The potential for monitoring and control of insect pests in Southern Hemisphere forestry plantations using semiochemicals

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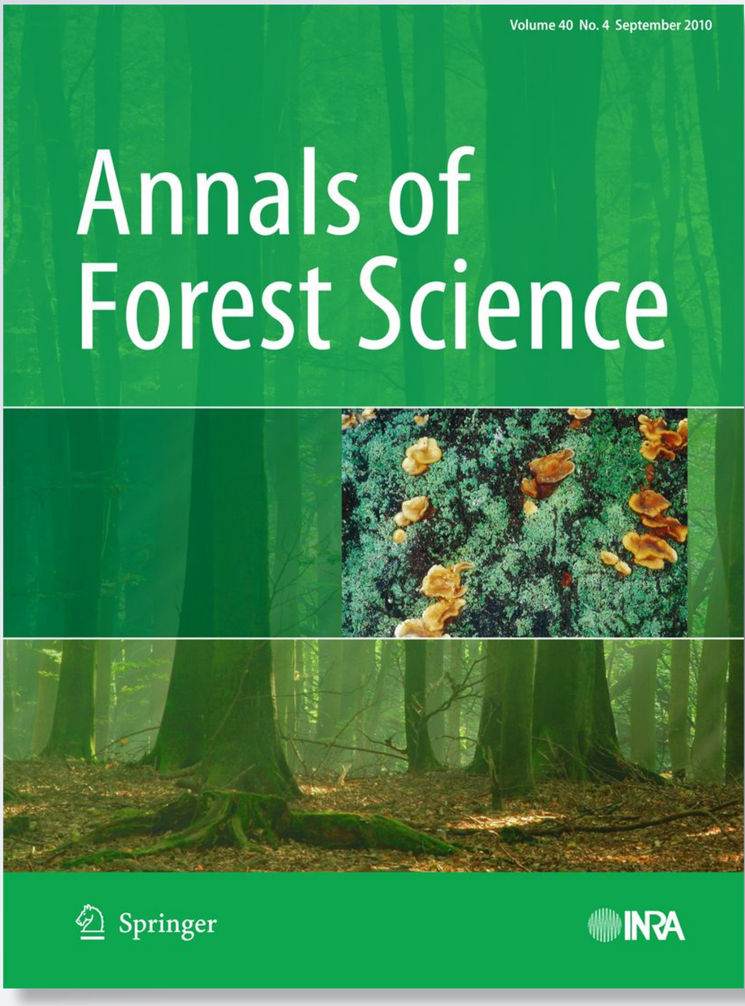

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REVIEW PAPER

The potential for monitoring and control of insect pests in Southern Hemisphere forestry plantations using semiochemicals

Ryan L. Nadel · Michael J. Wingfield · Mary C. Scholes · Simon A. Lawson · Bernard Slippers

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Abstract
• ***Context*** Southern Hemisphere plantation forestry has grown substantially over the past few decades and will play an increasing role in fibre production and carbon sequestration in future. The sustainability of these plantations is, however, increasingly under pressure from introduced pests. This pressure requires an urgent and matching increase in the speed and efficiency at which tools are developed to monitor and control these pests.
• ***Aim*** To consider the potential role of semiochemicals to address the need for more efficient pest control in Southern Hemisphere plantations, particularly by drawing from research in other parts of the world.
• ***Results*** Semiochemical research in forestry has grown exponentially over the last 40 years but has been almost exclusively focussed on Northern Hemisphere forests. In these forests, semiochemicals have played an important role to enhance the efficiency of integrated pest management programmes. An analysis of semiochemical research from 1970 to 2010 showed a rapid increase over time. It also indicated that pheromones have been the most extensively studied type of semiochemical in forestry, contributing to 92% of the semiochemical literature over this period, compared with research on plant kairomones. This research has led to numerous applications in detection of new invasions, monitoring population levels and spread, in addition to controlling pests by mass trapping or disrupting of aggregation and mating signals.
• ***Conclusion*** The value of semiochemicals as an environmentally benign and efficient approach to managing forest plantation pests in the Southern Hemisphere seems obvious. There is, however, a lack of research capacity and focus to optimally capture this opportunity. Given the pressure from increasing numbers of pests and reduced opportunities to use pesticides, there is some urgency to develop semiochemical research capacity.

Keywords Pheromone · Kairomone · Pest management · Forest entomology · Forest plantations

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Contributions of co-authors R.L. Nadel wrote the paper and analysed the data, as it formed part of his PhD project.

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1 Introduction

Large volumes of wood and fibre are produced in the Southern Hemisphere and tropics from non-native tree species cultivated in intensively managed forestry plantations

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(Sedjo 1999; FAO 2007, 2011). As greater areas of natural forests are being set aside for conservation, a larger proportion of the worlds wood supply is expected, in the next few decades, to come from planted forest plantations (Sedjo 2000; Carle and Holmgren 2008; FAO 2011). The high productivity and rapid growth that is achieved in many of these plantations of the Southern Hemisphere and tropics is in part due to the absence of damage to these trees by pests and diseases (Wingfield 2003; Wingfield et al. 2008). As a consequence, one of the greatest threats to fibre production in plantations of non-native trees arises from newly emerging pests and pathogens (Wingfield et al. 2008). Non-indigenous insect pests are introduced largely through international trade and travel (Work et al. 2005; Smith et al. 2007; Roques et al. 2008; Brockerhoff et al. 2006b). Assuming that conditions are favourable, they can become established extremely rapidly (Bartell and Nair 2004; Kolar and Lodge 2001; Peacock and Worner 2008; Wilson et al. 2009). Free from their natural enemies, and sometimes challenged by fewer environmental limitations, these pest populations can build up uncontrollably. The ultimate outcome can be substantial economic losses for forestry companies as a result of reduced tree growth or increased tree mortality. In this way, invasives threaten the future sustainability of these important economic and ecological resources.

Several approaches are used to control invasive pests in non-native forest plantations in the tropics and Southern Hemisphere. Silvicultural management has been effective in many cases, but it is not practical or effective for all insect pests (Carnegie et al. 2005; Stone 2001). Classical biological control has been extensively used in agriculture and non-native plantation forestry but with varying levels of success (DeBach 1974; Hurley et al. 2007; Bale et al. 2008). An accepted, but less desirable, short-term alternative to reduce pest populations rapidly is through the application of pesticides. Pesticides, however, have many negative impacts on the environment, including the continuing need for mass spraying that also has negative effects on beneficial insects and other non-target organisms (Pimentel et al. 1992).

Semiochemicals represent a key component of many integrated pest management (IPM) programs for forestry pests in the Northern Hemisphere (Otvos and Shepherd 1991; Goyer 1991; Lindgren and Fraser 1994; Leonhardt et al. 1996; Hosking et al. 2003; Asaro et al. 2004; Faccoli and Stergulc 2008; Norin 2001; Clarke 2001). They are particularly considered as efficient tools to monitor or reduce pest populations. They have, however, rarely been used in the Southern Hemisphere for these purposes. In this review, we argue that semiochemicals should be a key component of future plantation forest sustainability in the tropics and Southern Hemisphere.

2 Semiochemicals research and use to manage forest pests in the Northern Hemisphere

2.1 Analysis of semiochemical research

Semiochemical research in forestry has increased exponentially over the last 40 years. A search of the ISI Web of Knowledge, Web of Science databases (March 2010) for all scientific publications with the keywords: forest* AND (semiochemical* OR pheromone* OR kairomone* OR allelochemical*), revealed 429 publications between 1970 and 2009. The rise in the number of publications since 1970 is linked to the fact that semiochemicals were discovered and first synthesized in the 1960s after 22 years of research (Kelly 1990) and in addition, the inauguration of the *Journal of Chemical Ecology* in March 1975. The increased availability of scientific equipment and significant technological advances in semiochemical identification and synthesis has resulted in a substantial increase in research on the topic since 1990.

Pheromones are by far the most studied semiochemicals in forestry, contributing to 92% of the 429 forestry and semiochemical-related scientific papers. The majority of pheromone research (30%) has been conducted on Coleopterans, with Lepidopteran pests of forest trees constituting the second most abundant group (24%). Aggregation pheromones, for example, play an important role in sustaining insect attack and infestation levels (Hughes 1974; Silverstein 1981; Wood 1982; Vité and Baader 1990; Schlyter et al. 2001), especially of bark beetles. Sex pheromones have also been widely used for mass trapping and mating disruption to suppress various pests, especially relevant to the Lepidoptera (Fitzgerald 2008; Norin 2001; Thorpe et al. 1999; Silverstein 1981). Research on plant-derived semiochemicals such as volatile organic compounds can aid in plant protection but are often less specific and can be complex to dissect and apply. Consequently, this is an area of research that has received less attention. In a forestry context, protection through plant-derived semiochemicals has focussed on the development of kairomone lures that attract and monitor insect pests such as Coleopterans in *Pinus* and *Populus* forests (Gallego et al. 2008; Miller 2006; Borden et al. 1998; Sun et al. 2003).

2.2 Monitoring

One of the most important applications of semiochemicals in forest pest control lies in monitoring the spread and population levels of the target insect (Table 1). Monitoring can be done with either kairomone (an allelochemical that benefits the receiver) or pheromone baits in a variety of traps and for different insect orders. Kairomone traps have most commonly been used to monitor bark beetle populations. Several

Table 1 Examples of semiochemical research and application for monitoring of pests in forestry and other environments (e.g. urban high-risk entry points)

Insect[a]	Family	Country	Reference
Coleoptera			
Bark and wood boring insects[a]	Mainly Scolytidae, Platypodidae, Ceramabycidae, Buprestidae, Siricidae	New Zealand, Australia and USA	(Wylie et al. 2008; Miller 2006; Bashford 2008; Brockerhoff et al. 2006a; Costello et al. 2008)
	Cerambycidae		
Monochamus alternatus		Japan	(Nakamura et al. 1999)
M. galloprovincialis		Spain	(Pajares et al. 2004; Ibeas et al. 2007)
Anaglyptus subfasciatus		Japan	(Nakamuta et al. 1997)
Tetropium castaneum		Canada	(Sweeney et al. 2006)
T. cinnamopterum		Canada	(Sweeney et al. 2006)
Tetropium fuscum		Canada	(Sweeney et al. 2006)
	Chrysomelidae		
Chrysomela scripta		USA	(Kendrick and Raffa 2006)
	Cleridae		
Thanasimus dubius		USA	(Erbilgin and Raffa 2002)
T. formicarius		Sweden	(Schlyter and Lundgren 1993)
	Curculionidae		
Pissodes nemorensis[a]		USA	(Rieske 2000)
Hylobius pales[a]		USA	(Rieske 2000)
	Histeridae		
Platysoma cylindrical		USA	(Erbilgin and Raffa 2002)
P. parallelum		USA	(Erbilgin and Raffa 2002)
	Platypodidae		
Ambrosia beetles[a]		Australia and USA	(Wylie et al. 2008; Bashford 2008; Miller and Rabaglia 2009)
	Scolytidae		
Bark beetles[a]		Australia, USA and French Pyrenees	(Bashford 2008; Miller and Rabaglia 2009; Fettig et al. 2004; Aukema et al. 2000b; Hayes et al. 2008; Gaylord et al. 2006; Bouget et al. 2009)
Dendroctonus valens		China and USA	(Sun et al. 2003; Erbilgin and Raffa 2002)
Ips grandicollis[a]		Australia and USA	(Erbilgin and Raffa 2002)
I. pini		USA	(Erbilgin and Raffa 2002)
I. typographus[a]		Italy, Norway, Slovenia and Sweden	(Jurc et al. 2006; Faccoli and Stergulc 2006; 2004; Schlyter and Lundgren 1993; Weslien 1992; Weslien and Schroeder 1999)
Manarthrum mali		Italy	(Kirkendall et al. 2008)
Pityogenes chalcographus[a]		Slovenia	(Jurc et al. 2006)
Tomicus destruens		Europe and North Africa	(Gallego et al. 2008)
Hymenoptera			
	Diprionidae		
Neodiprion sertifer[a]		Finland, Japan, Europe and USA	(Anderbrant et al. 2000; Lyytikäinen-Saarenmaa et al. 2006; Goyer 1991)
	Siricidae		
Wood boring insects		USA	(Costello et al. 2008)
Lepidoptera			
	Lasiocampidae		
Dendrolimus punctatus		China	(Zhang et al. 2003)

Table 1 (continued)

Insect[a]	Family	Country	Reference
Malacosoma disstria[a]		North America	(Jones et al. 2009; Goyer 1991; Schmidt and Roland 2003)
	Lymantriidae		
Euproctis chrysorrhea		USA	(Khrimian et al. 2008)
Lymantria dispar[a]		Australia, Britain, New Zealand and North America	(Thorpe et al. 2007a; Cannon et al. 2004; Leonhardt et al. 1996)
L. monacha		Europe and North America	(Morewood et al. 2000; Morewood et al. 1999)
Orgyia pseudotsugata[a]		Canada	(Otvos and Shepherd 1991)
	Thaumetopoeidae		
Thaumetopoea pityocampa		France, Italy and Portugal	(Jactel et al. 2006a)
	Tortricidae		
Choristoneura conflictana		Canada	(Jones et al. 2009)
C. rosaceana		Canada	(Delisle 1992)
Rhyacionia frustrana[a]		USA	(Asaro et al. 2004)

[a] Systems where the knowledge is applied for monitoring

examples of kairomone monitoring include those used to monitor populations of the biological control agent *Rhizophagus grandis*, a species-specific predator of the Eurasian spruce bark beetle *Dendroctonus micans* (Meurisse et al. 2008). Kairomone attractants have also been used to monitor populations of the recently introduced European pine shoot beetle, *Tomicus piniperda*, infesting pine trees in North America (Poland et al. 2004). While certain volatiles have been found to be broadly applicable for this purpose, species- or group-specific kairomone baits have also been developed to detect and monitor pest populations (Erbilgin et al. 2007; Wainhouse 2005). For the detection of numerous forestry pests in the Northern Hemisphere, single component lures were found to be effective, both in native and invaded non-native ranges, such as in the case of the red turpentine beetle, *Dendroctonus valens*, in both North America and China (Erbilgin et al. 2007).

Pheromone-baited traps can be more effective in monitoring pests than kairomone baits because of the highly specific nature of pheromonal attraction. This is especially true for emerging pests that are present in relatively low numbers (Hosking et al. 2003). Extensive pheromone-baited trap networks, therefore, have been set up throughout the world to aid in the detection, monitoring and management of serious forest pests. Examples include the trap network established throughout Europe to aid in the detection and monitoring of the spruce bark beetle, *Ips typographus*, and the bark beetle, *Pityogenes chalcographus* (Kelly 1990; Vité and Baader 1990). Furthermore, outbreaks of the pine sawfly, *Neodiprion sertifer*, in Europe, and the Douglas-fir tussock moth, *Orgyia pseudotsugata*, in the United States, have also been monitored using sex pheromones (Grant 1991; Lyytikäinen-Saarenmaa et al. 2006; Lyytikäinen-Saarenmaa et al. 1999; Daterman et al. 2004).

An example of one of the largest pheromone-baited trap networks for a forestry pest is that used for the detection and eradication of the Gypsy moth, *Lymantria dispar*. In this network, roughly 130,000–150,000 traps are placed within and ahead of the leading edge dispersal zone throughout nine states of the United States of America (Tobin et al. 2007; Mayo et al. 2003; Tobin et al. 2004). Early detection allows for the targeted eradication of small, isolated *L. dispar* populations ahead of the leading zone. This in turn prevents the coalescence of these populations into larger more viable populations and significantly slows the spread of the moth (Tobin et al. 2007; Liebhold and Tobin 2006; Mayo et al. 2003). This trap network guides management decisions for isolated *L. dispar* populations. The detection of isolated populations results in the implementation of several management approaches to ensure their eradication, including mating disruption, mass trapping, sterile male release and the spraying of microbial or chemical pesticides. The above examples of trap monitoring emphasise the point that monitoring using semiochemicals can form an integral part of some of the largest IPM systems, allowing for the detection and assessments of the impact and range of forest pest species.

2.3 Control

Semiochemicals have been used in direct applications for control of some forest pest species. Their ability to attract or repel, enhance or inhibit the action of other chemicals has been shown to be extremely powerful for controlling insect pests (Table 2). Actions for which such semiochemicals are used include mass trapping, mating disruption and/or deterring pests from food and oviposition sites (Agelopoulos et al. 1999). Deterring pests using interruptant semiochemicals such as anti-aggregation pheromones significantly reduced infestations of trees by the Mountain pine beetle, *Dendroctonus ponderosae* (Gillette et al. 2009a; Shea et al. 1992), Southern pine beetle, *Dendroctonus frontalis* (Sullivan et al. 2007) and other bark beetles, *Ips typographus* and *Ips perturbatus* (Graves et al. 2008; Jakuš et al. 2003). Anti-aggregation pheromones have also been used to control outbreaks of the Douglas-fir beetle, *Dendroctonus pseudotsugae* (Gillette et al. 2009b; Werner et al. 2006). Mass trapping using aggregation pheromones has been successfully applied to enhance the control of, for example, bark beetles in various Northern Hemisphere forest plantations (Drumont et al. 1992; Stock et al. 1994; Schlyter et al. 2001; Wainhouse 2005). Aggregation pheromones are, for example, used to attract the beetles to felled trees rather than living trees, concentrating their reproduction on the trap trees and allowing these trees to be treated or removed prior to the emergence of the insect broods (Werner et al. 2006; Agelopoulos et al. 1999). Mass trapping with pheromones targeting the black pine bast scale *Matsucoccus thunbergianae* has also been undertaken in Korea, although there have been no reports of this pheromone being used subsequent to its development (Boo and Park 2005).

Mating disruption using semiochemicals in the form of sex pheromones has been most successfully applied to control Lepidopteran pests. Examples in forestry include mating

Table 2 Examples of semiochemical research and application for control of pests in forestry and other environments (e.g. urban high-risk entry points)

Insect pest[a]	Family	Country	Reference
Coleoptera			
	Cerambycidae		
Monochamus galloprovincialis		Spain	(Ibeas et al. 2007)
	Scarabaeidae		
Hylamorpha elegans			(Quiroz et al. 2007)
	Scolytidae		
Bark beetles[a]		USA	(Aukema et al. 2000a)
Dendroctonus frontalis		USA	
D. ponderosae[a]		USA	(Gillette et al. 2009a; Shea et al. 1992)
D. pseudotsugae[a]		USA	(Gillette et al. 2009b)
D. valens		China and USA	(Sun et al. 2003; Rappaport et al. 2001)
Dryocoetes confuses		Canada	(Stock et al. 1994)
Gnathotrichus sulcatus[a]		Canada	(Lindgren and Fraser 1994)
Ips sexdentatus		Spain	(Romón et al. 2007)
I. typographus[a]		Belgium, Italy, Poland, Slovakia and Sweden	(Zhang and Schlyter 2003; Drumont et al. 1992; Faccoli and Stergulc 2008)
Pityophthorus pubescens		Spain	(Romón et al. 2007)
Tomicus spp.		China	(Sun et al. 2005)
Trypodendron lineatum[a]		Canada	(Lindgren and Fraser 1994)
Hemiptera			
	Margarodidae		
Matsucoccus feytaudi		Corsica	(Jactel et al. 2006b)
Elatophilus nigricornis		Corsica	(Jactel et al. 2006b)
Lepidoptera			
	Lasiocampidae		
Malacosoma sp[a]		USA	(Fitzgerald 2008)
	Lymantriidae		
Lymantria dispar[a]		Britain and North America	(Thorpe et al. 2007a; Cannon et al. 2004; Leonhardt et al. 1996)
Orgyia thyellina[a]		New Zealand	(Hosking et al. 2003)
	Sesiidae		
Paranthrene robiniae		USA	(Brown et al. 2006)

[a] Systems where the knowledge is applied for control

disruption of *Eucosma sonomana* and *Rhyacionia zozana* for several weeks after pheromone application, resulting in a population reduction of two thirds for each of the separate years studied (Gillette et al. 2006). Sex pheromones used for mating disruption were shown to reduce isolated gypsy moth, *L. dispar*, populations by 90%, eliminating reproduction in these isolated populations beyond the leading edge of this pest (Thorpe et al. 1999, 2007b).

3 Potential use of semiochemicals in Southern Hemisphere plantations

Although semiochemical research has been undertaken for various insects in the tropics and Southern Hemisphere, there are few examples of this approach being used in intensively managed forestry plantations. The perceived high cost of discovery, development and application of semiochemicals for monitoring and/or control programmes has been suggested as the main reason for their minimal use in mainly non-native tree species forest plantations of the Southern Hemisphere and tropics (Brockerhoff et al. 2006a; Rodríguez and Niemeyer 2005). This is despite the already large areas and expected expansion of this region's intensively managed forest plantations (Sedjo 1999; Carle and Holmgren 2008; FAO 2011). A lack of research capacity is another reason for the minimal use of semiochemicals in this region, although recent efforts are being made in several countries to build capacity in this area. Thus, only 11 of the 429 scientific publications considered in this evaluation were from the Southern Hemisphere, with eight publications treating the development of the technology and only three focussed on its application.

Semiochemical research and development undertaken in the Northern Hemisphere has been applied in Southern Hemisphere forest plantation situations. For example, the Australian and New Zealand governments, as well as some private companies are using semiochemicals to monitor the presence of quarantine pests in high-risk areas such as seaports and airports, as well as in forests located close to these areas (Cole 2005; Brockerhoff et al. 2006a; Wylie et al. 2008). Extensive pheromone-trapping programmes for the Gypsy moth have been established in high-risk areas in New Zealand and Australia to serve as early warning systems to mitigate the risk of successful introductions (Cole 2005). This system proved highly effective in 2003 in New Zealand when a single male moth was detected in the city of Hamilton and intensive trapping was then used as part of the subsequent eradication campaign (MAF Biosecurity New Zealand 2008). In several Australian states, pheromone traps are also used to monitor the occurrence and population size of the exotic bark beetle *Ips grandicollis* in forest plantations (Bashford 2008). A national surveillance network was implemented in New Zealand by the Ministry of Agriculture and Forestry to detect exotic wood borers and bark beetles using pheromone and kairomone-baited traps (Brockerhoff et al. 2006a), and a similar trapping system has been used in several Australian states at high-risk sites since 2005 (Wylie et al. 2008). Results from both countries indicate that kairomone-baited traps placed in high-risk areas successfully trap both native and exotic Scolytidae and Cerambycidae.

An example of a strategy developed in the Southern Hemisphere using semiochemical technology from Northern Hemisphere is that for *Sirex* wood wasp monitoring. Here, within the intensively managed forestry plantations composed of non-native tree species, intentionally damaged trees, or trap trees, have been used to monitor the pest, because these trees are more attractive to *Sirex* than healthy surrounding trees (Neumann et al. 1982; Madden and Irvine 1971). In addition, Siricids in these trap trees are used as either a source of eggs and larvae on which wasp parasitoids such as *Ibalia leucospoides* and *Megarhyssa nortoni* can breed or for the application of the parasitic nematode, *Deladenus siricidicola*, (Madden and Irvine 1971; Neumann et al. 1982; Carnegie et al. 2005). Currently, various pine volatiles are being investigated as potential lures for traps, as an alternative to trap trees, for monitoring spread of *Sirex noctilio* in Australia and the United States of America (B. Slippers and B.P. Hurley, personal communication). Since 2007, a national network of monitoring traps using kairomone lures, simulating stressed pine trees, has been established across the South African non-native tree species commercial forestry plantation resource (P. Croft, personal communication). In this case, it is anticipated that monitoring *Sirex* ahead of the invasion front will allow for the early detection and swift release of biological control agents in newly invaded areas.

As suggested above, novel semiochemical development in intensively managed forestry plantations has been rather limited in the Southern Hemisphere. One of the first examples was the determination of the sex pheromone for the Pine Emperor moth, *Nudaurelia cytherea cytherea*, in South Africa (Henderson et al. 1972). Other more recent examples include the determination in New Zealand of the sex pheromone of the gum leaf skeletoniser *Uraba lugens*, an invasive eucalypt lepidopteran herbivore (Gibb et al. 2008), and of its subsequent use in predicting the moth's potential distribution and deployment as a monitoring tool as part of an incursion management programme (Kriticos et al. 2007; Suckling et al. 2005). In Australia, the sex pheromone of the Autumn gum moth, *Mnesampela privata*, has also been determined (Steinbauer et al. 2004; Walker et al. 2007) and shows potential as an effective population monitoring tool to be used in eucalypt plantation IPM in southern Australia (Östrand et al. 2007; Walker et al. 2007).

Partnerships between governments, universities and commercial forestry companies can contribute to address the lack of research on the use of semiochemicals in Southern Hemisphere forestry plantations. An example is the collaborative programme in Chile where pheromones were identified and synthesised to monitor populations of the pine shoot moth, *Rhyacionia buoliana* (Rodríguez and Niemeyer 2005). Australian and South African researchers at both government research institutions and universities have begun to explore the potential to use sex pheromones to control cossid wood moths. These insects, for example, the giant wood moth *Endoxyla cinereus* and Culama wood moth *Culama australis* in Australia and the goat moth *Coryphodema tristis* in South Africa that kill trees or lower timber value in commercial eucalypt plantations (Lawson et al. 2008). A sex pheromone formulation for *C. australis* was successfully tested in the field in Australia in 2008–2009 (Lawson, unpublished results). In addition, Australian researchers have begun to consider the potential to manage native *Eucalyptus* tortoise beetles in the genera *Paropsisterna* and *Paropsis* in commercially managed *Eucalyptus* plantations using plant volatiles to enhance attraction to lethal trap trees on plantation edges (Elek 2009).

4 Conclusions

In this review, we reflect on the growing and effective use of semiochemicals to detect, monitor and control many forest pest species in the Northern Hemisphere. Despite their proven potential, however, their adoption in Southern Hemisphere intensively managed forestry plantations has been slow. In our view, the most likely reason is a relatively small research capacity and a lack of funds to discover and develop semiochemicals in the Southern Hemisphere. Southern Hemisphere forest plantations will become increasingly valuable for fibre production and carbon sequestration, and there is thus an urgent need to develop and focus research capacity to develop specific semiochemical approaches for this sector.

Introduced pests are increasing in number and frequency in forest plantations of the Southern Hemisphere at an alarming rate (Wingfield et al. 2008, 2011). Consequently, there is a growing urgency to increase the efficiency of monitoring and to detect new arrivals as early as possible. Doing so will increase the likelihood of successful eradication and will contribute substantially to understanding the pathways of introduction. Semiochemical-baited traps are better suited to monitor insect occurrence than almost any other method used for this purpose, as has been shown for various insect pests in Southern Hemisphere countries such as New Zealand and Australia.

While early detection is important to address the growing number of introduced pests in Southern Hemisphere plantations, the extent of the problem is such that this is unlikely to be sufficient on its own. There is consequently also a need to increase the efficiency of control strategies to better use the limited resources available. Here too, semiochemical research can contribute by improving the accuracy of monitoring of dispersal and population levels for the pests. This is especially relevant given that the use of chemical pesticides is becoming less viable because they are expensive to apply over the large areas of expanding plantations. Applications of chemicals in forestry is also under pressure because of their toxicity and the consequent prohibition by forest sustainability certification agencies such as the Forestry Stewardship Council, which strives for low chemical usage and IPM systems (Rametsteiner and Simula 2003; Anonymous 2005a, b, c).

As semiochemical research is developed for Southern Hemisphere plantations in coming years, careful consideration will need to be given in choosing target insects and the forestry system in which they operate for semiochemical monitoring and control, because these methodologies are not necessarily suited to all candidate pest insects (e.g. as reviewed in Millar (2006) and El-Sayed et al. (2009)). It will be important to take these criteria into account when selecting insect targets so as to maximise the chances of success in future semiochemical research and development in forestry plantations. Early success stories will also give the industry increased confidence that semiochemical-based pest management is a viable option in plantation forestry. Developing semiochemicals for key pests will not only enable better monitoring and control but will also provide valuable tools for researchers to better understand their biology and ecology to serve as model systems for such research in Southern Hemisphere environments.

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