract non-target species that are associated with conifer trees, and states that previous REPHRAME projects conclude that it attracts in an unspecific manner. Other studies (McIntosh *et al.*, 2001; Morewood *et al.*, 2002; De Groot and Nott, 2003), conducted in Canada, detail bycatches of cerambycid and buprestid woodboring insects (including *Arhopalus* spp., *Asemum* spp., *Buprestis* spp., *Chalcophora* spp., *Chrysobothris* spp., *Dicerca* spp. and *Tetropium* spp.) whilst trapping *Monochamus* species in Canada (Halbig, 2013).

Table 6. Details of the Cerambycidae, Buprestidae, and Scolytinae beetle bycatches caught during trapping studies for *Monochamus* species in Austria. Information taken from Halbig (2013).

Family	Species
Cerambycidae	*Acanthocinus griseus*
	Acanthoderes clavipes
	Arhopalus rusticus
	Cyrtoclytus capra
	Judolia cerambyciformis
	Leptura rubra
	Spondylis buprestoides
	Rosalia alpina
	Strangalia melanura
	Leptura livida
	Rhagium inquisitor

Buprestidae	*Buprestis haemorrhoidalis*
	Chrysobothris chrysostigma
	Chrysobothris igniventris
	Buprestis rustica
	Anthaxia quadripunctata
	Agrilus graminis
Curculionidae, Scolytinae	*Crypturgus* sp.
	Ips typographus
	Pityogenes chalcographus
	Pityokteines vorontsovi
	Polygraphus polygraphus

These authors were testing different trap designs for their efficacy towards larger species of woodboring insects. Studies by Jurc *et al.* (2012, 2016) also detail target and non-target trap catches observed when using semiochemical-baited traps used for monitoring pine wilt nematode vectors in Slovenia. These authors used cross vane funnel traps baited with ethanol + α-pinene, Pheroprax® (ipsdienol, *cis*-verbenol, 2-methylbut-3-en-2-ol), Gallowit® (ipsdienol, ipsenol, DMWK, *cis*-verbenol, α-pinene, ethanol), and additionally ethanol + α-pinene and Galloprotect 2D® (2016) during their field studies. The majority of insects caught were Scolytinae (76.55%), however, with regard to species diversity, 24 different taxa of Cerambycidae were trapped along with 12 species of Scolytinae and eight species of Buprestidae. The Scolytinae species trapped included *Hylurgus ligniperda*, *Tomicus piniperda*, *T. minor*, *Orthotomicus erosus*, *Ips sexdentatus*, *Hylastes attenuatus*, *H. opacus*, *I. typographus*, *Dryocoetes autographus*, *Xyleborus germanus*, *Gnathotrichus materiarius* and *Taphrorychus villifrons*. As well as *Monochamus* species, other Cerambycidae trapped included the saproxylic species *Spondylis buprestoides*, *Arhopalus rusticus*, *Arhopalus ferus*, *Rhagium inquisitor*, *Neoclytus acuminatus* and *Acanthocinus asedilis*; these are all species frequently listed in other by-catch studies. The most effective of the lures used for catching the Cerambycidae species was ethanol + α-pinene and the least effective was Pheroprax®, with Gallowit® and Galloprotect® falling in between. Halbig (2013) reports that studies testing the attractancy of G2D® and G2D® + α-pinene to longhorn beetles in Italy report bycatches that included *A. rusticus*, *L. rubra*, *R. inquisitor* and *S. buprestoides* but a study in Asia reported a very low bycatch during trapping of *M. alternatus* using combinations of 2-undecyloxy-1-ethanol, α-pinene and ethanol combinations.

A field study in Romania (Duduman and Olenici, 2015) observed catches of four non-target bark beetle species using flight barrier traps (intercept traps) baited with *I. duplicatus* pheromone (ipsdienol: E-myrcenole: methyl-buthenole in a 1:1:38 ratio) and the monoterpenes α-pinene and (+)-limonene. The majority of the beetles caught were *I. duplicactus* (144,191 individuals) however, 2611 individuals of *I. typographus* were caught along with 184

Pityogenes chalcographus (L.), 107 *Hylastes cunicularius* Erichson and 24 *Dryocoetes autographus* (Ratzeburg). Whilst these authors demonstrated that the *I. typographus* were attracted by the *I. duplicatus* pheromone blend (as expected because ipsdeniol and E-myrcenole are also components of the *I. typographus* pheromone (Vité *et al.*, 1972; Schlyter *et al.*, 1987a), and that the attractancy was increased in the presence of α-pinene or α-pinene plus (+)-limonene (Vité et al., 1972), they concluded that the catches of the other three non-target species were accidental.

The ANOPLORISK II project (ANOPLORISK-II, 2015) also monitored by-catches in both the ChemTica traps (for catching Asian longhorned beetle) deployed around two high risk stone importer sites in Austria and in the *Monochamus* traps. Both trap types caught other cerambycid species (52 specimens in total (Table 7).

In addition to by-catch studies, investigations have been deliberately designed to assess the efficacy of trap designs and lures to capture multiple species. One such study compared trap type and height for capturing cerambycid beetles (Graham *et al.*, 2012). These authors compared cross-vane panel traps (AlphaScents, Portland) and 12-unit Lindgren multiple-funnel traps (Contech Enterprises, Inc., Delta, British Columbia, Canada) (both trap types were Fluon-coated) at two different heights: ground level (bottom of trap approximately 0.5 m above the ground) and canopy level (suspended at mid canopy level). Traps at sites within conifer stands were baited with α-pinene and ethanol (Contech Enterprises, Inc.,), and the racemic cerambycid pheromone 3-hydroxyhexan-2-one (3R*; also known as K6) was used in traps placed in deciduous tree stands. Sites in industrial and residential areas, containing a mix of coniferous and deciduous trees were baited with a combination of α-pinene, ethanol and 3R*.

Table 7. Combined numbers of *Anoplophora. glabripennis*, *Monochamus galloprovincialis* and other non-target cerambycids caught at the two high risk stone importer sites in Austria during the 2014-2015 trapping season using ChemTica ALB traps and ECONEX/SEDQ *Monochamus* traps. Information taken from the ANOPLORISK –II final report (2015).

Species	**Number of specimens caught in the ALB traps**	**Number of specimens caught in the *Monchamus* traps**
Anoplophora glabripennis	-	-
Monochamus galloprovincialis	-	4
Acanthocinus griseus	-	1
Anisarthron barbipes	1	-
Aromia moscata	1	3
Arhopalus rusticus	2	-
Chlorophorus figuratus	-	1
Chlorophorus sp.	-	1

Hylotrupes bajulus	7	-
Leptura rubra	-	1
Lepturinae	1	3
Obrium brunneum	-	1
Phymatodes testaceus	3	1
Rhopalopus clavipes	2	1
Spondylus buprestoides[1]	2	18
Trichoferus campestris[2]	-	1
Xylotrechus sp.	1	-

In total, 3,723 beetles from 72 cerambycid species were caught during the 33 day trapping period (Table 8; Graham *et al.*, 2012). The greatest number of species (61) were caught in the traps baited with the 3R* pheromone, traps baited with both pheromone and host volatiles caught 45 species whereas traps containing only the host volatiles caught the lowest number of different species (32) (Graham *et al.*, 2012). *Neoclytus m. mucronatus* (F.) and *Xylotrechus colonus* (F.) were the two most commonly caught species, predominantly in traps baited with the 3R* pheromone whereas *Astylopsis sexgutta* (Say) and *Monochamus carolinensis* were only caught in traps baited with the host volatiles. In Russian field studies the addition of the longhorn beetle pheromones *E*-fuscumol, *E*-fuscumol acetate, hydroxyhexan-2-one (K6) and hydroxyoctan-2-one (K8) to spruce blend volatiles (α-pinene, (—)-β-pinene, (+)-3-carene, (+)-limonene and α-terpinolene) and ethanol had neutral, positive or negative effects on Scolytinae and Cerambycidae catches depending on the blend used (Sweeney *et al.*, 2014). However, the combination of ethanol plus K6 was considered one of the better blends, successfully trapping 7 cerambycid species and 20 scolytinids (Sweeney *et al.*, 2014). Other studies, such as Hayes *et al.* (2016) also indicated that racemic 3-hydroxyhexan-2-one was also attractive to a number cerambycid species The Graham et al. (2012) study indicated that overall, the panel traps caught 1.5 times more beetles than the funnel traps. That said, the funnel traps still caught a high number of beetles so the authors concluded that either design would be acceptable to use, with factors such as cost and durability influencing the decision as to which trap to use. Their data also indicated that it was important to trap at both ground and canopy level in order to maximise the effectiveness of any survey. They concluded that if the reasoning behind surveying was to capture a new invading species, then the most likely way of doing this would be to use cross-vane panel traps at both ground and canopy level (Graham *et al.*, 2012).

Table 8. The cerambycid species caught by traps baited with the pheromone 3R*, pheromone + host volatiles and host volatiles only during the U.S.A. study by Graham *et al.* (2012). The attractancy of the traps are ranked from least attractive (✓) to most attractive (✓✓✓) according to the proportion of each species attracted to the three lures (- indicates no beetles caught).

Subfamily	Species	3R* pheromone bait	3R* pheromone + host plant volatiles bait	Host plant volatiles bait
Aseminae	*Arhopalus rusticus* (L.)	-	✓	✓✓
	Asemum striatum (L.)	✓✓	✓	✓✓✓
Cerambycinae	*Cyrtophorus verrucosus* (Olivier)	✓✓✓	✓✓	✓
	Phymatodes testaceus (F.)	✓✓	✓	-
	Clytoleptus albofasciatus (Castelnae & Gory)		✓	-
	Clytus ruricola (Olivier)	✓✓✓	✓✓	✓
	Megacyllene caryae (Gahan)	✓	-	-
	Neoclytus a, acuminatus (F.)	✓✓✓	✓✓	✓
	Neoclytus j. jouteli Davis	✓	✓	-
	Neoclytus m. mucronatus	✓✓	✓	-
	Neoclytus scutellaris (Olivier)	✓✓	✓	-
	Xylotrechus colonus (F.)	✓✓✓	✓✓	✓
	Xylotrechus convergens LeConte	✓	-	-
	Xylotrechus s. sagittatus (Germar)	✓	✓✓	✓✓✓
	Anelaphus pumilus (Newman)	✓	-	-
	Anelaphus villosus (F.)	✓✓	✓	-
	Elaphidion mucronatum (Say)	✓✓	✓✓	✓
	Parelaphidion aspersum (Haldeman)	✓✓	✓	-
	Parelaphidion incertum (Newman)	✓✓✓	✓✓	✓

	Psyrassa unicolor (Randall)	✓✓	✓	-
	Hesperophanes pubescens (Haldeman)	✓	-	-
	Tylonotus bimaculatus Haldeman	✓✓	✓	-
	Heterachthes quadrimaculatus Haldeman	✓	-	-
	Obrium maculatum (Olivier)	✓✓	✓	-
	Obrium rufulum Gahan)	✓	-	-
	Euderces picipes (F.)	✓✓✓	✓✓	✓
Lamiinae	*Acanthocinus obsoletus* (Olivier)	✓	✓	✓✓
	Acanthocinus pusillus Kirby	✓	-	✓
	Astylopsis macula (Say)	✓✓✓	✓✓	✓
	Astylopsis sexguttata (Say)	✓✓	✓	✓✓✓
	Graphisurus despectus (LeConte)	✓✓	✓	-
	Graphisurus fasciatus (DeGeer)	✓✓	✓	✓✓✓
	Hyperplatys aspersa (Say)	-	✓	-
	Leptostylus transversus (Gyllenhal)	✓✓✓	✓	✓✓
	Lepturges angulatus (LeConte)	✓	✓✓	-
	Lepturges confluens (Haldeman)	✓✓	✓	-
	Lepturges symmetricus (Haldeman)	✓	-	-
	Sternidius alpha (Say)	✓✓✓	✓✓	✓
	Sternidius variegatus (Haldeman)	✓✓	✓	-
	Urgleptes querci (Fitch)	✓✓✓	✓✓	✓

	Aegomorphus modestus (Gyllenhal)	✓✓✓	✓✓	✓
	Hippopsis lemniscata (F.)	✓✓	✓	-
	Eupogonius pauper LeConte	✓✓	✓	✓✓✓
	Eupogonius tomentosus (Haldeman)	✓	✓	✓✓
	Dorcaschema cinereum (Olivier)	✓✓	✓	-
	Dorcaschema nigrum (Say)	✓	-	-
	Goes pulcher (Haldeman)	✓	✓✓	-
	Goes pulverulentus (Haldeman)	-	✓	-
	Hebestola nebulosa Haldeman	-	-	✓
	Microgoes oculatus (LeConte)	-	-	✓
	Monochamus carolinensis (Olivier)	-	-	✓
	Monochamus scutellatus (Say)	-	-	✓
	Oberea praelonga Casey	✓	-	-
	Pogonocherus mixtus Haldeman	-	✓	✓✓
	Saperda discoidea F.	✓	-	-
	Saperda imitans Felt & Joutel	✓	-	-
	Saperda lateralis F.	✓	-	-
	Saperda tridentata Olivier	✓	-	-
	Saperda vestita Say	✓	-	-
Lepturinae	*Acmeops proteus* (Kirby)	-	-	✓
	Analeptura lineola (Say)	✓	-	-
	Bellamira scalaris (Say)	✓✓✓	✓✓	✓

	Brachyleptura champlaini Casey	✓	-	✓✓
	Brachyleptura rubrica (Say)	✓✓✓	✓	✓✓
	Strictoleptura canadensis (Olivier)	✓	-	-
	Strangalia famelica solitaria Haldeman	✓	-	-
	Strangalia luteicornis (F.)	✓	-	-
	Trachysida aspersa brevifrons (Howden)	-	✓	-
	Trigonarthris proxima (Say)	✓✓	-	✓
	Typocerus velutinus (Olivier)	✓	✓✓	-
Parandrinae	*Neandra brunnea* (F.)	✓✓✓	✓✓	✓
Prioninae	*Orthosoma brunneum* (Forster)	✓	-	-

Multiple pheromone blends

In 2012, *Wong et al.* report on a study to evaluate blends of known cerambycid pheromones to determine whether these blends could effectively trap multiple species simultaneously. Field studies were carried out at four locations using black flight intercept panel traps (Alpha Scents Inc., West Linn, OR) with the inner surfaces coated with Fluon. Racemic blends of the pheromone compounds were used either as single component lures or as a five-component blend. They targeted three native cerambycid species whose male-produced pheromones are known: *Neoclytus acuminatus* (F.) (2S,3S)-hexanediol), *Neoclytus mucronatus* (F.)((R)-3-hydroxyhexan-2-one) and *Xylotrechus colonus* (F.) ((R)- and (S)-3-hydroxyhexane-2-one and (2S,3S)- and (2R,3R)-hexanediol) and also included the pheromones fuscumol acetate and a 3:5 blend of neral and geranial (known as citral), which Wong *et al.* (2012) describe as logical candidates for inclusion in multispecies lures as they are known to attract species within the Spondylidinae and/or Lamiinae subfamilies of Cerambycidae. During their study, they trapped a total of 1,358 cerambycid beetles, 81.1% of which were the three native species *N. acuminatus*, *N. mucronatus* and *X. colonus* (Wong *et al.*, 2012). These three species were attracted to blends containing their pheromones despite the presence of fuscomol acetate and citral. In some cases the diastereomer compounds of the sympatric species did partially or completely inhibit attraction (as was the case for *N. acuminatus*). Three species from the subfamily Lamiinae (*Astyleiopus variegatus* (Haldeman), *Graphisurus fasciatus* (Degeer) and *Lepturges angulatus* (LeConte) were also effectively trapped by all blends containing the fuscumol acetate, indicating that this can be included with pheromones from Spondylidinae species to broaden the range of species caught by a single trap containing a multilure blend

(Wong *et al.*, 2012). Other cerambycid species were caught during the study but numbers were too low to be able to statistically analyse. The authors concluded that a degree of inhibition caused by multiplexing pheromones may not be critical in monitoring programmes, except when attraction is completely inhibited. However, partial inhibitions could mean that the lures become less sensitive, which could be problematic for early detection surveillance programmes, when population densities will be low (Wong *et al.*, 2012). Therefore, the authors suggest that the surveillance programmes will need to balance the need for sensitive detection with the increased costs of deploying multiple traps containing single pheromone components as opposed to single traps baited with a blend to attract multiple species.

In a continuation to the Wong *et al.* (2012) study, the attractiveness of further blends of cerambycid pheromones and host plant volatiles have been evaluated (Hanks *et al.* 2012). These authors used a blend of six pheromones that consisted of racemic 3-hydroxy-2-hexanone, 2,3-hexanediol isomers, fuscumol and fuscumol acetate, monochamol, and racemic 2-methyl-1-butanol (the *R*-enantiomer is a pheromone component of Cerambycid species across many genera; Hanks and Millar, 2016) (Hanks *et al.*, 2012). The host plant volatiles α-pinene and ethanol were also used. These authors used black flight intercept panel traps (Alpha Scents, Inc., West Linn, Oregon) treated with Fluon, and conducted four separate experiments. The first experiment compared the activity of the complete pheromone blend with treatments that each lacked a different component in a subtractive scheme. The second experiment compared the attractancy of the complete blend with each of the individual components, including a control trap without a lure; the third field study investigated the influence of the two plant volatiles together on attractancy of the complete pheromone blend and the final experiment determined which of the two plant volatiles was responsible for any increased attractancy of the pheromone blend (Hanks *et al.*, 2012).

During the course of the Hank *et al.* (2012) study, 3070 cerambycid beetles were trapped. Sufficient data were obtained to allow for statistical analyses for four species in the Cerambycinae subfamily (*Neoclytus acuminatus* (Fabricius), *Neoclytus mucronatus* (Fabricius), *Phymatodes lengi* Joutel and *Xylotrechus colonus* (Fabricius)) and six species in the Laminiae subfamily (*Aegomorphus modestus* (Gyllenhal in Schoenherr), *Astyleiopus variegatus* (Haldeman), *Astylidius parvus* (LeConte), *Graphisurus fasciatus* (DeGeer), *Lepturges angulatus* (LeConte) and *M. carolinensis*. The results of this extensive study indicated that as expected, beetles were attracted to their pheromone component within the blend with only two instances of inhibition apparent. Lower captures of *N. acuminatus* were observed in any lures that contained 3-hydroxy-2-hexanone, and *A. modestus* was significantly more attracted to its pheromone when presented as a single lure compared with the complete blend (Hanks *et al.*, 2012). In some cases (*N. mucronatus*, *L. angulatus* and *M. carolinensis*) the host plant volatiles synergised the attraction of the pheromone blend whereas in other cases (*G. fasciatus*) the volatiles inhibited the attractancy of the blend. These synergist effects were due to the ethanol component of the host plant volatile in all cases but for *M. carolinensis* where synergism was due to the α-pinene (Hanks *et al.*, 2012).

Hanks *et al.* (2012) drew several conclusions from their study. They concluded that reduced attraction to pheromone lure combinations, caused by inhibition would be undesirable when being used to detect invasive species that have recently entered a country and therefore at very low population levels. However, they do suggest that the optimal detection strategy would be to use pheromone blends in combination with the host plant volatiles, ethanol and α-pinene. For monitoring purposes, so long as inhibition does not completely prevent attraction, they concluded that one trap with a multi component lure would still be more cost effective than deploying multiple traps baited with single lures. And finally, these authors believe that the concept of multi-lure pheromone blends can be broadened to include other classes of pheromone components to further increase the diversity of species attracted to the blend (Hanks *et al.*, 2012). Hanks and Millar (2016) also report that there is promise for generic blends of pheromones for use in cerambycid trapping, stating that recent studies indicate that thousands of cerambycid specimens of more than 100 species can be caught in traps baited with a pheromone blend, with optimal species attraction occurring when the components are from more distantly related species in different subfamilies or when different types of pheromones are used.

Relying on the suggestions of Hanks *et al.* (2012), tests using multiple lure combinations have been carried out in France since 2014 in order to develop trapping methods to detect xylophagous beetles, especially cerambycids, in ports-of-entry (Roques *et al.*, 2017). In 2014, the trapping efficiency of two multilure blends were compared using black cross-vane traps coated with teflon in 20 different forests in different bioclimatic regions of France. The first blend combined Fuscumol, Fuscumol Acetate, Geranyl acetone and Monochamol diluted in isopropanol, the second one combined 3-hydroxyhexan-2-one, 2-methylbutanol, 2R*,3S*-hexanediol, and Prionic acid also diluted in isopropanol; control traps contained only isopropanol. These trappings caught a total of 2433 cerambycids corresponding to 55 species with a rather good generic effect for 4 subfamilies and 6 tribes at least, which differed according to each multilure blend, whereas few specimens were trapped in the controls. However, few bark beetles were also trapped. Based on these preliminary results the PORTRAP project, funded by the French Ministry of Agriculture, tested the efficiency of the same blends in 11 ports-of-entry in 2015 and in 12 in 2016. A mixture of (-) α-pinene and ethanol was added to the first blend in order to get a better efficiency for bark beetles. A total of 12 species of cerambycids were trapped in these ports during the first year, of which two were alien species never recorded in Europe (*Xylotrechus altaicus* and *Uraecha angusta,* both originating from Asia), whilst 25 species (410 individuals) were caught in 2016, including numerous specimens of the exotic *Xylotrechus smei* in several places. Bark beetles were also trapped in large numbers, including exotic platypodid species. The final objective was to minimize as much as possible the trapping efforts involved for early detection at arrival. In order to do this the trapping efficiency of a combination of the two multilure blends on the same trap was also compared to a trap baited with each individual blend in 20 forests in 2016. The combination on the same trap resulted in a limited decrease of the total number of trapped cerambycid species (49 vs. 56 for the sum of the traps with a single blend), but the decrease was not significant when the numbers of species were compared at forest level. These results have to be confirmed but clearly suggest that a multilure blend combining the ten above compounds have limited repellency effects and could be considered for trappings at ports-of-entry (Alain Roques pers. comm.).

Available traps and lures

Pheromone traps, along with their fixings and fittings, the chemical lures and the means to retain the trapped insects are usually relatively inexpensive; typical costs for Delta traps would be € 7-10 (£5-8) with cross-vane and funnel traps being 3-4 times as expensive. However, the deployment and monitoring of traps typically costs several hundred or thousand times more than the traps themselves (Anoplorisk-II final report).

Lures that release pheromone, host plant volatile and kairomone components are commercially available from numerous sources, including Synergy Semiochemical Corp. (Burnaby, BC, Canada), Sylvar Technologies Inc. (Frederiction, New Brunswick, Canada), ChemTica Internacional SA (San Jose, Costa Rica), Alpha Scents (West Linn OR), Econex (Murcia, Spain), SEDQ (Barcelona, Spain) and Witasek (Feldkirchen in Kärnten, Austria).

Available traps and lures from Synergy Semiochemical Corporation:

Information taken directly from the Synergy Semiochemical Corporation website http://www.semiochemical.com/index.html

Anoplophora glabripennis/ Asian longhorned beetle lure	Part #3269
Monochamus basic lure	Part #3290
Monochamus lite lure	Part #3280
Monochamus Xylotrechus/Sawyer and Zebra beetle lure	Part #3053
Sponylinidae combo lure	Part #3054
Synthetic C6 diols (2R, 3R hexane diol)	Part #3257
Mixed C6 ketols bubbles	Part #3245
3-hydroxy-2-hexanone bubble (C6 ketol)	Part #3002
Fuscumol acetate	Part #3244
Fuscumol	Part #3249
Mixed C6 diols	Part #3246
3-hydroxy-2-octanone	Part #3009
Monochamol	Part #3005
± 2-methylbutan-1-ol bubble	Part #3291

Agrilus plannipennis/Emerald ash borer – Z3 hexenol lure	Part #3136
Agrilus plannipennis/Emerald ash borer – Lactone lure	Part #6013
Buprestis lyrata/Pink-faced jewel beetle	Part #3029

Ips compounds:
Ipsdienol (optically active, R or S, e.e=90+%)
Trans-myrcenol
Armtinol
2-methyl-6-methylene-octa-1,7-dien-3-ol (sec-Myrcenol)

Numerous kairomones (plant volatiles) are also available, including a range of monoterpenes, sesquiterpenes, terpenoids, greenleaf volatiles, aliphatic, aromatic and bicyclic compounds.

Synergy Multitrap 4 funnels (black, EAB purple or EAB green)	Part #4050
Synergy Multitrap 5 funnels (black, EAB purple or EAB green)	Part #4049
Synergy Multitrap 5 funnels (black, EAB purple or EAB green)	Part #4056

(Wet or dry cups are included in these traps)

Scolytus sticky panel trap Part #4019

Unitrap (green, white, yellow) Part #4003
Purple prism trap (EAB) Part #4006
Green prism trap (EAB) Part #4005
Prism trap hangers Part #4007

Available traps and lures from Sylvar Technologies:
Information taken directly from the Sylvar Technologies http://www.sylvar.ca/

aPhinity EAB® ((3Z)-lactone) pheromone lure for *Agrilus planipennis*
aPhinity HEX® (cis-3-hexen-1-ol) plant volatile lure for *Agrilus planipennis*
Sylvar Green®: EAB green prism trap loaded with a sticky coating, Z3 hexenol lure, wire trap spreader and hanger for *Agrilus planipennis*
aPhinity EZ and EZ-A® (EZ-fuscumol and EZ-fuscumol acetate, respectively) for longhorn beetles in the Lamiinae subfamily

Available traps and lures from ChemTica Internacional SA:
Information taken directly from ChemTica Internacional SA website http://www.chemtica.com/

Anoplophora glabripennis: P518 – Complete 10x lure consisting of two pheromone componenents and three kairomone components
Cerambycid pheromone lures: Generic (P538) and species specific lures (P539) are available for over 100 species in the Cerambycinae, Lamiinae, Lepturinae, Spondylidinae and Prioninae subfamilies

Scolytidae: P494 lure (-)-Myrtenol component of *Dendroctonus valens* pheromone
Pheromone and kairomone lures for *Dendroctonus adjunctus*, *Dendroctonus brevicomis*, *Dendroctonus frontalis*, *Dendroctonus micans* (kairomone only) and *Dendroctonus ponderosae* (P262, P130, P152, P373, P113-lure M and P113-Lure T, respectively)

EAB purple prism trap P385 for *Agrilus planipennis* and other related buprestids
Multifunnel (4 ,8, 12 and 16 unit) trap (P218) for cerambycid and *Dendroctonus* species
Black panel traps for cerambycid species available on request

Available traps and lures from Alpha Scents:
Information taken directly from the Alpha Scents website http://www.alphascents.com/

Alpha-pinene (APINLO) $5.00
Alpha-pinene UHR (APINHI) $7.00
Ambrosia beetle (AMBRO) $10.50
Beta-pinene (BPINLO) $5.00
Beta-pinene UHR (BPINHI) $7.00
Brown spruce longhorn beetle (*Tetropium fuscum*) (TETFUS) $10.50
Chinese white pine beetle (*Dendroctonus armandi*) (DENARM) $10.00
Douglas fir beetle (*Dendroctonus pseudotsugae*) (DENPSE) $6.50
Eastern five spined *Ips* (Ips grandicollis) (IPSGRA) $8.00
Engraver beetle Acuminatus (*Ips acuminatus*) (IPSACU) $7.00
Engraver beetle Perturbatus (*Ips perturbatus*) (IPSPER) $7.00
Ethanol, low release rate (ETOHLO) $5.00
Ethanol UHR (ETOHHI) $7.00

European larch bark beetle (*Ips cembrae*) (IPSCEM) $10.00
European spruce bark beetle (*Ips typographus*) (IPSTYP) $7.00
Fir engraver beetle (*Scolytus ventralis*) (SCOVEN) $6.00
Ips acuminatus (IPSACU) $7.00
Ips grandicollis (IPSGRA) $7.00
Ips sexcentatus (IPSSEX) $8.00
Japanese pine sawyer (*Monochamus alternatus*) (MONALT) $10.50
Jeffrey pine beetle (*Dendroctonus jeffreyi*) (DENJEF) $6.00
Longhorn beetle (*Monochamus* spp. (MONOCH) $10.50
Longhorn beetle (*Prionus* spp.) (PRINUS) $6.00
Northern bark beetle (*Ips duplicatus*) (IPSDUP) $8.00
Pine engraver beetle (*Ips pini*) (IPSPIN) $6.00
Prionus californicus (PRICAL) $6.00
Prionus longhorn beetle spp. $6.00
Red Turpentine beetle (*Dendroctonus valens*) $10.00
Six-toothed spruce bark beetle (*Pitygenes chalcographus*) $10.00
Southern pine beetle (*Dendroctonus frontalis*) (DENFRO) $8.00
Spruce beetle (*Dendroctonus rufipennis*) (DENRUF) $6.00
Striped ambrosia beetle (*Trypodendron lineatum*) (TRYLIN) $40.00
Western pine beetle (*Dendroctonus brevicomis*) (DENBRE) $7.50

Panel trap ($26.00), collecting cup ($04.50), collecting cup attachment ($0.30), hanging wire ($0.60)

NB. Prices are for single units, however, some of these components are available in multipacks.

Available traps and lures from Econex SA:
Information taken directly from the Econex SA website https://www.e-econex.eu/insect-traps/

Crosstrap® - various types (TA132, TA184, TA227, TA204, TA224, TA226) with various attachments

Diffusers:

Econex *Dendroctonus brevicomis* (VA130)
Econex *Dendroctonus frontalis* (VA131)
Econex *Dendroctonus ponderosae* (VA132)
Econex *Dendroctonus pseudsugae* (VA133)
Econex *Dendroctonus rufipennis* (VA134)
Econex *Ips acuminatus* (VA187)
Econex *Ips cembrae* (VA139)
Econex *Ips sexdentatus* 3C (VA294)
Econex *Ips typographus* (VA140)
Econex *Monochamus galloprovincialis* (VA195)

Available traps and lures from SEDQ:
Information taken directly from the SEDQ website http://www.sedq.es/en/company.php

An extensive range of pheromones are available from this company; please see their website for details.

Mass trapping formulates are available:

ACUMIPROTECT – Engraver beetle, *Ips acuminatus*
IPSPROTECT – Six-toothed bark beetle, *Ips sexdentatus*
GALLOPROTECT – Pine sawyer, *Monochamus galloprovincialis*

THEYSOHN traps are available from this supplier.

Available traps and lures from Witasek:
Information taken directly from the Witasek catalogue

Traps (all with various accessories available):

MultiWit bark beetle slit trap (314051)
WitaTrap bark beetle slit trap (314031)
WitaPrall IntPT-Wet trap (315611) for wet tapping bark beetles, metallic wood-boring beetles and longhorned beetles
WitaTrap Multifunnel trap for dry trapping bark beetles, metallic woo-boring beetles and longhorned beetles

Pheromones:

Ipsowit® Standard (323411) for European spruce bark beetle, *Ips typographus*
Dupliwit® (322211) pheromone for northern bark beetle, *Ips duplicatus*
Sexowit® (324811) pheromone for six-spined engraver beetle, *Ips sexdentatus*
Cembräwit® (320811) pheromone for larch bark beetle, *Ips cembrae*
Acuwit® (320411) pheromone for engraver beetle, *Ips acuminatus*
Chalcoprax® Ampoule (321211) and Chalcowit® dispenser for six-toothed spruce bark beetle, Pityogenes chalcographus
Kombiwit Tube® (323711) combined pheromone for European spruce bark beetle and six-toothed spruce bark beetle
Trypowit® (325611) pheromone for the striped ambrosia beetle, *Trypodendron lineatum*
Lineatin Kombi® (323821) combined pheromone for *Trypodendron* species
Gallopro Pinowit® (322621) combined pheromone combination for *Monochamus galloprovincialis*, *Ips sexdentatus*, *Orthotomicus erosus* and *Hylurgus ligniperda*

GLV Plus (green leaf volatiles) (322921) for Asian longhorned beetle, *Anoplophora glabripennis*

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Appendix 2. Known attractiveness of the components used in the tested lures

A. Pheromones

Fuscumol = (E)-6,10-dimethyl-5,9-undecandien-2-ol (= geranyl acetol): A pheromone of certain species in subfamilies Aseminae/Spondylidinae and attractive for many species of Lamiinae (Hanks *et al*., 2012).

Fuscumol acetate = (E/Z)-6,10-dimethyl-5,9-undecadien-2yl acetate: Attractant and potential pheromone for some Lamiinae (Hanks *et al*., 2012).

Geranylacetone: Fuscumol is synthesized by reduction of geranylacetone (Sweeney et al. 2010).

Monochamol = 2-(undecyloxy)-ethanol: Pheromone of many species of Monchamus (Lamiinae) (Hanks *et al*., 2012).

3-hydroxy-2-hexanon: Pheromone of many species in subfamily Cerambycinae (Hanks *et al*., 2012).

Prionic acid = 3,5-dimethyldodecanoic acid: Female produced sex pheromone of Prionus spp. (Barbour *et al*., 2011).

2-methyl-1-butanol: Pheromone component for Cerambycinae in several genera (Hanks *et al*., 2012).

2,3-hexanediol: Pheromone component of many Cerambycinae (Hanks *et al*., 2012).

B. Kairomones

Ethanol and α -Pinene: Attractive kairomone for many bark and wood boring beetles, such as Cerambycidae (Hanks *et al*., 2012).

Appendix 3. Standard protocols for trap deployment and dry-sample collection

A. Equipment

a. Three black 8-funnel traps with white collection beakers (to screw on to bottom of trap), see figure 1. The beaker bottoms are replaced with wire mesh to allow drainage. Traps are coated with fluon to aid insect capture.

Figure 1. Black 8-funnel trap with white collection beaker.

b. Materials for the whole trapping period:
   i. Vials containing 1 ml α-pinene – labelled A
   ii. Vials containing 1 ml 8-pheromone cerambycid lure – labelled B
   iii. Vials containing 5 ml ethanol – labelled C
   iv. Re-sealable polyethylene bags containing cotton pads
   v. Pesticide nets
   vi. Wires to fasten lures to traps
   vii. Rope for hanging traps
   viii. Sample tubes

B. Trap location

Ensure traps are located where they will not be damaged or interfere with working operations. If no suitable position inside site, choose boundary fence or just outside. The best location would be close to wood waste deposits.

C. Preparing traps

   i. Ensure trap is fully extended (figure 1)
   ii. Place one insecticide net in bottom of white collection beaker
   iii. Screw collection beaker onto bottom of trap
   iv. Hang traps from a height of 2 metres in selected location using rope provided. If outside, secure trap at bottom so it doesn't swing
   v. Traps should be placed at least 50 metres apart
   vi. Where possible, traps should be placed in shade

D. Preparing lures

a. Empty chemicals in vials labelled A, B and C (figure 2) into re-sealable plastic bags
   i. Empty A and B separately into two different re-sealable plastic bags containing 1 cotton wad each (figure 2b)
   ii. Empty C in re-sealable bag containing 3 cotton wads (figure 2c)

Figure 2. Chemical lures (A, B and C) in vials provided (2A) and re-sealable plastic bags containing 1 cotton wad (2B) for chemicals A and B, and 3 cotton wads (2C) for chemical C.

b. Ensure bags are sealed correctly

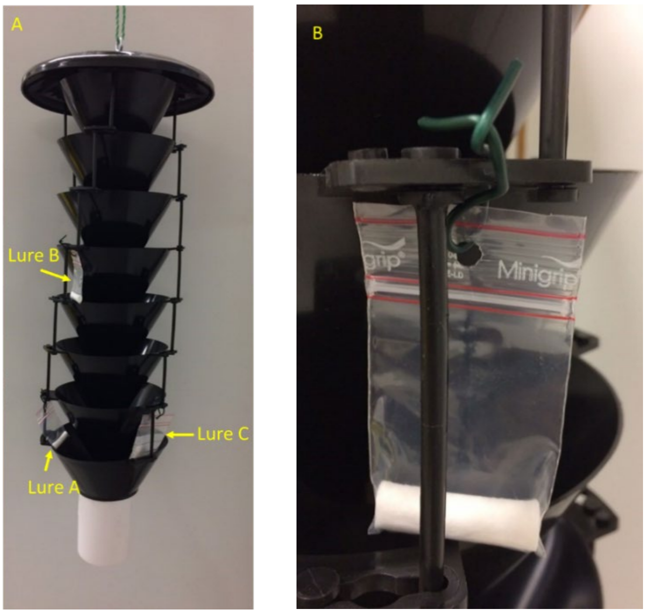

Figure 3. Trap showing positions of plastic bags containing lures (A) and close-up of bag on trap (B).

c. Fasten bags with wire provided onto trap at the following positions (figure 3a)
   i. A – middle of trap
   ii. B and C – penultimate funnel before collection beaker

E. Servicing traps

Collect samples and replace lures every 3 weeks.

a. Sample collection
   i. Remove white collection beaker from bottom of trap
   ii. Shake off pesticide net above the collection beaker and ensure small insects, including the remains of insects, collected. A visual check of the net is necessary to ensure that no insects remain hooked. Remove debris where possible
   iii. Transfer contents into sample tube provided, and fill the tube with ethanol sufficient to cover all of the sample
   iv. Add label writing in pencil the site, date, trap number (plan of trap location within site can be provided)
   v. Send samples in stamped addressed envelope provided

b. Traps
   i. If dirty give a quick brush or wipe with a dry brush/cloth
   ii. Place new pesticide net into bottom of collection beaker and re-attached to bottom of trap
   iii. Remove old lure and replace with new lures by repeating step D (lures) as described above. Dispose of old lures

Appendix 4. Constraints of multi-plex trapping

Category	Issues	Solutions
Identifying sites	• Identifying proper sites (high risk locations), which can fluctuate between years (owner has no obligation to report (s)he moved). • Engaging with local phytosanitary inspectors. Not always interested to deploy traps in the areas they are responsible for.	• Double check? Check in advance of start (contact before visiting). • Sites and procedures to be agreed by the Ministry in charge of the phytosanitary controls. • Establish relationship with inspectors in advance. • Motivate inspectors by communicating results (specific results directly to the inspector). • Deal with head of plant inspection services.
Access to sites	• Access to private woodlands and forests dependent on land-owner permission. • Access to sites at ports dependent on willingness of wood importers to engage. • Owners perceive monitoring as an inspection and concerned about consequences. • Owner (risk location, nature reserve) locks the gate or does not give access (causes problems for access and change of traps.	• Establish a relationship with terrain / property owners and use plant health inspectors to gain and maintain access to owners and sites. • Fully explain purpose of traps, disseminate results we have. • Appointment with owner or hang traps just outside the site on public terrain.
Safety and security	• Health and safety of inspectors.	• Communicate well in advance. • Conform to local and site regulations.

	• Direct damage caused by trap (consequence of trap location on property). • Vandalism in public or natural environment.	• Take care not to cause damage (wet trapping) to property. • Clearly identify traps and include information on traps the experiment aims, and contact details. • Avoid deploying near public footpaths.
Location of traps on site	• No trees or poles available on site. • Damage as a result of onsite activity in progress.	• Trap at the fence; place traps outside site. • Take care not to cause damage to property • Do not hang traps where work is in progress, avoid working corridors where machinery is used.
Management of traps (procedures)	• Need all personnel at all sites to follow same procedures for deploying traps, placing and replacing lures and collecting and handling samples.	• Provide a clear Standard Operating Procedure. • Writing a simple pictorial procedure, hand-out.
Regulatory issues	• Consequence of trapping a regulated (or non-regulated) invasive pest. • Consequence of trapping a protected /red list species. • Time lapse between trap catch an IAS and identification of IAS.	• Immediate mention of the record of any alien species to regulatory authorities, with sending of the specimens for official confirmation. • Inform, arrange a derogation if possible and propose solutions if relevant. • First screening to "suspect/unknown/different" from normal (see "Processing").
Time and Costs	• Annual budget constraints (trap management).	• Timely planning and spreading of surveys amongst 1-3 years (intern)

	• Costs and availability of lures / traps. • Reliability of lures. • Costs of processing samples.	• Use annual research budget for surveys (extern) • Confirm lure composition through analysis in case of no or bad results. • Inspection and processing budgets.
Processing the samples and data	• Sorting trapped specimens. • Identification of specimens. • Identification of beetles to species requires specialist taxonomist (may not be available). • Experts may be at different organisations to operators of trap.	• Hire student for a pre-sorting of the specimens per large taxonomic group (e.g. cerambycids, buprestids, bark beetles) and select "suspect material" for direct analysis before giving the material to taxonomists. • (Photographic) catalogue groups or species of interest. • Long-term capacity building on taxonomy (develop more accessible keys). • Develop molecular techniques for quicker target species identification. • Agree on how to process and report data in a standardized way.

Appendix 5. List of Cerambycidae species trapped in 2018. Non-native species are shown in red

Subfamily	Tribe	Species	Total
Cerambycinae	Callichromatini	*Aromia moschata*	1
Cerambycinae	Callidiini	*Anoplodera sexguttata*	1
Cerambycinae	Callidiini	*Callidium aeneum*	20
Cerambycinae	Callidiini	*Ropalopus macropus*	1
Cerambycinae	Callidiini	*Ropalopus clavipes*	2
Cerambycinae	Callidiini	*Hylotrupes bajulus*	14
Cerambycinae	Callidiini	*Phymatodes testaceus*	1795
Cerambycinae	Callidiini	*Poecilium alni*	20
Cerambycinae	Callidiini	*Pyrrhidium sanguineum*	238
Cerambycinae	Clytini	*Anaglyptus mysticus*	5
Cerambycinae	Clytini	*Chlorophorus glabromaculatus*	20
Cerambycinae	Clytini	*Chlorophorus varius*	14
Cerambycinae	Clytini	*Clytus arietis*	5
Cerambycinae	Clytini	*Clytus lama*	3
Cerambycinae	Clytini	*Clytus rhamni*	2
Cerambycinae	Clytini	*Clytus tropicus*	31
Cerambycinae	Clytini	*Plagionotus arcuatus*	4
Cerambycinae	Clytini	*Plagionotus detritus*	2
Cerambycinae	Clytini	*Rusticolytus rusticus*	135
Cerambycinae	Clytini	*Xylotrechus antilope*	2
Cerambycinae	Clytini	*Xylotrechus arvicola*	32
Cerambycinae	Clytini	*Xylotrechus stebbingi*	178
Cerambycinae	Hesperophanini	*Trichoferus fasciculatus*	1
Cerambycinae	Molorchini	*Glaphyra umbellatorum*	1
Cerambycinae	Molorchini	*Molorchus umbellatarum*	1
Cerambycinae	Nathriini	*Nathrius brevipennis*	2
Cerambycinae	Phoracanthini	*Cordylomera spinicornis*	1
Lamiinae	Acanthocinini	*Acanthocinus aedilis*	2
Lamiinae	Acanthocinini	*Acanthocinus griseus*	3
Lamiinae	Acanthocinini	*Leiopus femoratus*	100
Lamiinae	Acanthocinini	*Leiopus linnei*	33
Lamiinae	Acanthocinini	*Leiopus nebulosus*	75
Lamiinae	Acanthocinini	*Exocentrus lustitanus*	1
Lamiinae	Acanthoderini	*Aegomorphus clavipes*	99
Lamiinae	Acanthoderini	*Aegomorphus francottei*	6
Lamiinae	Agapanthiini	*Agapanthia villosoviridescens*	1
Lamiinae	Mesosini	*Mesosa curculionides*	4

Lamiinae	Mesosini	*Mesosa nebulosa*	5
Lamiinae	Monochamini	*Monochamus galloprovincialis*	388
Lamiinae	Monochamini	*Monochamus saltuarius*	29
Lamiinae	Monochamini	*Monochamus sartor*	6
Lamiinae	Monochamini	*Monochamus sutor*	16
Lamiinae	Phytoeciini	*Oberea linearis*	5
Lamiinae	Pogonocherini	*Pogonocherus caroli*	1
Lamiinae	Pogonocherini	*Pogonocherus decoratus*	1
Lamiinae	Pogonocherini	*Pogonocherus fasciculatus*	2
Lamiinae	Pogonocherini	*Pogonocherus ovatus*	1
Lamiinae	Pteropliini	*Niphona pectinicornis*	3
Lamiinae	Saperdini	*Saperda populnea*	1
Lamiinae	Saperdini	*Saperda punctata*	1
Lamiinae	Saperdini	*Saperda scalaris*	4
Lamiinae	Saperdini	*Stenostola ferrea*	1
Lamiinae	Saperdini	*Stenostola dubia*	1
Lamiinae	Tetropini	*Tetrops praeustus*	1
Lepturinae	Lepturini	*Anastrangalia sanguinolenta*	13
Lepturinae	Lepturini	*Cortodera humeralis suturalis*	5
Lepturinae	Lepturini	*Grammoptera ruficornis*	4
Lepturinae	Lepturini	*Grammoptera ustulata*	3
Lepturinae	Lepturini	*Leptura quadrifasciata*	6
Lepturinae	Lepturini	*Alosterna tabacicolor*	3
Lepturinae	Lepturini	*Paracorymbia fulva*	1
Lepturinae	Lepturini	*Paracorymbia maculicornis*	6
Lepturinae	Lepturini	*Ruptela maculata*	3
Lepturinae	Lepturini	*Stenurella bifasciata*	3
Lepturinae	Lepturini	*Stenurella melanura*	5
Lepturinae	Lepturini	*Stenurella nigra*	1
Lepturinae	Lepturini	*Stictoleptura rubra*	10
Lepturinae	Rhaginini	*Acmaeops marginatus*	2
Lepturinae	Rhaginini	*Acmaeops pratensis*	7
Lepturinae	Rhaginini	*Acmaeops smaragdinus*	1
Lepturinae	Rhaginini	*Rhagium bifasciatum*	34
Lepturinae	Rhaginini	*Rhagium inquisitor*	83
Lepturinae	Rhaginini	*Rhagium mordax*	16
Lepturinae	Rhaginini	*Stenocorus meridianus*	5
Prioninae	Aegosomatini	*Aegosoma scabricorne*	3
Prioninae	Prionini	*Prionus coriarius*	655
Spondilyinae	Asemini	*Arhopalus ferus*	2
Spondilyinae	Asemini	*Arhopalus rusticus*	546
Spondilyinae	Asemini	*Arhopalus syriacus*	5
Spondilyinae	Asemini	*Asemum striatum*	3
Spondilyinae	Asemini	*Tetropium castaneum*	1

Spondilyinae	Asemini	*Tetropium gabrieli*	10
Spondilyinae	Spondylini	*Spondylis buprestoides*	794