Forest Health Technology Enterprise Team

TECHNOLOGY TRANSFER

Bioinsecticides

Semiochemicals of Forest and Shade Tree Insects in North America and Management Applications

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FHTET-96-15
September 1997

ACKNOWLEDGMENTS

We are grateful to Drs. Gary E. Daterman, Gary G. Grant, Gerhardt and Regine Gries, G. Staffan Lindgren, and Kenneth R. Raffa for providing reviews of the manuscript and reprints of recent publications. This project was supported by USDA Forest Service Cooperative Agreement No. 42-821 (92-821-A1) from the National Center of Forest Health Management, Morgantown, WV, and by funds allocated by the Georgia Agricultural Experiment Stations.

Semiochemicals of Forest and Shade Tree Insects in North America and Management Applications

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Background

Semiochemical is a general term for compounds by which organisms communicate (Law and Regnier 1971). Increasing environmental concerns over the use of conventional control techniques has provided impetus for researchers to attempt to exploit insect chemical communication systems as management tools. Advantages of semiochemicals are that many are highly specific, often effective in small quantities, and biodegradable (Tette 1974). Although few data are available on their toxicity, many semiochemicals appear to be nontoxic or only slightly toxic to mammals and nontarget insects. Some secondary compounds formed by the breakdown of semiochemicals and used for defense are exceptions.

Potential for the integration of semiochemicals into the development of forest insect management techniques include gathering further details on insect biologies; monitoring for infestations, adult activity periods, or population trends; and control. Potential use for control include trap out, disruption of mating or interference with host location. More accurate predictions of pest outbreaks and intensity through monitoring allow for more timely and focused control efforts, thereby reducing cost and increasing efficacy. Research to develop pest management techniques using semiochemicals has increased dramatically since the sixties, as related technology has become more sophisticated.

Purpose

This paper reports on semiochemicals which have been identified for forest and shade tree insects in North America, and describes their operational and potential uses for insect management. It gives the chemical identities of these compounds, pilot tests and uses, and the status for uses that require U.S. Environmental Protection Agency registration. This paper is meant to be used as a quick reference rather than as an exhaustive source of information.

Terminology

In this paper the following terms, as described by Nordlund (1981), are used:

Pheromones-Compounds that incite reactions between organisms of the same species (Karlson and Butenandt 1959, Karlson and Luscher 1959, Nordlund and Lewis 1976). Pheromones may be used for sex attraction, trails, aggregation, and antiaggregation.

Allomones-Compounds that, when contacted by other individuals, produce a reaction favorable to the emitter not the receiver (Brown 1968, Nordlund and Lewis 1976).

Kairomones-Compounds that, when contacted by other individuals, produce a reaction that is favorable to the receiver not the emitter (Brown et al. 1970).

Host Compounds-Any host-produced chemical that affects the behavior of insects, e.g., attractants, repellents or synergists for any of the chemical groups previously mentioned.

Organization

This paper is organized according to insect feeding habits, taxonomic classification, and alphabetical order of species. For each insect a table gives information on semiochemical availability and uses, at a glance. Where appropriate, some commercial sources of semiochemicals are listed.

Literature Sources Reviewed

Several reference books were used for the preliminary review: *Forest Entomology, Ecology and Management* (Coulson and Witter 1984), *Insects of Eastern Forests* (USDA Forest Service 1985), *Western Forest Insects* (Furniss 1977) and *Insects that Feed on Trees and Shrubs* (Johnson and Lyon 1991). We began searching electronic databases using Agricola and searching for: semiochemical, kairomone or pheromone, 1984-March 1996. Then the same search terms were applied to specific pest families or orders of concern. A similar search of CAB abstracts 1987-March 1996 was conducted using the search terms: forest pest, forest insect, semiochemical, kairomone, pheromone, or chemical-ecology. The abstracts were reviewed for relevant North American pests, concentrating on applied literature. References published before establishment of the electronic databases were selected from those cited in papers collected for review. To ensure the information was up to date, before writing we conducted a search of each pest species in Current Contents and BIOSIS.

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Gnathotrichus retusus LeConte (Coleoptera: Scolytidae)
Ambrosia Beetle

Aggregation Pheromones

S-(+)-Sulcatol 6-methylhept-5-en-2-ol

Sulcatol is produced by boring males with the *S*-(+) enantiomer attractive in the laboratory and in the field (Borden et al. 1980a).

Antiaggregation Pheromones

R-(-)-Sulcatol 6-methylhept-5-en-2-ol

The *R*-(-) enantiomer inhibits response of *G. retusus* (Borden et al. 1980a).

Host Compounds

α-Pinene and ethanol

α-Pinene and ethanol synergized sulcatol in the field (Borden et al. 1980b, Shore and McLean 1985, Liu and McLean 1989).

Other Compounds

G. retusus and *G. sulcatus* both respond to (±)-sulcatol combined with lineatin, the *Trypodendron lineatum* attractant, even though *G. retusus* is inhibited by (-)-sulcatol (Borden et al. 1981). Nijholt (1980) reported that pine oil and oleic acid interrupted attack by *G. retusus* and suggested combining repellents with pheromone-based disruption.

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available	√	
Current Operational Uses		
Monitoring	√	
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out	√	

Commercial Sources

Phero Tech Inc., Delta, BC—*G. retusus* lure

Comments

Interspecific interactions among sympatric species must be considered in devising an effective pheromone-based control program for *G. retusus* and its associates *G. sulcatus* and *T. lineatum*. For best response of *T. lineatum, G. sulcatus* and *G. retusus*, ethanol and α-pinene added to lineatin and sulcatol baits has a synergistic effect (Shore and McLean 1983, 1985).

Lindgren et al. (1983) found that male *G. retusus* responded best to vane traps and females to funnel and drainpipe traps (Lindgren 1983). Lindgren et al. (1983) recommended a combination of vane traps and multiple funnel or drainpipe traps for mass trapping in timber processing areas.

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Gnathotrichus sulcatus LeConte (Coleoptera: Scolytidae) Ambrosia Beetle

Aggregation Pheromones

S-(+)-Sulcatol 6-methylhept-5-en-2-ol

R-(-)-Sulcatol

Sulcatol is produced by boring males in a 65:35 mixture of *S*-(+) and *R*-(-) enantiomers (Byrne et al. 1974). This mixture is essential for attraction in the field (Borden et al. 1976, 1980a). The optimal release rate for catching *G. sulcatus* appears to be 1.5 mg/day (Liu and McLean 1989).

Host Compounds

Ethanol and α-pinene

Ethanol has been shown to be a primary attractant for *G. sulcatus* in laboratory bioassays (Cade et al. 1970) and field tests (McLean and Borden 1975, Borden et al. 1982, Liu and McLean 1989). McLean and Borden (1977) proposed that ethanol acts as a boring stimulant rather than a strong attractant and recommend the use of sulcatol baited stumps treated with ethanolic solutions of insecticides to trap and kill ambrosia beetles. α-Pinene and ethanol have been reported to be synergistic in the field (Borden et al. 1980b, Shore and McLean 1985, Liu and McLean 1989).

Other Compounds

G. retusus and *G. sulcatus* both responded to (±)-sulcatol when combined with the *Trypodendron lineatum* attractant, lineatin, despite *G. retusus* inhibition by (-)-sulcatol (Borden et al. 1981). Nijholt (1980) found that pine oil and oleic acid interrupted attack by *G. sulcatus* and suggested combining repellents with pheromone-based disruption.

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available	√	
Current Operational Uses		
Monitoring	√	
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out	√	

Commercial Sources

Phero Tech Inc., Delta, BC—*G. sulcatus* lure

Comments

McLean and Borden (1979) proposed an operational pheromone-based suppression program for management of *G. sulcatus*, incorporating sticky-traps baited with racemic sulcatol. This trap-out technique captured an estimated 65.1% of the total population around a commercial sawmill. The traps required only 1 man-day/mo. maintenance and eliminated the need for conventional insecticides. This system could be adapted for use in dryland log sorting areas.

Interspecific interactions among sympatric species must be considered in devising an effective pheromone-based control program for *G. sulcatus* and its associates *G. retusus* and *T. lineatum*. For best response of *G. sulcatus, Trypodendron lineatum*, and *G. retusus*, ethanol and α-pinene added to lineatin (*T. lineatum* attractant) and sulcatol baits has a synergistic effect (Shore and McLean 1983, 1985).

Lindgren et al. (1983) reported that *G. sulcatus* responds best to multiple funnel traps, vane traps, and Scandinavian drainpipe traps and not as well to sticky cylinder traps. Baits placed in the middle or bottom of drainpipe traps increased their efficiency. They recommended using a combination of vane traps and multiple funnel or drainpipe traps for mass trapping in timber processing areas. Lindgren and Borden (1983) recommended a mass trapping program with improved log inventory management.

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Trypodendron lineatum (Olivier) (Coleoptera: Scolytidae) Ambrosia Beetle

Aggregation Pheromones

Lineatin 3,3,7-trimethyl-2,9-dioxatricyclo $[3.3.1.0^{4,7}]$ nonane

Lineatin is produced by females (MacConnell et al. 1977) attracting both sexes (Borden et al. 1979, Vité and Bakke 1979). Lindgren et al. (1983) reported the optimal release rate of lineatin to catch *T. lineatum* to be 40 μg/24 h. While Salom and McLean (1988) reported highest wind tunnel responses at lineatin release rates of 8 and 64 μg/24 h. Later work by Salom and McLean showed lures approximating 100 μg/24 h, to be most effective (Lindgren 1997).

Host Compounds

α-Pinene and ethanol

α-Pinene and ethanol are reported synergists with lineatin in European populations (Vité and Bakke 1979), but not in North American populations (Borden and McLean 1981, Andryszak et al. 1987, Borden et al. 1982). Salom and McLean (1990) found ethanol synergistic for females when searching for hosts, while males rely mainly on lineatin to locate mates. Moeck (1970) found ethanol attractive to both sexes in laboratory bioassays.

Other Compounds

Setter and Borden (1992) reported that *T. lineatum* is attracted to the *Dendroctonus* spp. pheromone frontalin in western North America. Nijholt (1980) showed that pine oil and oleic acid interrupted attack by *T. lineatum* and suggested combining repellents with pheromone-based disruption.

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available	√	
Current Operational Uses		
Monitoring	√	
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out	√	

Commercial Sources

Phero Tech Inc., Delta, BC—*T. lineatum* lure

Comments

König (1988) found mass trapping *T. lineatum* in Germany to reduce numbers of beetles by about 50% year after year. For control of *T. lineatum,* Lindgren and Borden et al. (1983) recommended mass trapping, synthetic pheromones, multiple funnel traps and sticky vane traps in timber processing areas on Vancouver Island. Lindgren et al. (1983) recommend using a combination of vane traps and multiple funnel or drainpipe traps for mass trapping in timber processing areas. McLean et al. (1987) reported that Biolure-baited traps caught more *T. lineatum* of both sexes than those baited with Linoprax, and drainpipe traps caught fewer females than did multiple funnel or borkenkafer Schlitzfalle traps (bark beetle bumper traps). Shore and McLean (1984) found that maximum catches from pheromone-baited sticky traps at, or immediately below, the height of surrounding underbrush. Mass trapping at a dryland sorting area in British Columbia yielded a 5 to 1 benefit to cost ratio including an estimated $400,000 over 12 years. This experiment supports mass trapping as being operationally and economically successful (Lindgren and Fraser 1994).

Trap logs used in conjunction with mass trapping have been shown to be effective in managing *T. lineatum* infestations in timber processing areas (Lindgren et al. 1982, Borden 1990). A processing area with a 1000-meter perimeter would require about 100 to 200 traps for mass trapping and 10 to 15 bundles of trap logs to reduce infestations of *T. lineatum.*

Interspecific interactions among sympatric species must be considered in devising an effective pheromone-based control program for *T. lineatum* and its associates *Gnathotrichus sulcatus* and *G. retusus*. For best response of *T. lineatum* and *G. sulcatus,* ethanol and α-pinene added to lineatin and sulcatol (*G. sulcatus* pheromone) baits has a synergistic effect. For optimal catches of *T. lineatum* alone, traps without the *G. sulcatus* pheromone are more effective (Shore and McLean 1983). Mark-recapture techniques can be used to optimize the efficiency of mass trapping of *T. lineatum* (Shore and McLean 1988).

Kelsey (1994) reported ambrosia beetle densities were 9-16 times higher in delimbed felled Douglas-fir (*Pseudotsuga menziesii)* logs than in branched logs. The author presumed the ethanol concentrations in felled logs could contribute to the ambrosia beetle attack densities. Branched logs have lower water content because of capillary action to branches and subsequent evaporation creating unfavorable conditions for ethanol production.

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Dendroctonus adjunctus Blanford (Coleoptera: Scolytidae)
Roundheaded Pine Beetle

Aggregation Pheromones

Frontalin — 1,5-dimethyl-6,8-dioxabicyclo [3.2.1.] octane (Kinzer et al. 1969)

exo-Brevicomin — *exo*-7-ethyl-5-methyl-6,8-dioxabicyclo [3.2.1.] octane (Silverstein et al. 1968)

Hughes et al. (1976) extracted volatiles from *D. adjunctus* hindguts and found frontalin in feeding females and *exo*-brevicomin in emergent males. Males responded more strongly to frontalin, and females responded more strongly to *exo*-brevicomin in field tests.

Antiaggregation Pheromone

Verbenone — 4,6,6-trimethylbicyclo[3.1.1] hept-3-en-2-one (Renwick 1967)

Livingston et al. (1983) reported that response of *D. adjunctus* to attractant baited ponderosa pine trees was inhibited by verbenone.

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption	√	
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No lure is currently available specifically to manage *D. adjunctus*.

Comments

The use of verbenone to disrupt *D. adjunctus* colonization has been successfully demonstrated in ponderosa pine stands. Trees baited with frontalin, *exo*-brevicomin and host resin have produced mass attack by *Dendroctonus adjunctus* (Livingston et al. 1983). This lure in combination with cacodylic acid (Buffam 1971) could provide a valuable tool for managing this pest by creating trap trees for subsequent removal.

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Dendroctonus brevicomis LeConte (Coleoptera: Scolytidae)
Western Pine Beetle

Aggregation Pheromones

exo-Brevicomin	*exo*-7-ethyl-5-methyl-6,8-dioxabicyclo [3.2.1.] octane (Silverstein et al. 1968); (+)-*exo*-brevicomin (Wood et al. 1976)
Frontalin	1,5-dimethyl-6,8-dioxabicyclo [3.2.1.] octane (Kinzer et al. 1969); (-)-frontalin (Wood et al. 1976)

(+)-*exo*-Brevicomin is released by females at approximately 4.1 μg/day (Browne et al. 1979) inducing an aggregation response (Wood and Bedard 1977). Attacking males release (-)-frontalin at approximately 0.86 μg/day (Browne et al. 1979).

Antiaggregation Pheromone

Verbenone	4,6,6-trimethylbicyclo[3.1.1] hept-3-en-2-one (Byers and Wood 1980, Bertram and Paine 1994a)
trans-Verbenol	*trans*-4,6,6-trimethylbicyclo [3.1.1] hept-3-en-2-ol (Renwick 1967, Pitman et al. 1968)

Verbenone and has been isolated from male western pine beetle and *trans*-verbenol from females (Renwick 1967, Pitman et al. 1968). *Trans*-verbenol may serve as a multifunctional pheromone that is repellent at high concentrations and attractive at low concentrations (Bedard et al. 1980a, b).

Host Compounds

Myrcene	(Silverstein 1970, Bedard et al. 1969, Byers 1982)

Bedard et al. (1969) reported that myrcene enhanced response of *D. brevicomis* males and females to *exo*-brevicomin in laboratory and field tests.

Other Compounds

(+)-Ipsdienol	2-methyl-6-methylene-2, 7-octadien-4-ol

D. brevicomis males produce (+) ipsdienol which inhibits the response of males and females to their aggregation pheromones (Byers 1982). (+) Ipsdienol could also repel or attract certain *Ips* species thereby possibly influencing interspecific competition. More studies must be conducted to understand its biological function (Byers and Wood 1981, Byers et al. 1984, Paine and Hanlon 1991, Bertram and Paine 1994a).

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available	√	
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

Phero Tech Inc., Delta, BC—*D. brevicomis* lure.

Comments

Verbenone may terminate or greatly reduce *D. brevicomis* aggregation when released in large enough quantities (Bedard et al. 1980b, Bertram and Paine 1994a,b). However, Byers and Wood (1980) proposed that the mechanism that ends the aggregation phase of colonization by *D. brevicomis* is reduction in the quantity of *exo*-brevicomin and frontalin. The use of verbenone to interrupt or disrupt mating of *D. brevicomis* was not successful for Tilden et al. (1981) and did not reduce beetle catches at baited bolts. Release rates of pheromones also played a role in regulating beetle density. Detailed studies of combinations of pheromones should be conducted to fully understand *D. brevicomis* colonization (Byers et al. 1984). Experimental mass trapping has been only partially effective for controlling *D. brevicomis* (Bedard and Wood 1981).

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Dendroctonus frontalis Zimmermann (Coleoptera: Scolytidae)
Southern Pine Beetle

Aggregation Pheromones

Frontalin	1,5-dimethyl-6,8-dioxabicyclo [3.2.1.] octane (Kinzer et al., 1969), primarily the (-) enantiomer (Stewart et al. 1977, Ohira et al. 1990)
trans-Verbenol	*trans*-4,6,6-trimethylbicyclo [3.1.1] hept-3-en-2-ol (Renwick 1967)

The primary pheromone of southern pine beetle (SPB) is frontalin which is found concentrated in the hindguts of emergent females (Kinzer et al. 1969, Payne et al. 1978, 1988). Pioneering females release frontalin and *trans*-verbenol as they land on host trees to attract conspecifics. Host volatiles such as α-pinene are released by boring beetles which enhances attraction of SPB (Renwick and Vité 1969).

Antiaggregation Pheromone

Verbenone	4,6,6-trimethylbicyclo[3.1.1] hept-3-en-2-one (Renwick 1967)
endo-Brevicomin	*endo*-7-ethyl-5-methyl-6,8-dioxabicyclo [3.2.1.] octane (Silverstein et al., 1968)
Myrtenol	4,6,6-trimethylbicyclo [3.1.1] hept-3-en-10-ol (Rudinsky et al. 1974)

Verbenone is a multifunctional pheromone produced by both males and females. Males release large quantities when host resources become limited, signaling other beetles to search elsewhere for hosts or mates (Rudinsky 1973). Females produce smaller amounts than males, and at low concentrations verbenone is aggregative (Rudinsky 1973). Salom et al. (1992a) found that verbenone containing 34-50% of the (+) enantiomer is the most effective deterrent to attractant baited traps. A registration package for verbenone has been submitted to the Environmental Protection Agency (EPA). Upon EPA approval, verbenone will be commercially available. Myrtenol functions similarly to verbenone: antiaggregative at high concentrations in males and aggregative at low concentrations in females (Rudinsky et al. 1974). *Endo*-Brevicomin, produced by males, is antiaggregative when released with verbenone (Renwick and Vité 1969; Vité and Renwick 1971, Payne et al. 1978), and produces rivalry stridulation in males (Rudinsky and Michael 1974, Ryker 1988).

Host Compounds

α-pinene, 3-carene, camphene, myrcene, β-pinene, limonene, α-thujene, 3-carene, terpinolene and 4-allylanisole

Hayes et al. (1994) reported SPB response to frontalin baited funnel traps was greatly reduced by 4-allylanisol. 4-allylanisol will be commercially available, pending EPA registration.

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available	√	
Current Operational Uses		
Monitoring	√	
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

Phero Tech Inc., Delta, BC—*D. frontalis* lure, Frontalure—frontalin and α-pinene.

Comments

Forest managers may soon be able to use this complex system of insect and host produced chemicals to better manage SPB infestations. Semiochemical-based suppression tactics exploit the anti-aggregation properties of verbenone and *endo*-brevicomin to stop expansion of SPB attacks. This approach reduces successful colonization of uninfested trees and significant reduction in brood production (Richardson and Payne 1979, Watterson et al. 1981) without negatively impacting SPB's natural enemies (Payne and Billings 1989, Payne et al. 1992, Salom et al. 1995). Richerson et al. (1980) conducted field tests with frontalure in an attempt to disrupt normal synchrony of reemergent adults. Further research is needed to test the ability of this method to arrest SPB infestations.

Regional differences in pheromone mixtures pose a challenge in optimizing the effectiveness of semiochemicals for pest management (Berisford et. al 1990). Grosman et al. (1997) reported geographic and gender variation in pheromone production of SPB from Texas, South Carolina, and North Carolina. Females contained 10 times more *cis*-verbenol and 39 times more *trans*-verbenol than did males, and females contained 68-125 times more verbenone than did females. South Carolina females contained significantly more *trans*-verbenol than did North Carolina females, and Texas females contained significantly more *trans*-verbenol than North Carolina females.

Billings (1988) developed a method of forecasting SPB population trends using multiple funnel traps baited with frontalin and turpentine. Populations were rated by comparing relative proportions of SPB and *Thanasimus dubius* (F.) (Coleoptera: Cleridae), an SPB predator, and means of SPB collected per day to county and state infestation trends. A simple dichotomous key was developed to predict summer infestation levels from multifunnel trap catches in early spring. The rating categories were defined as follows:

1. Low level populations were characterized by less than six SPB collected per day regardleess of the number of *T. dubius*.
2. Declining populations were characterized by an average of fewer than 40 percent SPB regardless of the number collected per day.

3. Increasing or high level populations were characterized by an average of 35 SPB per day and greater than 40 percent SPB collected.
4. Static populations were characterized by a mean percent SPB of 40 percent or greater and mean SPB per day ranged from 6 to 35. Static populations may require 2 years of data to adequately detect population trends.

Turchin and Odendaal (1996) reported that the effective sampling area of multifunnel traps baited to collect *D. frontalis*, defined as the translation coefficient between trap catch and the density of emerging beetles, to be approximately 0.1 ha. The authors results indicated that increased stand density decreases trap efficiency.

Taylor et al. (1992) modified a phloem sandwich allowing natural colonization of the device rather than researchers introducing insects. This modified sandwich could be used to screen potential biological control candidates or investigate pheromone response.

Much is known about southern pine beetle (SPB) olfactory communication (Smith et al. 1993), however, mechanisms of this system—pheromone biosynthesis, perception, and mediated behavior—require further inquiry (Salom et al. 1992b). What role do microorganisms play in pheromone biosynthesis? How do multifunctional pheromones mediate beetle behavior? How does SPB select hosts and become attracted to or repelled from a particular tree? Smith et al. (1993) urges researchers to address these questions and derive better approaches to pest management.

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Dendroctonus jeffreyi Hopkins (Coleoptera: Scolytidae)
Jeffrey Pine Beetle

Attractants

1-Heptanol attracts both sexes of *D. jeffreyi* in the field and 2-heptanol inhibits beetle response. Both compounds were identified from the hindguts of females (Renwick and Pitman 1979). Little is known about these compounds or their potential for use in pest management.

Status	Yes	No
Experimental Quantities Available		√
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No baits are commercially available at this time.

Comments

No semiochemical is currently used to manage *D. jeffreyi*.

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Dendroctonus ponderosae (Hopkins) (Coleoptera: Scolytidae)
Mountain Pine Beetle

Aggregation Pheromones

trans-Verbenol	*trans*-4,6,6-trimethylbicyclo [3.1.1] hept-3-en-2-ol (Renwick 1967, Pitman et al. 1968, Pitman 1971, Conn et al. 1983, Borden et al. 1983a, Hunt and Smirle 1988)
cis-Verbenol	*cis*-4,6,6-trimethylbicyclo [3.1.1] hept-3-en-2-ol (Miller and LaFontaine 1991)
exo-Brevicomin	*exo*-7-ethyl-5-methyl-6,8-dioxabicyclo [3.2.1.] octane (Silverstein et al. 1968; Rudinsky et al. 1974; Ryker and Rudinsky 1982; Libbey et al. 1985; Seu and Mori 1986)
Frontalin	1,5-dimethyl-6,8-dioxabicyclo [3.2.1.] octane (Borden et al. 1990)

trans-Verbenol is produced by attacking female mountain pine beetles (MPB) and attracts both sexes in combination with the host volatile α-pinene (Pitman et al. 1968, Pitman 1971) or myrcene (Billings et al. 1976, Conn et al. 1983, Borden and Lacey 1985, Borden et al. 1987). *exo*-Brevicomin is a multifunctional pheromone produced by both sexes and is attractive at low concentrations and inhibitory at high concentrations (Rudinsky et al. 1974). It has been shown to attract beetles on lodgepole pine, but to inhibit attack on similarly baited white pines (Pitman et al. 1978). MPB responses to *exo*-brevicomin have been reported as follows: release rates of 0.04 mg/day and below elicit no response (Libbey et al. 1985); at 0.05 mg/day attraction has been reported (Conn et al. 1983, Borden et al. 1987); while higher concentrations of 4, 5, 6, 10 and 12 mg/day repelled MPB (Ryker and Rudinsky 1982, Libbey et al. 1985, Borden et al. 1987).

Miller and LaFontaine (1991) found *cis*-verbenol to be an aggregation pheromone of MPB with sex-specific responses. The addition of *cis*-verbenol to lures containing myrcene and *exo*-brevicomin increased catches of males to multiple-funnel traps. There was no increased response to baited traps when *cis*-verbenol was added to lures containing *trans*-verbenol, myrcene, and *exo*-brevicomin. Female response to baited traps increased when *cis*-verbenol was added regardless of whether *trans*-verbenol was present in the bait.

Frontalin is a multifunctional, male produced pheromone (Ryker and Libbey 1982, Chatelain and Schenk 1984) that produces behavioral responses similar to *exo*-brevicomin: attractive at low concentrations and inhibitory at high concentrations (Borden et al. 1987, Borden et al. 1990). Chatelain and Schenk (1984) field tested frontalin as a kairomone for MPB predators and found it instead induced MPB attack on 11 of 16 trees. Borden et al. (1990) supported this finding in field experiments where frontalin induced MPB attack on 5 of 10 trees (4 of the 5 were mass attacked) in treated plots compared to no successful infestations in trees in control plots.

Antiaggregation Pheromones

Verbenone	4,6,6-trimethylbicyclo[3.1.1] hept-3-en-2-one (Renwick 1967, Pitman et al. 1969, Rudinsky et al. 1974, Borden et al. 1983a, Ryker and Yandell 1983, Libbey et al. 1985, Hunt et al. 1989, Hunt and Borden 1990, Schmitz and McGregor 1990)
endo-Brevicomin	*endo*-7-ethyl-5-methyl-6,8-dioxabicyclo [3.2.1.] octane (Silverstein et al. 1968, Rudinsky et al. 1974, Ryker and Rudinsky 1982, Libbey et al. 1985)
Frontalin	1,5-dimethyl-6,8-dioxabicyclo [3.2.1.] octane (Kinzer et al., 1969, Ryker and Libbey 1982, Chatelain and Schenk 1984, Borden et al. 1986)
Pinocarvone	(Libbey et al. 1985)

Verbenone is considered the principal antiaggregation pheromone component of *Dendroctonus ponderosae* derived from three sources: female beetles, autoxidation of α-pinene, and micro-organisms growing in established galleries (Hunt and Borden 1989). Researchers hypothesize that one function of this pheromone is to regulate density of breeding pairs to reduce intraspecific competition on suitable hosts (Renwick and Vité 1970, Geiszler and Gara 1978, Geiszler et al. 1980, Borden 1982, Berryman et al. 1985, Borden et al. 1987). However, Kostyk et al. (1993) and Amman and Lindgren (1995) question this interpretation, favoring a hypothesis that verbenone is an indication of host quality and hence not a pheromone at all, at least for some species. *endo*-Brevicomin is produced by males and also has an antiaggregative effect (Rudinsky et al. 1974). Frontalin is considered a multifunctional pheromone, repellant at high concentrations (Ryker and Libbey 1982, Libbey et al. 1985, Borden et al. 1987) and attractive at low concentrations (Borden et al. 1990). Libbey et al. (1985) conducted field tests where pinocarvone reduced MPB response to 48% of attractant controls when added to baits consisting of *trans*-verbenol and monoterpenes.

Host Compounds

α-pinene	(Billings et al. 1976, Pierce et al. 1986, Gara et al. 1984, Gries 1990)
Myrcene	(Billings et al. 1976, Conn et al. 1983, Borden and Lacey 1985, Borden et al. 1987)
Terpinolene	(Billings et al. 1976)
4-Allylanisole	(Hayes and Strom 1994)

Billings et al. (1976) reported that myrcene and terpinoline are better synergists for *trans*-verbenol than is α-pinene. However, Borden et al. (1993) later found that myrcene was a redundant and unnecessary additive to *D. ponderosae* synthetic baits based on field efficacy of baits containing *trans*-verbenol and *exo*-brevicomin alone and when myrcene is included in the mixture. The authors suggested it should be eliminated from commercial baits to reduce cost, eliminate leakage problems, and reduce odors during storage. However, in traps myrcene is a critical component (Conn et al. 1983). 4-Allylanisole has been shown to inhibit *D. ponderosae* response but has not yet been extensively tested (Hayes and Strom 1994, Hobson 1995). Cobb et al. (1972) found 4-allylanisole to be lower in *Pinus ponderosae* trees injured from photochemical air pollution than in healthy trees.

Other Compounds

(*S*)-(+)-, (*R*)-(-)-, and (±)-Ipsdienol 2-methyl-6-methylene-2, 7- octadien-4-ol

Hunt et al. (1986) reported that *D. ponderosae* produce significant amounts of (*S*)-(+)-ipsdienol that may function as an antiaggregation pheromone. In field experiments, the addition of (±)-Ipsdienol to baits containing myrcene, *trans*-verbenol and *exo*-brevicomin significantly reduced *D. ponderosae* attraction (Hunt and Borden 1988). (*S*)-(+)-ipsdienol produced similar but less consistent effects when added to baits. *D. ponderosae* may produce (*S*)-(+)-ipsdienol as a repellent allomone to avoid interspecific competition with *Ips pini* where *I. pini* populations use (*R*)-(-)-ipsdienol as an aggregation pheromone. However, the inhibitory effects of (*S*)-(+)-Ipsdienol on *I. pini* may be replaced by *D. ponderosae* aggregation pheromones in southwest British Columbia (Hunt and Borden 1988). *I. pini* populations use (±)-ipsdienol as an attractant pheromone in this region, and in field tests were attracted to (±)-ipsdienol alone but not when *D. ponderosae* baits were offered (Hunt and Borden 1988).

Gries et al. (1990) isolated five metabolites of α-pinene from emergent MPB females: toluene, verbenene (4-methylene-6,6-dimethylbicyclohept-2-ene), *p*-mentha-1,5,8-triene, *o*-cymene, *p*-cymene. Their biological significance is not known. Syed and Graham (1987) report that *D. ponderosae* was arrested by ethanol in a laboratory olfactometer. Gries et al. (1992) isolated 3,7,7-trimethyl-1,3,5-cycloheptatriene from *D. ponderosae* females. Field studies showed no increased attraction when this compound was added to the synthetic *D. ponderosae* bait.

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available	√	
Current Operational Uses		
Monitoring	√	
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out	√	

Commercial Sources

Phero Tech Inc., Delta, BC—*D. ponderosae* lure, Pondelure.

Comments

Mountain pine beetle (MPB) colonization is mediated by a variety of kairomones, pheromones and allomones which provide opportunities and challenges for researchers to derive management strategies for this major pest (McCambridge 1966, Pitman and Vité 1969, Klein 1978, Moeck et al. 1981, Wood 1982, Borden 1984, McMullen et al. 1986, Whitehead 1986, Borden 1989, Whitehead 1989, Moeck and Simmons 1991, Borden 1995). Semiochemical-based suppression tactics exploit the antiaggregation properties of verbenone in an attempt to stop expansion of MPB attacks (Lindgren et al. 1989, Payne and Billings 1989, Amman et al. 1991, Gibson et al. 1991, Shea et al. 1991, Shore et al. 1992, Kostyk et al. 1993, Lindgren and Borden 1993). Verbenone has been shown to inhibit *D. ponderosae* response to multiple-funnel traps baited with aggregation pheromone (Schmitz and McGregor 1990, Miller et al. 1995). Amman et al. (1991) reported the optimum dosage of verbenone for control of MPB to be a rate of 100 verbenone capsules per hectare (release rate of 5 mg per capsule per day at 25° C). This dosage is most effective at densities of 6 to 14 infested trees per hectare.

Not all studies achieve significant arrestment of the MPB attack through suppression with verbenone alone (Bentz 1989). Miller et al. (1995) report a high dose-dependent variation in response to verbenone-based interruption of attraction. Populations may best be controlled at low densities, unless other chemical signals that mimic unacceptable hosts are added to baits, such as green leaf volatiles or pheromones of sympatric species. Host selection by MPB at high densities is not well understood. They may be attracted to areas where high levels of verbenone are present, but attack adjacent hosts where verbenone concentrations are low, presenting significant management problems. Additional experiments are needed to better understand how verbenone affects infestations of unbaited hosts (Amman et al. 1989).

Amman and Lindgren (1995) reviewed the status of semiochemicals for use in MPB management and did not recommend the use of antiaggregation pheromones on an operational basis. Field tests have shown inconsistent results ranging from inadequate verbenone release devices, changes in stand micro-climate (Schmitz et al. 1989), large or small beetle populations, photoisomerization of verbenone (Kostyk et al. 1993) to genetic selection of beetles. Compounds with stronger more consistent chemical messages as to the unsuitability of the host resource are currently being sought by researchers to make operational use of semiochemicals more feasible (Amman and Lindgren 1995).

Shore et al. (1992) tested the response of MPB to verbenone and *exo*-brevicomin. The mean number of attacked trees in a 5-meter radius of *exo*-brevicomin (high, 2.5 mg/day and low 0.5 mg/day doses) baited trees were significantly different from other treatments with verbenone and *exo*-brevicomin or verbenone alone. Verbenone reduced MPB attack on *exo*-brevicomin treated trees such that they were not significantly different from the controls. However, trees treated with verbenone alone were not significantly different from unbaited trees. The authors concluded that verbenone may make trees within a 5-meter radius of attacked trees less susceptible to attack by MPB by interfering with the aggregation properties of *exo*-brevicomin, but verbenone alone is not a successful repellant. No trees treated with verbenone were mass-attacked, thereby supporting previous studies (Amman et al. 1989, Lindgren et al. 1989).

Trap trees or stands for MPB control has been tested experimentally (Amman 1983, Borden et al. 1983b, Borden et al. 1983c, Borden and Lacey 1985, Borden et al. 1986, Gray and Borden 1989, Bergvinson and Borden 1991, Borden 1992) and in combination with aggregation pheromones that attract entomophagous insects (Chatelain and Schenk, 1984). Trap trees could be used in less valuable stands to remove individuals repelled from more valuable verbenone-treated stands (Schmitz and McGregor 1990, Lindgren and Borden 1993). Competition between other species may also help reduce damage by MPB (Rankin and Borden 1991, Poland and Borden 1994, Safranyik et al. 1996).

4-Allylanisole inhibits *D. ponderosae* and other scolytid response to hosts and could be a valuable management tool in the future (Hayes and Strom 1994).

Variation in horizontal and vertical wind movements could influence *D. ponderosae* dispersal. Field tests revealed that wind direction changed over 40 times per day. These data may be important in stopping beetle infestations through containment in relatively small areas. Such variation in wind direction would indicate baits should be placed, at the very least, on opposite sides of each spot (Schmid et al. 1992).

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Dendroctonus pseudotsugae Hopkins (Coleoptera: Scolytidae)
Douglas-Fir Beetle

Aggregation Pheromones

Frontalin	1,5-dimethyl-6,8-dioxabicyclo [3.2.1.] octane (Kinzer et al., 1969, Pitman and Vité 1970, Furniss and Schmitz 1971, Dickens et al. 1983)
Seudenol	3-methyl-2-cyclohexen-one-ol (Vité et al. 1972, Dickens et al. 1983)
trans-Pentenol	*trans*-pent-3-en-2-ol (Ryker et al. 1979)
MCOL	1-methylcyclohex-2-en-1-ol (Lindgren et al. 1992)

Frontalin (Pitman and Vité 1970), seudenol (Vité et al. 1972), MCOL (Lindgren et al. 1992) and *trans*-pentenol (Ryker et al. 1979) have all been isolated or identified from female hindguts or volatiles. Seudenol and ethanol have been shown to synergize the field attractiveness of frontalin (Pitman et al. 1975, Ross and Daterman 1995a).

Antiaggregation Pheromones

Verbenone	4,6,6-trimethylbicyclo[3.1.1] hept-3-en-2-one (Rudinsky et al. 1974)
3,2 MCH	3-methylcyclohex-2-en-1-one (Kinzer et al. 1971, Pitman and Vité 1975, Dickens et al. 1983)
3,3 MCH	3-methylcyclohex-3-en-1-one (Libbey et al. 1976, Dickens et al. 1983)
Methylheptenone	6-methylhept-5-en-2-one (Ryker et al. 1979)

3,2 MCH (Rudinsky 1973, Rudinsky et al. 1972a, Rudinsky and Ryker 1980) and verbenone (Rudinsky et al. 1974) are attractive with other volatiles at low concentrations and inhibitory at high concentrations. 3,3-MCH (Rudinsky and Ryker 1979) and methylheptenone (Ryker et al. 1979) inhibit beetle response.

Host Compounds

α-pinene, camphene, limonene, ethanol (Dickens et al. 1983)

Other Compounds

trans-Verbenol	*trans*-4,6,6-trimethylbicyclo [3.1.1] hept-3-en-2-ol (Renwick 1967, Pitman et al. 1968)

Rudinsky et al. (1972a) reported *trans*-verbenol to be synergistic with frontalin, but later tests were unable to confirm this function (Rudinsky et al. 1972b).

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available	√	
Current Operational Uses		
Monitoring	√	
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

Phero Tech Inc., Delta, BC—*D. pseudotsugae* lure, Douglure.

Comments

MCOL could be useful in forest management for monitoring or mass trapping of Douglas-fir beetles (Lindgren et al. 1992). However, Ross and Daterman (1995b) reported no benefit by adding MCOL to a lure containing ethanol or seudenol, because of geographic variation in the Douglas-fir beetle pheromone system (Rudinsky et al. 1972a).

Furniss et al. (1974) found baiting susceptible trees with a low elution rate of 3,2-MCH significantly lowered brood production. This antiaggregative management method is advantageous because beetles are prevented from attacking adjacent susceptible trees and forced to search longer or to attack more resistant hosts. This reduces survivorship and populations diminish. 3,2-MCH in a granular controlled-release formulation has been used successfully in aerial applications but has not been registered with the EPA. It was applied at 4.48 kg/ha to 76.9 ha to uninfested windthrown Douglas-fir on May 11-13, 1982. Granules on treated plots measured an average of 2.04-2.69 kg/ha and reduced *D. psuedotsugae* infestation by 96.4 percent by the end of June 1982 (McGregor et al. 1984). Ross and Daterman (1995b) applied 3,2-MCH to Douglas-fir stands at high risk for infestation by *D. pseudotsugae*. Plots ranging from 2.1 to 2.6 ha were treated with MCH in bubble cap formulation stapled to trees at rates of 45-76 g/ha. Significantly fewer trees greater than 20 cm dbh were mass attacked in treated plots compared to untreated plots. Attractant-baited Lindgren-funnel traps caught significantly fewer Douglas-fir beetles in MCH treated plots than in control plots. Further testing is needed to find the lowest effective dose, and the most economical application (Ross and Daterman 1995b).

Knopf and Pitman (1971) attracted *D. pseudotsugae* to trees with Douglure which subsequently killed 58.5% of adjacent unbaited trees with a DBH of 4 inches or larger. Pitman (1972) found "deadtrapping" (the baiting of large sticky traps with Douglure) to be ineffective and possibly detrimental to Douglas-fir beetle predators. More information is needed on Douglas-fir beetle chemical aggregation cues to adequately use these pheromones to suppress tree damage (Bennett and Borden 1971, Baker and Trostle 1973, Ringold et al. 1975). Ross and Daterman (1994) examined the efficacy of antiaggregation and aggregation pheromones in limiting mass attacks of *D. pseudotsugae*. The mean percentage of attacked trees was reduced by 80% in plots treated with MCH on the perimeter and with Frontalin, Seudenol, MCOL, and ethanol bait traps in the interior. However, trees outside the treated plots and in the vicinity of the funnel traps showed an eightfold increase in percentage of mass attacked trees. The authors concluded this strategy could be used to reduce the probability of infestation in small, valuable stands.

Gibson and Oakes (1991) reported an effective "bait and cut" strategy where tree baits can be used in infested stands to create trap trees for subsequent removal. The authors cautioned that baited attack trees must be harvested before beetles emerge the following year or exceptionally high tree mortality could occur in that area.

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Dendroctonus rufipennis (Kirby) (Coleoptera: Scolytidae)
Spruce Beetle

Aggregation Pheromones

Frontalin	1,5-dimethyl-6,8-dioxabicyclo [3.2.1.] octane (Gries et al. 1988)
Seudenol	3-methyl-2-cyclohexen-one-ol (Furniss et al. 1976)
MCOL	1-methyl-2-cyclohexen-one-ol (Borden et al. 1996)
Verbenone	4-methylene-6,6-dimethylbicyclo [3.1.1] hept-2-ene (Gries et al. 1992)

Antiaggregation Pheromone

3,2-MCH	methyl-2-cyclohexen-1-one (Dyer and Hall 1977)

Host Compounds

α-pinene, limonene, 4-allylanisole, beta phellandrene, myrcene, ethanol (Gray et al. 1990, Werner 1995)

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available	√	
Current Operational Uses		
Monitoring		√
Attack Disruption	√	
Spray Timing		√
Phenologic Models		√
Trap Out	√	

Commercial Sources

Phero Tech Inc., Delta, BC—*D. rufipennis* lure.

Comments

Several potential uses for semiochemicals for control of *Dendroctonus rufipennis* are discussed in the literature (Furniss et al. 1976, Dyer and Hall 1977, Dyer and Hall 1983). However, a precise pheromone complex, incorporating required host tree volatiles has not been found for spruce beetle (Dyer and Hall 1983). The use of 3,2-MCH to disrupt *D. rufipennis* colonization has been successfully demonstrated in spruce trees (Kline et al. 1974, Furniss et al. 1976, Lindgren et al. 1989). However, 3,2-MCH and *trans*-verbenol did not successfully disrupt *D. rufipennis* colonization in spruce stumps (Dyer and Hall 1977).

In some cases, creating trap trees for spruce beetle is effective for controlling epidemic populations. Frontalin baited trees have produced mass attack by *D. rufipennis* (Dyer and Hall 1983). Frontalin used in combination with insecticide treatments or removal of infested trees can provide effective control (Dyer 1973, 1975; Dyer and Safranyik 1977; Gray et al. 1990; Shore et al. 1990). Conversely, Gray et al. (1990) found semiochemical baiting with frontalin and α-pinene ineffective in Alaska.

Host volatiles and beetle-produced pheromones play a significant role in luring attacking spruce beetles and their potential predators. Moeck (1981) found that *D. rufipennis* was attracted to ethanol when it was sprayed on the bark of living spruce trees. The clerid beetle *Thanasimus undatulus* Say, a predator of *D. rufipennis*, is also strongly attracted to frontalin (Dyer 1975). Defensive host volatiles regulate bark beetle colonization and could be useful management tools. Werner (1995) reported 100% mortality when *D. rufipennis* was exposed to 80 ppm of limonene and 4-allylanisole for 24 h. Host volatiles limonene, 4-allylanisole, beta phellandrene, and myrcene are reported to inhibit the response of *D.* rufipennis to frontalin (Werner 1995).

Borden et al. (1996) isolated MCOL from female frass of *D. rufipennis* and reported some regional variation in response to this attractant. Field trapping experiments in Alaska showed increased attraction of *D. rufipennis* with the addition of (±) or (+) MCOL to standard baits of α-pinene and frontalin. (+)-MCOL enhanced attraction while (-)-MCOL inhibited response in south-central British Columbia. Three field tests were conducted in southeastern British Columbia and northern Alberta where (+), (-), and (±)-MCOL were only weakly attractive in one of the experiments. Where scolytid species span wide geographic ranges, Borden et al. (1996) concluded that researchers testing semiochemical based management strategies must consider regional pheromone variation.

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Dendroctonus simplex LeConte (Coleoptera: Scolytidae)

Eastern Larch Beetle

Pheromones

No known pheromones have been isolated from *D. simplex*.

Host Compounds

Werner (1995) reported 88-98% mortality when he exposed *D. simplex* to 80 ppm of limonene, 4-allylanisole, myrcene, and beta phellandrene for 24 h. Host monoterpenes, limonene, and myrcene were reported to inhibit the response of *D. simplex* in the field (Werner 1995).

Status	Yes	No
Experimental Quantities Available		√
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No baits are commercially available at this time.

Comments

No semiochemical is currently used to manage *D. simplex*.

References

Werner, R.A. 1995. Toxicity and repellency of 4-allylanisole and monoterpenes from white spruce and tamarack to the spruce beetle and eastern larch beetle (Coleoptera: Scolytidae). *Environmental Entomology*. 24(2):372-379.

Dendroctonus terebrans (Olivier) (Coleoptera: Scolytidae)
Black Turpentine Beetle

Sex Pheromones

Frontalin	1,5-dimethyl-6,8-dioxabicyclo [3.2.1.] octane (Kinzer et al. 1969)
exo-Brevicomin	*exo*-7-ethyl-5-methyl-6,8-dioxabicyclo [3.2.1.] octane (Silverstein et al. 1968, DeLorme and Payne 1990)
endo-Brevicomin	*endo*-7-ethyl-5-methyl-6,8-dioxabicyclo [3.2.1.] octane (Silverstein et al., 1968)

Phillips et al. (1989) characterized the function of frontalin and *exo*-brevicomin as sex pheromones as opposed to aggregation or antiaggregation pheromones, because *D. terebrans* males are the primary responders. Males were more responsive to turpentine mixed with (-)-frontalin than to (+)-frontalin in field tests. This response was enhanced by (+)-*endo*-brevicomin but not (-)-*endo*-brevicomin (Phillips et al. 1990). In electroantennogram bioassays, male and female antennal sensitivity was greatest to *endo*-brevicomin (Delorme and Payne 1990). Female *D. terebrans* showed enhanced attraction to turpentine mixed with (-)-frontalin but not (+)-frontalin. Female attraction to turpentine was enhanced by (+), (-), (±)-*exo*-brevicomin and (+)-*endo*-brevicomin but not (-)-*endo*-brevicomin (Phillips et al. 1990). Frontalin acts as a lure for females to attract mates, while *exo*-brevicomin is produced by males and can inhibit the response of competing males to frontalin (Phillips et al. 1989).

Host Compounds

Turpentine, ethanol

For many years, turpentine has been known to attract *D. terebrans* (Hopkins 1909). Ethanol synergizes response to turpentine (Phillips et al. 1988).

Other Compounds

Trans-pinocarveol, *cis*-verbenol, *trans*-verbenol, myrtenal, verbenone, myrtenol

These compounds are produced by both sexes during gallery construction (Payne et al. 1987). *Trans*-verbenol, verbenone and myrtenol had no significant effect on *D. terebrans* behavior in the field (Phillips et al. 1989). Fatzinger et al. (1987) reported that *trans*-verbenol was a synergist for turpentine and ethanol, but inactive when released alone. Payne et al. (1987) reported that *trans*-verbenol attracted *D. terebrans* males in a bioassay.

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No lure is currently available specifically to manage *D. terebrans.*

Comments

D. terebrans is a pest of trees damaged by logging or other mechanical injury and those stressed by drought, fire, disease, lightening, or old age (Kowal and Coyne 1951, Smith and Lee 1957, Merkel 1981). More research is needed to determine how the pheromone system of *D. terebrans* may be use to develop control methods. There is currently no semiochemical based management tactic to control *D. terebrans* (Smith et al. 1993).

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Dryocoetes affaber (Mannerheim) (Coleoptera: Scolytidae)
A Bark Beetle

Aggregation Pheromone

(+)-*endo*-Brevicomin — *endo*-7-ethyl-5-methyl-6,8-dioxabicyclo [3.2.1.] octane (Camacho et al. 1994)

Antiaggregation Pheromone

(-)-*endo*-Brevicomin — *endo*-7-ethyl-5-methyl-6,8-dioxabicyclo [3.2.1.] octane (Camacho et al. 1994)

The (-) enantiomer of *endo*-brevicomin inhibited response of *D. affaber* in field and laboratory tests (Camacho et al. 1994).

Other Compounds

(+) or (±)-*exo*-Brevicomin — *exo*-7-ethyl-5-methyl-6,8-dioxabicyclo [3.2.1.] octane (Camacho et al. 1994)

Exo-brevicomin is a multifunctional pheromone. It acted as a synergist when combined with *endo*-brevicomin, at ratios of 1:1 (Camacho et al. 1993) or less, and inhibits response at higher ratios (Camacho et al. 1994). The most effective blend to attract *D. affaber* was a 1:2 mixture of (+)-*exo*-brevicomin and (+)-*endo*-brevicomin. *D. confusus*, a sympatric species, responded best to a 9:1 ratio, thereby preventing mating between heterospecifics (Camacho et al. 1994).

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No lure is currently available specifically to manage *D. affaber*.

Comments

Biological control of *Dendroctonus ponderosae* via competitive displacement by *Ips pini* has been a successful technique (Borden 1992). Camacho et al. (1994) proposed a similar strategy using pheromones to attract *Dryocoetes affaber* to competitively displace *Dendroctonus rufipennis* (McCambridge and Knight 1972). No semiochemical is currently used to manage *D. affaber*.

References

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Dryocoetes autographus (LeConte) (Coleoptera: Scolytidae)

Pheromones

No known pheromones have been isolated from *D. autographus*.

Host Compounds

Chénier and Philogène (1989) found that *D. autographus* was attracted to host monoterpenes β-pinene, myrcene, limonene, camphene, and carene when added to ethanol baited sticky stovepipe traps and Lindgren multiple funnel traps. However, α-pinene did not synergize with ethanol.

Status	Yes	No
Experimental Quantities Available		√
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No baits are commercially available at this time.

Comments

No semiochemical is currently used to manage *D. autographus*.

References

Chénier, J.V.R., B.J.R. Philogène. 1989. Field responses of certain forest Coleoptera to conifer monoterpenes and ethanol. *Journal of Chemical Ecology* 15(6):1729-1745.

Dryocoetes confusus Swaine (Coleoptera: Scolytidae)
Western Balsam Bark Beetle

Aggregation Pheromones

exo-Brevicomin — *exo*-7-ethyl-5-methyl-6,8-dioxabicyclo [3.2.1.] octane (Borden et al. 1987)

Myrtenol — 6,6-dimethyl-bicyclo [3.1.1] hept-2-ene-2-methanol (Borden et al. 1987)

exo-Brevicomin and myrtenol combined were most effective in field trapping experiments for *D. confusus*. *exo*-Brevicomin is produced by boring males and attracts both sexes. Both racemic and (+) *exo*-brevicomin attracted female beetles in laboratory bioassays, with no indication that (-) *exo*-brevicomin inhibited response (Borden et al. 1987).

Antiaggregation Pheromone

(+)-*endo*-Brevicomin — *endo*-7-ethyl-5-methyl-6,8-dioxabicyclo [3.2.1.] octane (Stock et al. 1990)

The (+) enantiomer of *endo*-brevicomin inhibited response of both sexes of *D. confusus* in field and laboratory tests (Stock et al. 1990).

Host Compounds and Other Compounds

Stock and Borden (1983) reported that *D. confusus* was attracted to host volatiles, indicating that primary attraction might play a role in colonization. Verbenone, *trans*-verbenol, *trans*-pinocarveol, *cis*- and *trans-p*-menthen-7-ol, 3-caren-10-ol and other monoterpenes and sesquiterpenes have been isolated from the hindguts of boring male *D. confusus*, although in lesser quantities than *exo*-brevicomin. Both males and females contained *trans*-verbenol. The function of these chemicals in the *D. confusus* communication system is unknown (Borden et al. 1987).

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available	√	
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

Phero Tech Inc., Delta, BC—*D. confusus* tree bait.

Comments

Camancho et al. (1993) and Camacho and Borden (1994) found that a 9:1 blend of (+)-*exo*-brevicomin and (+)-*endo*-brevicomin for *D. confusus*, was a better attractant than racemic *exo*-brevicomin. Camacho et al. (1993) found the same 9:1 blend effective in laboratory tests. Stock et al. (1993, 1995) reported that an effective release rate of (+) and (-) *exo*-brevicomin was 0.8 mg/24 h and that baiting multiple trees increased attack intensity on adjacent trees, suggesting some potential for semiochemical based management of *D. confusus*.

References

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Hylastes nigrinus (Mannerheim) (Coleoptera: Scolytidae)
Root Bark Beetle

Pheromones

No known pheromones have been isolated from *H. nigrinus.*

Host Compounds

Witcosky et al. (1987) reported *H. nigrinus* attraction to the host chemicals α-pinene and ethanol. They suggested that plant stress or injury produces volatiles that attract *H. nigrinus* to suitable hosts. Jacobi (1992) found *H. nigrinus* responsive to 1% to 10% Douglas-fir resin in 95% ethanol baited pitfall and window traps. Pitfall traps were the most effective at capturing this pest.

Status	Yes	No
Experimental Quantities Available		√
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No baits are commercially available at this time.

Comments

No semiochemical is currently used to manage *H. nigrinus.*

References

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Witcosky, J.J., T.D. Schowalter, E.M. Hansen. 1987. Host-derived attractants for the beetles *Hylastes nigrinus* (Coleoptera: Scolytidae) and *Steremnius carinatus* (Coleoptera: Curculionidae). *Environmental Entomology* 16(6):1310-1313.

Hylastes salebrosus Eichhoff (Coleoptera: Scolytidae)
A Pine Bark Beetle

Pheromones

No known pheromones have been isolated from *H. salebrosus*.

Host Compounds and Kairomones

Phillips (1990) found that *H. salebrosus* was attracted to turpentine and ethanol, as well as to the *Dendroctonus* pheromone *exo*-brevicomin. *H. salebrosus* may exploit communications among some *Dendroctonus* spp. to locate suitable hosts.

Status	Yes	No
Experimental Quantities Available		√
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No baits are commercially available at this time.

Comments

No semiochemical is currently used to manage *H. salebrosus*.

References

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Hylurgopinus rufipes (Eichhoff) (Coleoptera: Scolytidae)
Native Elm Bark Beetle

Pheromones

No pheromones have been reported for *H. rufipes* (Gardiner 1979, Peacock 1979, Millar et al. 1986).

Host Compounds

Millar et al. (1986) reported *H. rufipes* adults locate hosts by attraction to host volatiles, including α-cubebene. Gardiner (1979) suggested *H. rufipes* locates suitable elms by host volatiles alone because of attraction to trees killed with the herbicide cacodylic acid.

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No lure is currently available specifically to manage *H. rufipes*.

Comments

Peacock (1979) created trap trees with cacodylic acid, although successful breeding did occur in some parts of the upper bole. This could be used as a management strategy for protecting elm trees against beetle attack and potentially against Dutch elm disease. Millar et al. (1986) reported that diseased trees were significantly more attractive to beetles than those killed by cacodylic acid. This treatment obviously left the trees less desirable for breeding than those dying naturally and could pose a problem for management of this pest. Millar et al. (1986) suggested monitoring *H. rufipes* populations with sesquiterpene-baited traps, although much work is need to refine the bait mixture. The chiral specificity of the 20 or so elm volatiles attracting *H. rufipes* has not been examined and could be important in developing effective baits.

References

Gardiner, L.M. 1979. Attraction of *Hylurgopinus rufipes* to cacodylic acid-treated elms. *Entomological Society of America Bulletin* 25(1):102-104.

Millar, J.G., C.H. Zhao, G.N. Lanier, D.P. O'Callaghan, M. Griggs, J.R. West, R.M. Silverstein. 1986. Components of moribund american elm trees as attractants to elm bark beetles, *Hylurgopinus rufipes* and *Scolytus multistriatus*. *Journal of Chemical Ecology* 12(3):583-608.

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Ips avulsus (Eichhoff) (Coleoptera: Scolytidae)
Small Southern Pine Engraver

Aggregation pheromones

R-(-)-Ipsdienol	2-methyl-6-methylene-2,7-octadien-4-ol (Vité et al. 1972, Hughes 1974, Vité et al. 1978)
2-methyl-3-buten-2-ol	
Lanierone	2-hydroxy-4,4,6-trimethyl-2,5-cyclohexadien-1-one (Teale et al. 1991)

Both sexes of *I. avulus* were attracted in the field (Renwick and Vité 1972) to the *R*-(-) enantiomer of ipsdienol (Vité et al. 1978) and to male *I. avulsus* infested bolts (Birch et al. 1980, Svihra et al. 1980, Svihra 1982, Smith et al. 1993). Females were attracted by 2-methyl-3-buten-2-ol produced by males (Birgersson et al. 1995). Lanierone has been shown to be synergistic with ipsdienol (Birgersson et al. 1995).

Antiaggregation pheromones

S-(+)-Ipsdienol	2-methyl-6-methylene-2,7-octadien-4-ol (Vité et al. 1978)

Attraction of both sexes is interrupted by *S*-(+)-Ipsdienol (Vité et al. 1978).

Host Compounds

Turpentine

High volumes of turpentine significantly reduced *I. avulsus* attraction to pheromone baited traps (Billings 1985).

Other Compounds

S-(-)-Ipsenol	2-methyl-6-methylene-7-octen-4-ol
exo-Brevicomin	*exo*-7-ethyl-5-methyl-6,8-dioxabicyclo [3.2.1.] octane (Silverstein et al. 1968)
endo-Brevicomin	*endo*-7-ethyl-5-methyl-6,8-dioxabicyclo [3.2.1.] octane (Silverstein et al. 1968)

Response to these kairomones illustrates the close association of *I. avulsus* with the southern pine beetle guild. Hedden (1976) reported a significant attraction to *S-(-)*-ipsenol, the aggregation pheromone used by a sympatric species *I. grandicollis*. Smith et al. (1993) noted that the response was stronger by males, the colonizing sex, than by females, supporting the premise of primary attraction from a cohabiting species.

Richerson and Payne (1979) found that *I. avulsus* landed on host trees treated with *endo-* and *exo-*brevicomin with or without verbenone. However, verbenone alone did not prevent them from landing. Watterson et al. (1982) reported that *endo-, exo-*brevicomin and verbenone eluted near host trees significantly increased parent adult reemergence, brood emergence, and gallery density of southern pine beetle while populations of *I. avulsus* increased. It is therefore likely that *I. avulsus* populations are responding to declines in *D. frontalis* populations and not to pheromone lures (Smith et al. 1993). Birgersson et al. (1995) found that *I. avulsus* was not inhibited by any compound produced by other sympatric *Ips* species.

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No lure is currently available specifically to manage *I. avulsus*.

Comments

Although the chemical communication system of *I. avulsus* is fairly well known, there is no semiochemical currently used to manage this pest (Smith et al. 1993). Further studies should be conducted concerning the enantiomeric ratios preferred by *I. avulsus* (Birgersson et al. 1995).

References

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Ips calligraphus (Germar) (Coleoptera: Scolytidae)
Sixspined Ips

Aggregation pheromones

R-(-)-Ipsdienol	2-methyl-6-methylene-2,7-octadien-4-ol (Renwick and Vité 1972, Hughes 1974)
S-cis-verbenol	*cis*-4,6,6-trimethylbicyclo [3.1.1] hept-3-en-2-ol
trans-Verbenol	*trans*-4,6,6-trimethylbicyclo [3.1.1] hept-3-en-2-ol

R-(-)-ipsdienol, *S-cis*-verbenol, and *trans*-verbenol are produced by males (Renwick and Vité 1972, Hughes 1974). *R*-(-)-ipsdienol (Vité et al. 1978) and *trans*- or, primarily, *S-cis*-verbenol (Vité et al. 1976) are attractive in field tests. Billings (1985) used a pheromone mixture consisting of 2% racemic ipsenol, 2% racemic ipsdienol, and 2% *S-cis*-verbenol in a vaseline-based paste to attract *I. calligraphus* and other *Ips* species. Birgersson et al. (1995) found males more responsive than females to *cis*-verbenol and its synergist ipsdienol.

Antiaggregation pheromones

S-(+)-Ipsdienol	2-methyl-6-methylene-2,7-octadien-4-ol
R-cis-Verbenol	*cis*-4,6,6-trimethylbicyclo [3.1.1] hept-3-en-2-ol

S-(+)-ipsdienol and *R-cis*-verbenol interrupt response of conspecifics to attractive pheromones (Vité et al. 1976, Vité et al. 1978).

Host Compounds

I. calligraphus was not significantly affected by the presence of high volumes of turpentine added to pheromone-baited traps (Billings 1985). However, Renwick and Vité (1972) reported that low release rates of host volatiles increased the response of *I. calligraphus* to ipsenol and ipsdienol.

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No lure is currently available specifically to manage *I. calligraphus*.

Comments

There is no semiochemical currently used to manage *I. calligraphus* (Smith et al. 1993). Further studies should be conducted concerning the enantiomeric ratios preferred by *I. calligraphus* (Birgersson et al. 1995).

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Ips grandicollis (Eichhoff) (Coleoptera: Scolytidae)
Eastern Fivespined Ips

Aggregation pheromones

S-(-)-Ipsenol	2-methyl-6-methylene-7-octen-4-ol
cis-Verbenol	*cis*-4,6,6-trimethylbicyclo [3.1.1] hept-3-en-2-ol
E-Myrcenol	*trans*-2-methyl-6-methylene-7-octen-2-ol

Ipsenol was isolated from male hindguts (Vité and Renwick 1971, Vité et al. 1972, Hughes 1974). The *S-(-)*-ipsenol enantiomer attracted both sexes in field experiments (Vité et al. 1976). *Cis*-verbenol is a strong synergist for ipsenol, particularly for attracting females. E-myrcenol is a synergist for male response to ipsenol (Birgersson et al. 1995).

Antiaggregation pheromones

R-(+)-Ipsenol	2-methyl-6-methylene-7-octen-4-ol

Smith et al. (1990) found that the *R*-(+)-ipsenol enantiomer can interrupt the attraction of its optical enantiomer *S*-(-)-ipsenol.

Host Compounds

Werner (1972a) reported that male beetles responded to gerinol, myrcene, methyl chavicol and limonene and that female beetles were attracted primarily to myrcene and camphene. Ascoli-Christensen et al. (1992) reported *I. grandicollis* response to α-pinene in electrophysiological recordings of antennal cells. In field tests, Billings (1985) found that *I. grandicollis* was attracted to turpentine alone.

Other Compounds

I. grandicollis is closely associated with other species in the southern pine bark beetle guild, specifically other *Ips* spp. and *Dendroctonus* spp. Werner (1972b) proposed that *I. grandicollis* detects pheromones of *Dendroctonus* spp., *trans*-verbenol and frontalin in combination with host volatiles and thereby avoids hosts colonized by *Dendroctonus* spp. Ascoli-Christensen et al. (1992) reported that *I. grandicollis* responded in electroantennogram evaluations to frontalin, *endo*-brevicomin, verbenone, *trans*-verbenol, *cis*-verbenol, ipsdienol, and ipsenol showing a lack of specificity in most pheromone and host odor receptor cells. These results are inconsistent with those for other *Ips* species. These electrophysiological recordings from antennal olfactory receptor cells show that females are more responsive to *I. grandicollis* pheromones and males more responsive to antiaggregation pheromones of *Dendroctonus frontalis*. This could support the hypothesis that colonizing male *I. grandicollis* cue on heterospecific pheromones in selecting a host, thereby avoiding interspecific competition.

Dixon and Payne (1980) found that *I. grandicollis* was attracted to *trans*-verbenol and frontalin with or without turpentine. Smith et al. (1993) suggested that *I. grandicollis* cue on *D. frontalis* pheromones for initial host selection, but avoid micro-habitats colonized by *D. frontalis*. Birgersson et al. (1995) reported that ipsdienol and lanierone inhibited response of *I. grandicollis* to ipsenol-baited traps. Ipsdienol is produced by *I. pini*, *I. avulsus* and *I. calligraphus* and lanierone by *I. avulsus* and *I. pini*. These results suggest *I. grandicollis* avoids competition with these sympatric species as well.

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No lure is currently available specifically to manage *I. grandicollis*.

Comments

Although the chemical communication system of *I. grandicollis* has been described, there is no semiochemical currently used to manage this pest (Smith et al. 1993). Further studies should be conducted concerning the enantiomeric ratios preferred by *I. grandicollis* (Birgersson et al. 1995).

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Ips hoppingi Lanier (Coleoptera: Scolytidae)
A Pine Bark Beetle

Aggregation pheromones

Lanier and Wood (1975) reported that female *I. hoppingi* were strongly attracted to the attractant pheromone of *I. paraconfusus (*Ipsenol: 2-methyl-6-methylene-7-octen-4-ol) in laboratory olfactometer experiments.

Other Compounds

Cane et al. (1990) reported that *I. hoppingi* was attracted to *I. confusus* infested bolts in field tests. These closely related species are allopatric but show no divergence in pheromone communication systems.

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No baits are commercially available at this time.

Comments

Little is known about the pheromone communication system of *I. hoppingi*. No semiochemical is currently used to manage this pest.

References

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Ips latidens (LeConte) (Coleoptera: Scolytidae)

Aggregation pheromones

Ipsenol 2-methyl-6-methylene-7-octen-4-ol

Ipsenol is produced only by males (Miller et al. 1991), attracting both sexes to suitable hosts (Wood et al. 1967, Furniss and Livingston 1979). Males are slightly more attracted to the *S*-(-)-ipsenol enantiomer (Miller et al. 1991).

Host Compounds

Miller et al. (1986) reported that *I. latidens* showed significant attraction for high-girdled lodgepole pines, over undamaged trees. *I. latidens* responded to multiple-funnel traps baited with β-phellandrene (Miller and Borden 1990). Miller and Borden (1990) suggested that response to monoterpenes by *I. latidens* facilitates chemical communication between conspecifics.

Other Compounds

cis-Verbenol is not produced by either sex of *I. latidens*, however, Miller et al. (1991) found that it inhibits response to ipsenol-baited traps. Miller and Borden (1992) reported that *S*-(+)-ipsdienol, a pheromone for *Ips pini* (Say) inhibited response to ipsenol (Miller et al. 1989). In south-central British Columbia *I. latidens* and *I. pini* may both infest lodgepole pine partitioning resources by their choice of breeding material; *I. latidens* infests drier phloem material than *I. pini* (Miller and Borden 1985). Regional variation in enantiomeric blends may show differences in responses by sympatric species (Plummer et al. 1976, Birch et al. 1980, Miller et al. 1989).

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No lure is currently available specifically to manage *I. latidens*.

Comments

Although the communication system of *I. latidens* has not been completely elucidated, clearly host compounds and kairomones play a significant role in successful colonization. Research into this facet of attack and colonization may allow scientists and foresters to determine if semiochemicals can be used to manage infestations of *I. latidens*. No semiochemical is currently used to manage *I. latidens*.

References

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Ips lecontei Swaine (Coleoptera: Scolytidae)
A Fivespined Ips

Aggregation pheromones

I. lecontei males produce (+)-ipsdienol and (-)-ipsenol in high optical purity (Francke et al. 1986).

(+)-ipsdienol 2-methyl-6-methylene-2,7-octadien-4-ol (Francke et al. 1986)

(-)-ipsdienol 2-methyl-6-methylene-7-octen-4-ol (Francke et al. 1986)

Host Compounds

α-Pinene, β-pinene, camphene, Δ^3-Carene, myrcene, limonene, β-phellandrene, terpinolene were isolated from hindguts of the pine engraver *I. lecontei*. The biological significance of these compounds is unknown (Francke et al. 1986).

Other Compounds

Ipsenone and ipsdienone were both isolated from hindguts of males. The biological function of these compounds is unknown (Francke et al. 1986).

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No lure is currently available specifically to manage *I. lecontei*.

Comments

No semiochemical is currently used to manage *I. lecontei*.

References

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Ips mexicanus (Hopkins) (Coleoptera: Scolytidae)

A Pine Ips

Pheromones

No pheromones have been reported for *I. mexicanus.*

Other Compounds

I. mexicanus was unexpectedly attracted to funnel traps where racemic pheromone of a sympatric species, *I. paraconfusus*, was released. Fox et al. (1990) suggested this mixture was not representative of the optical purity released by boring *I. paraconfusus* in a natural setting.

Status	Yes	No
Experimental Quantities Available		√
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No baits are commercially available at this time.

Comments

Fox et al. (1990) found that *I. mexicanus* attacks Monterey pines infected with pitch canker, *Fusarium subglutinans* (Wollenw and Reink) Nelson, Toussoun, and Marasas, that seems to predispose the trees to beetle colonization. The beetles also act as a vector for this fungus resembling the relationship between Dutch elm disease and its European elm bark beetle vector (Fox et al. 1991). This relationship is cause for concern for urban tree owners and the softwood timber industry and could ultimately spread to other hosts across the western United States. No semiochemical is currently used to manage *I. mexicanus.*

References

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Ips paraconfusus Lanier (Coleoptera: Scolytidae)
California 5-Spined Ips

Aggregation pheromones

S-(-)-Ipsenol 2-methyl-6-methylene-7-octen-4-ol (Silverstein et al. 1966)

S-(+)-Ipsdienol 2-methyl-6-methylene-2,7-octadien-4-ol (Silverstein et al. 1966, Vité et al. 1972)

S-cis-verbenol *cis*-4,6,6-trimethylbicyclo [3.1.1] hept-3-en-2-ol (Silverstein et al. 1966)

These compounds are produced by males (Silverstein et al. 1966) and are attractive in laboratory and field tests (Wood et al. 1968). Akers et al. (1993) reported that *cis*-verbenol regulates the effects of ipsenol and ipsdienol in laboratory bioassays. For instance, *cis*-verbenol exerts maximal inhibition when ipsdienol is at its lowest concentrations. Additional studies must be conducted to understand the function that relative concentrations of these compounds have on *I. paraconfusus* behavior (Seybold 1993).

Antiaggregation pheromones

R-(-)-Ipsdienol 2-methyl-6-methylene-2,7-octadien-4-ol (Vité et al. 1972)

R-(-)-Ipsdienol inhibits response of conspecifics to attractive pheromones (Light and Birch 1979, Birch et al. 1980). Kohnle et al. (1994) report a similar inhibitory effect of *R*-(-)-Ipsdienol in field experiments.

Host Compounds

Methyl chavicol (Hobson 1995)

Other Compounds

2-Phenylethanol is produced by males and in field tests enhanced attraction to male-infested logs (Renwick et al. 1968)

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No lure is currently available specifically to manage *I. paraconfusus*.

Comments

Fox et al. (1990) found *Ips paraconfusus* to bore near Monterey pines infected with pitch canker, *Fusarium subglutinans* (Wollenw and Reink) Nelson, Toussoun, and Marasas, that seems to predispose the trees to beetle colonization. The beetles also act as a vector for this fungus resembling the relationship between Dutch elm disease and its European elm bark beetle vector (Fox et al. 1991). This relationship is cause for concern for urban tree owners and the softwood timber industry and could ultimately spread to other hosts across the western United States.

The use of juvenile hormone analog, fenoxycarb, has been shown to induce pheromone production in *Ips paraconfusus* and could be a valuable management tool (Chen et al. 1988). Storer (1994) reported methyl chavicol to reduce *I. paraconfusus* catch in pheromone baited traps by 40%. Host compounds could be useful in management strategies because they affect the behavior of multiple pests and are inexpensive to produce (Hobson 1995). Recognition of chemical signals from other bark beetle species allows *I. paraconfusus* to congregate on unexploited resources. This close association could possibly be exploited for control of certain bark beetle pests. Paine and Hanlon (1991) reported a significant reduction in catches from pheromone baited traps with verbenone (*Dendroctonus* spp. antiaggregation pheromone) added.

Shea and Neustein (1995) reported a successful use of semiochemical based "trap out" management strategy (Bakke 1991, Wood 1980) in a rare stand of Torrey pine. The tactic consisted of trapping beetles with aggregation pheromones in areas where trees were already dead and using antiaggregation pheromones in areas where trees were not yet infested. Within several seasons of pheromone mediated trapping, attack from *I. paraconfusus* was controlled. This example was not a scientific experiment because of the urgent need to protect these rare pines. The authors suggest further studies on semiochemical management strategies for *I. paraconfusus*.

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Ips perturbatus (Eichhoff) (Coleoptera: Scolytidae)
An Engraver Beetle

Aggregation pheromones

No aggregation pheromones have been isolated from *I. perturbatus*. However, *I. perturbatus* were found to respond to Lindgren funnel traps baited with (±)-ipsdienol released at 0.2 or 0.4 mg/24 h. *Exo*-brevicomin and (±)-ipsdienol combined are also attractive at release rates of 0.2 and 0.4 mg/24 h (Werner 1993).

Antiaggregation pheromones

No aggregation pheromones have been isolated from *I. perturbatus*. However, *I. perturbatus* response was inhibited to funnel traps baited with (±)-ipsdienol (0.4 mg/24 h), 2-methyl-3-buten-2-ol (3.8 mg/24 h) and (±)-ipsenol (0.2 mg/24 h) (Werner 1993).

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No baits are commercially available at this time.

Comments

Werner (1993) recommended the use of (±)-ipsdienol released at 0.2 mg/24 h in Lindgren funnel traps or on trap trees to most effectively catch *I. perturbatus*.

References

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Ips pini (Say) (Coleoptera: Scolytidae)
Pine Engraver

Aggregation pheromones

Ipsdienol	2-methyl-6-methylene-2,7-octadien-4-ol (Vité et al. 1972)
Lanierone	2-hydroxy-4,4,6-trimethyl-2,5-cyclohexadien-1-one (Teale et al. 1991)

Ipsdienol is a terpene alcohol produced by *I. pini* males which attracts both sexes. No pheromone production has been reported from female beetles (Miller et al. 1989). There is regional variation in the relative proportions of the two optical isomers of ipsdienol. *Ips pini* males in California (Birch et al. 1980) and Idaho (Plummer et al. 1976) produce only (R)-(-)-ipsdienol. (R)-(-)-ipsdienol attracts California beetles but (S)-(+)-ipsdienol is antiaggregative (Birch et al. 1980). Beetles from New York produce a 65:35 mixture of (S)-(+) and (R)-(-)-ipsdienol and responded best to a racemic mixture (Lanier et al. 1980). Seybold et al. (1995a) reported two distinct regional pheromonal blends from New York, 32% to 56% (-)-ipsdienol, and California, 94% to 98% (-)-ipsdienol. Analysis of enantiomeric composition by Miller et al. (1997) supports the hypothesis of Seybold et al. (1995b) that the New York race of *I. pini* has a range extending west to British Columbia. Four western British Columbian populations showed enantiomeric mixtures of ipsdienol at ratios ranging from 63:37 to 71:29.

Teale et al. (1991) isolated and identified lanierone from *I. pini* males through fractionation, spectrometry, and bioassay (Silverstein et al. 1967) from New York populations. Lanierone acted as a strong synergist for ipsdienol in laboratory and field experiments in New York and Wisconsin, and a weak synergist in Montana and British Columbia. California populations do not produce lanierone and are unaffected by its presence in synthetic baits (Teale et al. 1991, Seybold et al. 1992, Miller et al. 1997).

Antiaggregation pheromones

E-Myrcenol	2-methyl-6-methylene-7-octen-2-ol (Gries et al. 1990, Miller et al. 1990)

Miller et al. (1990) found that *E*-myrcenol reduced catches of ipsdienol-baited traps in a dose-dependent manner, and assumed it to be an antiaggregation pheromone of *Ips pini*. However, they noted that *E*-myrcenol was also attractive when released with ethanol in field tests.

Host Compounds

4-Allylanisole, β-phellandrene

Hayes and Strom (1994) reported 4-allylanisole to inhibit *Ips pini* response to ipsdienol baited traps. Miller and Borden (1990) reported *Ips pini* to be attracted to traps baited with β-phellandrene, and concluded that it is used as a host kairomone.

Other Compounds

Verbenone (*Dendroctonus* spp.), ipsenol (*Ips paraconfusus*), linalool (*Ips paraconfusus*)

Ipsdienol-baited control traps catch significantly fewer beetles when antiaggregants verbenone and ipsenol (Borden, et al. 1991, Devlin and Borden 1994), verbenone (Miller et al. 1995), or ipsenol (Furniss and Livingston 1979) are included in the lure. Devlin and Borden (1994) proposed a management tactic where timely, broadcast application of antiaggregants could prevent damaging populations of *Ips pini.* Response of *Ips pini* to chemical signals from other species reduces interspecific competition for host resources (Birch and Wood 1975).

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available	√	
Current Operational Uses		
Monitoring	√	
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out	√	

Commercial Sources

Phero Tech Inc., Delta BC—*I pini* lure.

Comments

Chiral preferences of *Ips* spp. may be a strategy to avoid predators such as *Thanasimus dubius* (F.) (Coleoptera: Cleridae) and *Cylistix cylindrica* (Paykull) (Coleoptera: Histeridae) (Raffa and Klepzig 1989, Raffa and Dahlsten 1995). Geographic variation in chiral specificity of *Ips pini* implies selection imposed by predation (Miller et al. 1989). Because predators use kairomones and pheromones to locate potential prey, they are often caught in traps baited with scolytid pheromones (Dixon and Payne 1980, Bakke and Kvamme 1981, Wood 1982, Billings and Cameron 1984). This emphasizes the need to understand predator-prey interactions when applying pheromone management tactics that could destabilize pest and predator populations. Timing pheromone trapping late in the *Ips pini* flight season can minimize predator attraction and maintain predator-prey balance (Raffa 1991).

Induction of attack by *Ips pini* may be used as a management tool to competitively displace the mountain pine beetle, *Dendroctonus ponderosae* (Rankin and Borden 1991, Poland and Borden 1994). Safranyik et al. (1996) manipulated *I. pini* attack densities in lodgepole pine trees using baits containing ipsdienol and lanierone to competitively displace *D. ponderosae*. Success using this technique requires re-baiting during the following spring and temporal variation in placement of baits. The degree to which induced *I. pini* attacks cause *D. ponderosae* mortality is not known.

Ips pini has the capacity for change in its pheromone system with a theoretical potential to develop resistance to mass trapping (Lanier et al. 1972, Slessor et al. 1985, Borden et al. 1986, Miller et al. 1989). A successful trap-out system would therefore require knowledge of the precise pheromone mixtures for different regions and perhaps rotations of mixtures to prevent resistance (Herms et al. 1991). It is not known whether the level of mortality needed to select for altered gene frequencies is actually achieved during trap-out operations.

Gast et al. (1993) examined physiological factors associated with *Ips pini* host location and concluded that beetles responded differently to host volatiles or male pheromones relative to their physiological state and sex. Males which were most attracted to host volatiles were highly desiccated, and contained air in their ventriculus. Females which were predominately attracted to male pheromone were highly desiccated, contained air in their ventriculus, and had visibly fewer fat bodies than those that did not respond. The authors suggested differences in fat and water content in emerging males determine their fitness for dispersal. Well watered and fed males will fly to and arrest on distant hosts as their energy reserves are used up, while weaker males are most likely destined to colonize nearby hosts.

Differential responses of predators to pheromones of their bark beetle prey could be exploited in control efforts (Raffa and Dahlsten 1995). For instance, some Wisconsin predators are not attracted to lanierone while California *Enoclerus lecontei* (Wolcott) (Coleoptera: Cleridae) were highly attracted (Seybold et al. 1992, Miller et al. 1997). Thus, introductions of predators from different regions might be used to control *I. pini*.

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Other Compounds

Verbenone (*Dendroctonus* spp.), ipsenol (*Ips paraconfusus*), linalool (*Ips paraconfusus*)

Ipsdienol-baited control traps catch significantly fewer beetles when antiaggregants verbenone and ipsenol (Borden, et al. 1991, Devlin and Borden 1994), verbenone (Miller et al. 1995), or ipsenol (Furniss and Livingston 1979) are included in the lure. Devlin and Borden (1994) proposed a management tactic where timely, broadcast application of antiaggregants could prevent damaging populations of *Ips pini.* Response of *Ips pini* to chemical signals from other species reduces interspecific competition for host resources (Birch and Wood 1975).

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available	√	
Current Operational Uses		
Monitoring	√	
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out	√	

Commercial Sources

Phero Tech Inc., Delta BC—*I pini* lure.

Comments

Chiral preferences of *Ips* spp. may be a strategy to avoid predators such as *Thanasimus dubius* (F.) (Coleoptera: Cleridae) and *Cylistix cylindrica* (Paykull) (Coleoptera: Histeridae) (Raffa and Klepzig 1989, Raffa and Dahlsten 1995). Geographic variation in chiral specificity of *Ips pini* implies selection imposed by predation (Miller et al. 1989). Because predators use kairomones and pheromones to locate potential prey, they are often caught in traps baited with scolytid pheromones (Dixon and Payne 1980, Bakke and Kvamme 1981, Wood 1982, Billings and Cameron 1984). This emphasizes the need to understand predator-prey interactions when applying pheromone management tactics that could destabilize pest and predator populations. Timing pheromone trapping late in the *Ips pini* flight season can minimize predator attraction and maintain predator-prey balance (Raffa 1991).

Induction of attack by *Ips pini* may be used as a management tool to competitively displace the mountain pine beetle, *Dendroctonus ponderosae* (Rankin and Borden 1991, Poland and Borden 1994). Safranyik et al. (1996) manipulated *I. pini* attack densities in lodgepole pine trees using baits containing ipsdienol and lanierone to competitively displace *D. ponderosae*. Success using this technique requires re-baiting during the following spring and temporal variation in placement of baits. The degree to which induced *I. pini* attacks cause *D. ponderosae* mortality is not known.

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Pityogenes knechteli (Swaine) (Coleoptera: Scolytidae)

Aggregation Pheromones

Poland and Borden (1994) reported that *P. knechteli* males produce an aggregation pheromone attractive to both sexes. However, no chemicals have been identified.

Kairomones

P. knechteli males, more so than females, are attracted to bolts infested with a sympatric species *Ips pini.* Poland and Borden (1994) hypothesized that males, the pioneering sex, cue on *I. pini* aggregation pheromones in host selection.

Status	Yes	No
Experimental Quantities Available		√
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No baits are commercially available at this time.

Comments

It is unlikely that *P. knechteli* could significantly impact *I. pini* populations because of their ability to coexist successfully. However, attack disruption of *Dendroctonus ponderosae* populations could be enhanced with the instigation of attack by both *I. pini* and *P. knechteli* (Poland and Borden 1994).

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Polygraphus rufipennis (Kirby) (Coleoptera: Scolytidae)
Four-Eyed Spruce Bark Beetle

Aggregation Pheromones

3-methyl-3-buten-1-ol

The pheromone, 3-methyl-3-buten-1-ol, is produced by boring males and attracts both sexes to baited traps when released at 4390 μg/24 h (Bowers et al. 1991).

Host Compounds

P. rufipennis apparently shows no primary attraction to host volatiles (Bowers and Borden 1990, Bowers et al. 1991).

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No baits are commercially available at this time.

Comments

No semiochemical is currently used to manage *P. rufipennis*. 3-Methyl-3-buten-1-ol has potential for future monitoring or pest management operations (Bowers et al. 1991). Bowers and Borden (1992) reported the attraction of *Lasconotus intricatus* Kraus (Coleoptera: Colydiidae) to the pheromone of *P. rufipennis*. *Lasconotus intricatus* may have an important impact on bark beetle populations, therefore, management practices designed to reduce *P. rufipennis* populations should consider impacts on *L. intricatus*.

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Scolytus multistriatus (Marsham) (Coleoptera: Scolytidae)
Smaller European Elm Bark Beetle

Pheromones

Methylheptanol — 4-methylheptan-3-ol (Gore et al. 1977)

α-Multistriatin — 2,4-dimethyl-5-ethyl-6,8-dioxabicyclo [3.2.1] octane (Gore et al. 1977)

δ-Multistriatin

Methylheptanol and α-multistriatin are produced by virgin females, and found in the abdomen (Gore et al. 1977). Lanier et al. (1977) reported that α-multistriatin was more attractive than δ-multistriatin in laboratory bioassays.

Host Compounds

α-Cubebene (Pearce et al. 1975, Millar et al. 1986), δ-cadinene, γ-cadinene, γ-muurolene, β-elemene, and calamenene (Millar et al. 1986).

Millar et al. (1986) found these elm volatiles most attractive to *S. multistriatus* in laboratory bioassays. α-Cubebene synergizes α-multistriatin.

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available		√
Current Operational Uses		
Monitoring	√	
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out	√	

Commercial Sources

No lure is currently available specifically to manage *S. multistriatus*.

Comments

French et al. (1984) reported *S. multistriatus* were attracted to bacterial isolates from elm trees including, *Bacillus subtilis*, *B. pumilus* and *Enterobacter cloacae*. The applications for bacterial isolates in management tactics is unknown.

Multilure, which consists of both beetle- and host-produced chemicals, is potent enough to effectively manipulate populations of *S. multistriatus* in mass trapping operations (Pearce et al. 1975, Peacock et al. 1981). Trap placement and bait elution rates significantly impact the effectiveness of mass trapping as a viable management strategy, but it could be used in conjunction with other management practices, such as sanitation (Lanier 1978, Lanier 1979). It is difficult to evaluate the efficacy of mass trapping alone and whether it has real impacts on natural populations of *S. multistriatus* (Birch et al. 1977, Birch 1979, Cuthbert and Peacock 1979). Birch et al. (1981) speculated that mass trapping alone is ineffective. Lanier and Jones (1985) suggested that the most effective management strategy to control *S. multistriatus* and Dutch elm disease would be to use trap trees killed with cacodylic acid, baited with multilure and sprayed with 0.5% chloropyrifos on the lower bole.

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Conophthorus coniperda (Schwarz) (Coleoptera: Scolytidae), White Pine Cone Beetle

Sex Pheromone

(+)-*trans*-Pityol (2R, 5S)-(+)-2-(1-hydroxy-1-methylethyl)-5-methyltetrahydrofuran (Pierce et al. 1995)

Repellent

(*E*)-(-)-spiroacetal (5S,7S)-(-)-7-methyl-1,6-dioxaspiro(4.5)decane

Males responded to a female-produced pheromone in laboratory bioassays and in field trapping experiments (de Groot 1991, Birgersson et al. 1995). Pierce et al. (1995) report that racemic *trans*-pityol was as effective as (+)-*trans*-pityol alone. Both sexes produce spiroacetal which acts as a repellent to rival males (Birgersson et al. 1995).

Host Compounds

Birgersson et al. (1995) reported that male and female responses were enhanced by host volatiles. Ongoing studies show that *C. coniperda* requires host volatiles added to pheromone baits for the most effective response. This is in contrast to the red pine cone beetle, *C. resinosae* (DeBarr 1996).

Status	Yes	No
Experimental Quantities Available		√
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No baits are commercially available at this time.

Comments

Pityol and spiroacetal could be used to disrupt colonization of both *C. coniperda* and *C. resinosae* as part of integrated pest management programs (Birgersson et al. 1995). No semiochemical mediated management strategy is currently in use to control *C. coniperda*. Additional research is underway to determine if the attractants, antiaggregation pheromone, or both may be integrated into a management system (G. L. DeBarr, personal communication).

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Conophthorus resinosae Hopkins (Coleoptera: Scolytidae)
Red Pine Cone Beetle

Sex Pheromone

(+)-*trans*-Pityol ((2R, 5S)-(+)-2-(1-hydroxy-1-methylethyl)-5-methyltetrahydrofuran (Pierce et al. 1995)

Repellent

(*E*)-(-)-spiroacetal (5S,7S)-(-)-7-methyl-1,6-dioxaspiro(4.5)decane

Males responded to female-produced volatiles in laboratory bioassays (de Groot et al. 1991). Pierce et al. (1995) found that racemic *trans*-pityol was as effective as (+)-*trans*-pityol alone. Racemic or optical isomers of spiroacetal added to baits act as repellents to rival males (Pierce et al. 1995).

Host Compounds

De Groot et al. (1991) reported that both males and females responded to host volatiles. (±)-α-Pinene, (1S)-(-)-β-pinene, (R)-(+)-limonene and myrcene did not enhance *C. resinosae* attraction to traps baited with (±)-*trans*-pityol (de Groot and Zylstra 1995). Ongoing studies show that *C. resinosae* does not require host volatiles added to pheromone baits for most effective response. This is in contrast to the white pine cone beetle, *C. coniperda* (DeBarr 1996).

Status	Yes	No
Experimental Quantities Available		√
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No baits are commercially available at this time.

Comments

De Groot and Zylstra (1995) found that traps placed in the cone-bearing region of the tree captured 10 times more *C. resinosae* males than traps anchored to the tree trunk 2 m from the ground. Pityol and spiroacetal could be used to disrupt colonization of both *C. coniperda* and *C. resinosae* as part of integrated pest management programs (Birgersson et al. 1995); however, no semiochemical is currently used to control *C. resinosae*.

References

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Barbara colfaxiana (Kearfott) (Lepidoptera: Tortricidae)
Douglas-Fir Cone Moth

Sex Pheromones

(*Z*)-9-dodecen-1-yl acetate

Weatherston et al. (1977) reported that (*Z*)-9-dodecen-1-yl acetate attracted males in field tests. Traps baited with reared females were ineffective.

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No baits are commercially available at this time.

Comments

No semiochemical is currently used to manage *B. colfaxiana.*

References

Weatherston, J., A.F. Hedlin, D.S. Ruth, L.M. MacDonald, C.C. Lenznoff, T.M. Fyles. 1977. Chemical and field studies on the sex pheromones of the cone and seed moths *Barbara colfaxiana* and *Laspeyresia youngana*. *Experientia* 33:723-724.

Cydia ingens (Heinrich) (Lepidoptera: Tortricidae)
Longleaf Pine Seedworm

Sex Pheromone

(*E*,*E*)-8,10-dodecadienyl acetate

Roelofs, DeBarr and Berisford (unpublished data) isolated the sex pheromone, (*E*,*E*)-8,10-dodecadienyl acetate from abdomens of *C. ingens* females. Field tests with synthetic pheromone consistently attracted male moths, while traps baited with reared females were ineffective. Weatherston et al. (1977) found similar results with traps baited with live female *C. youngana* adults. Apparently, laboratory rearing and handling techniques affect female *Cydia* spp. calling behavior (DeBarr et al. 1984).

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No baits are commercially available at this time.

Comments

No semiochemical is currently used to control *C. ingens*. This pest shares the same pheromone components with the pitch pine tip moth, *Rhyacionia rigidana* (Fernald).

References

DeBarr, G.L., C.W. Berisford, J. L. Hanula. 1984. Use of sex pheromones for seed and cone insect pest management in conifer seed orchards. In: Yates, H.O., III, editor. Proceedings of IUFRO cone and seed insects working party conference. Asheville, NC: USDA Forest Service, Southeastern Forest Experiment Station; 194-203.

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Cydia toreuta (Grote) (Lepidoptera: Tortricidae)
Eastern Pine Seedworm

Sex Pheromone

(*E,Z*)-8,10-dodecadienyl acetate

Katovich et al. (1989) isolated the sex pheromone (*E,Z*)-8,10-dodecadienyl acetate from pheromone glands of *C. toreuta* females using gas chromatography. Electroantennogram bioassays and field tests strongly support that (*E,Z*)-8,10-dodecadienyl acetate is the primary sex pheromone of *C. toreuta*.

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No baits are commercially available at this time.

Comments

Pheromone traps baited with (*E,Z*)-8,10-dodecadienyl acetate were attractive to *C. toreuta* males in field tests, and trap catches did not differ significantly from traps baited with live females. The addition of the *E,E* isomer to the *E,Z* lure increased trap catch, although not significantly, and may act as a synergist. The *Z,E* and *Z,Z* isomers reduced trap catch when mixed with the *E,Z* isomer, although only the *Z,Z* isomer reduced trap catches significantly (Katovich et al. 1989). No semiochemical is currently used to control *C. toreuta*.

References

Katovich, S.A., P.D. Swedenborg, M. Giblin, E.W. Underhill. 1989. Evidence for (*E,Z*)-8,10-dodecadienyl acetate as the major component of the sex pheromone of the eastern pine seedworm, *Cydia toreuta* (Lepidoptera: Tortricidae). *Journal of Chemical Ecology*. 15(2):581-590.

Cydia youngana (Kearfott) (Lepidoptera: Tortricidae)
Spruce Seed Moth

Sex Pheromone

(*Z*)-7-dodecen-1-ol (Weatherston et al. 1977)

(*E*)-8-dodecenyl acetate (Grant et al. 1989)

Weatherston et al. (1977) reported that (*Z*)-7-dodecen-1-ol alone or mixtures containing up to 10% of the *E* isomer attracted males in field tests. Traps baited with reared females were ineffective. Apparently, laboratory rearing and handling techniques affect female *Cydia* spp. calling behavior (DeBarr et al. 1984). The spruce seed moth *Cydia youngana* has previously been named both *Cydia strobilella* and *Laspeyresia youngana* (Brown 1979, Brown and Miller 1983). Grant et al. (1989) reported males were most responsive to (*E*)-8-dodecenyl acetate in electroantennogram bioassays. Field tests showed the optimum bait dosage to be 0.3-3 μg using red rubber septa. Traps placed in the upper crown of both white and black spruce trees collected the most males.

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No baits are commercially available at this time.

Comments

No semiochemical is currently used to manage *C. youngana*.

References

Brown, R.L. 1979. The valid generic and trivial names for the codling moth *Cydia pomonella* (Olethreutinae: Tortricidae). *The Annals of the Entomological Society of America* 72:565-567.

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Grant, G.G., W.H. Fogal, R.J. West, K.N. Slessor, G.E. Miller. 1989. A sex attractant for the spruce seed moth, *Cydia strobilella* (L.), and the effect of lure dosage and trap height on capture of male moths. *The Canadian Entomologist* 121:691-697.

Weatherston, J., A.F. Hedlin, D.S. Ruth, L.M. MacDonald, C.C. Lenznoff, T.M. Fyles. 1977. Chemical and field studies on the sex pheromones of the cone and seed moths *Barbara colfaxiana* and *Laspeyresia youngana*. *Experientia* 33:723-724.

Dioryctria abietivorella (Grote) (Lepidoptera: Pyralidae)

Host Compounds

Shu et al. (1997) reported that volatiles emitted from *Pinus strobus* twigs stimulated oviposition of *D. abietivorella* in laboratory bioassays. Three compounds were shown to be most active including myrcene, car-3-ene, (-)-limonene.

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No baits are commercially available at this time.

Comments

No semiochemical is currently used to manage *D. abietivorella*.

References

Shu, S., G.G. Grant, D. Langevin, D.A. Lombardo, J.G. MacConnell. 1997. Oviposition and electroantennogram responses of *Dioryctria abietivorella* (Lepidoptera: Pyralidae) elicited by monoterpenes and enantiomers from eastern white pine. *Journal of Chemical Ecology*. 23(1):35-49.

Dioryctria amatella (Hulst) (Lepidoptera: Pyralidae)
Southern Pine Coneworm

Sex Pheromones

(Z)-11-hexadecenyl acetate (Meyer et al. 1986)

(Z)-11-hexadecenyl acetate, was isolated from *D. amatella* females and reported to be its primary sex pheromone in laboratory and field tests (Meyer et al. 1986).

Host Compounds

The monoterpenes α-pinene, limolene and myrcene, isolated from loblolly pines (*Pinus taeda*), have been shown to stimulate oviposition in *D. amatella*. More research is needed to examine the potential utility of host monoterpenes for monitoring oviposition in the field (Hanula et al. 1985a).

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available		√
Current Operational Uses		
Monitoring	√	
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No baits are commercially available at this time.

Comments

Detection and survey of *D. amatella* with synthetic sex pheromones and sticky traps have been useful in pine seed orchards in the southeastern United States (DeBarr et al. 1982, DeBarr et al. 1984, Grant 1990). Monitoring with pheromone baited sticky traps can determine seasonal activity, relative population densities and provide early warnings of potential outbreaks in a species-specific manner (DeBarr et al. 1984, Hanula et al. 1985b).

Optimal spray timing based on degree-day models similar to those used for control of the Nantucket pine tip moth, *Rhyacionia frustrana* (Berisford 1982, Gargiullo et al. 1983), could ultimately be a useful management technique. Hanula et al. (1984b) reported peak oviposition by *D. amatella* occurs between 5 and 7 days after adults emerge and estimated that 86.6 degree-days are needed for egg hatch. Peak egg hatch should be the best time for insecticidal control.

The high value of seed crops and the small size of most orchards creates an optimal context for mating disruption. Saturation of infested areas with sex pheromones has been attempted for *D. disclusa* with little initial success because of unusually high rainfall, high density *D. disclusa* populations, and premature application of disruptant. This tactic may be useful for *Dioryctria* spp. only when pest densities are low (DeBarr et al. 1984).

Monitoring for *Dioryctria* spp. is simplified by pheromone cross-attraction among *D. amatella*, *D. clarioralis*, *D. disclusa*, and *D. merkeli*. However, the sex attractant of *D. amatella* reduced the response of *D. disclusa* and *D. merkeli* to pheromone traps, and *D. amatella* males were inhibited by *D. disclusa* sex attractant requiring that two sets of traps be used to monitor all four species (Hanula et al. 1984c). Hanula et al. (1984a) found traps placed in the tops of loblolly pine, *Pinus taeda*, to be more attractive to male *Dioryctria* spp. than those placed at the base of the tree crown. Traps in taller trees were somewhat more effective than those in shorter trees. There was some evidence of trap competition at densities of eight traps per 0.1 ha but not at densities of four or fewer traps per 0.1 ha.

References

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Hanula, J.L., C.W. Berisford, G.L. DeBarr. 1984a. Pheromone cross-attraction and inhibition among four coneworms, *Dioryctria* spp. (Lepidoptera: Pyralidae) in a loblolly pine seed orchard. *Environmental Entomology* 13:1298-1301.

Hanula, J.L., C.W. Berisford, G.L. DeBarr. 1985a. Monoterpene oviposition stimulants of *Dioryctria amatella* in volatiles from fusiform rust galls and second-year loblolly pine cones. *Journal of Chemical Ecology* 11(7):943-952.

Hanula, J.L., G.L. DeBarr, C.W. Berisford. 1984b. Oviposition behavior and temperature effects on egg development of the southern pine coneworm, *Dioryctria amatella* (Lepidoptera: Pyralidae). *Environmental Entomology* 13:1624-1626.

Hanula, J.L., G.L. DeBarr, C.W. Berisford. 1985b. Adult activity of *Dioryctria amatella* (Lepidoptera: Pyralidae) in relation to development of immature stages in loblolly pine cones. *Environmental Entomology* 14:842-845.

Hanula, J.L., G.L. DeBarr, W.M. Harris, C.W. Berisford. 1984c. Factors affecting catches of male coneworms, *Dioryctria* spp. (Lepidoptera: Pyralidae), in pheromone traps in southern pine seed orchards. *Journal of Economic Entomology* 77:1449-1453.

Meyer, W.L., G.L. DeBarr, J.L. Hanula, B. Kovalev, R.S. Cameron, C.W. Berisford, W.L. Roelofs. 1986. Z-11-hexadecenyl acetate, a sex pheromone component for the southern pine coneworm, *Dioryctria amatella* (Lepidoptera: Pyralidae). *Environmental Entomology* 15:316-320.

Dioryctria auranticella (Grote) (Lepidoptera: Pyralidae)

Ponderosa Pine Coneworm

Sex Pheromones

No sex pheromone has been identified for *D. auranticella*. The synthetic pheromone for *D. disclusa*, (*Z*)-9-tetradecenyl acetate (Meyer et al. 1982), has been used to trap *D. auranticella* in baited sticky traps (Pasek and Dix 1989).

Status	Yes	No
Experimental Quantities Available		√
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No baits are commercially available at this time.

Comments

No semiochemical is currently used to manage *D. auranticella.*

References

Meyer, W.L., G.L. DeBarr, C.W. Berisford, L.R. Barber, W.L. Roelofs. 1982. Identification of the sex pheromone of the webbing coneworm moth, *Dioryctria disclusa* (Lepidoptera: Pyralidae). *Environmental Entomology* 11(4):986-988.

Pasek, J.E., M.E. Dix. 1989. Life history of a ponderosa pine coneworm, *Dioryctria auranticella* (Lepidoptera: Pyralidae). *Journal of Economic Entomology*. 82(3):879-885.

Dioryctria clarioralis Walker (Lepidoptera: Pyralidae)
Blister Coneworm

Sex Pheromones

(*Z*)-9-tetradecenyl acetate (Meyer et al. 1984)

(*E*)-9-tetradecenyl acetate (Meyer et al. 1984)

(*Z*)-11-hexadecenyl acetate (Meyer et al. 1984)

Female ovipositor tips were excised and their pheromone components extracted and identified. *D. clarioralis* males were attracted to a synthetic pheromone mixture of 30 μg (*Z*)-9-tetradecenyl acetate, 12% (*E*)-9-tetradecenyl acetate, and 5 to 10% (*Z*)-11-hexadecenyl acetate in field and laboratory tests (Meyer et al. 1984).

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available		√
Current Operational Uses		
Monitoring	√	
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No commercial sources are available at this time.

Comments

Pheromones offer a convenient and species-specific method for monitoring seed and cone pests, thereby determining seasonal activity and relative population densities, and providing early warnings of potential outbreaks. The high value of seed crops and the small size of most orchards creates an optimal context for mating disruption. Saturation of infested areas with sex pheromones has been attempted for *D. disclusa* with little initial success because of unusually high rainfall, high *D. disclusa* populations and premature application of disruptant. This may only be a useful control tactic for *Dioryctria* spp., when densities are low (DeBarr et al. 1984).

Optimal spray timing based on degree-day models similar to those in operation for control of the Nantucket pine tip moth, *Rhyacionia frustrana* (Berisford 1982, Gargiullo et al. 1983), could ultimately be a useful management tool. No models presently exist for use in an integrated pest management system (DeBarr et al. 1984).

Monitoring for *Dioryctria* spp. is simplified by pheromone cross-attraction among *D. amatella*, *D. clarioralis*, *D. disclusa*, and *D. merkeli*. Hanula et al. (1984a) reported the sex attractant of *D. disclusa* to be strongly attractive to *D. merkeli* and *D. clarioralis* in field tests. Traps baited with synthetic (*Z*)-9-tetradecenyl acetate can adequately monitor all three species. Hanula et al. (1984b) found male *Dioryctria* spp. more attracted to traps placed in the tops of loblolly pine, *Pinus taeda*, than to those placed at the base of the tree crown. Traps in taller trees were somewhat more effective than those in shorter trees. There was some evidence of trap competition at densities of eight per 0.1 ha but not at densities of four or fewer per 0.1 ha.

References

Berisford, C.W. 1982. Pheromones of *Rhyacionia* spp.: Identification, function and utility. *Journal of the Georgia Entomological Society*. 17 (Supplement 2):23-30.

DeBarr, G.L., C.W. Berisford, J.L. Hanula. 1984. Use of sex pheromones for seed and cone insect pest management in conifer seed orchards. In: Yates, H.O., III, editor. Proceedings of IUFRO cone and seed insects working party conference. Forest Experiment Station Publication 52.07-01. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 194-203.

Gargiullo, P.M., C.W. Berisford, C.G. Canalos, J.A. Richmond. 1983. How to time dimethoate sprays against the Nantucket pine tip moth. *Georgia Forestry Commission Research Paper* 44:1-11.

Hanula, J.L., C.W. Berisford, G.L. DeBarr. 1984a. Pheromone cross-attraction and inhibition among four coneworms, *Dioryctria* spp. (Lepidoptera: Pyralidae) in a loblolly pine seed orchard. *Environmental Entomology* 13:1298-1301.

Hanula, J.L., G.L. DeBarr, W.M. Harris, C.W. Berisford. 1984b. Factors affecting catches of male coneworms, *Dioryctria* spp. (Lepidoptera: Pyralidae), in pheromone traps in southern pine seed orchards. *Journal of Economic Entomology* 77:1449-1453.

Meyer, W.L., R.S. Cameron, A. Tamhankar, G.L. DeBarr, C.W. Berisford, W.L. Roelofs. 1984. Sex pheromone of the blister coneworm moth, *Dioryctria clarioralis* (Lepidoptera: Pyralidae). *Environmental Entomology* 13:854-858.

Dioryctria disclusa Heinrich (Lepidoptera: Pyralidae)
Webbing Coneworm

Sex Pheromones

(*Z*)-9-tetradecenyl acetate (Meyer et al. 1982)

(*Z*)-9-tetradecenyl acetate, was extracted from *D. disclusa* ovipositor tips and reported to be its primary sex pheromone in laboratory and field tests (Meyer et al. 1982).

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available	√	
Current Operational Uses		
Monitoring	√	
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

Hercon Environmental Corp., Emigsville, PA—*D. disclusa* lure and mating disruptant.

Comments

Pheromones offer a convenient and species specific method for monitoring seed and cone pests, thereby, determining seasonal activity, relative population densities and providing early warnings of potential outbreaks (DeBarr and Berisford 1981, DeBarr et al. 1984). DeBarr et al. (1982) tested pheromone baited trap monitoring as part of an integrated pest management program for control of *D. disclusa* in southeastern seed orchards. DeBarr et al. (1982) related trap catch to potential cone damage by creating loss classes: high, > 100 moths; moderate, 10-100 moths; and low, < 10 moths, based on total catch in six traps at each location sampled. DeBarr et al. (1982) recommend preventive insecticidal treatments be applied to seed orchards falling in high or moderate risk classes. The use of pheromone traps in seed orchards should help prevent epidemic coneworm populations and high cone losses as seen in the past.

The high value of seed crops and the small size of most orchards creates an optimal context for mating disruption. Saturation of infested areas with sex pheromones has been attempted for *D. disclusa* with little success because of unusually high rainfall, high *D. disclusa* populations and premature application of disruptant. This may only be a useful control tactic for *Dioryctria* spp., when densities are low (DeBarr et al. 1984).

Optimal spray timing based on degree-day models similar to those in operation for control of the Nantucket pine tip moth, *Rhyacionia frustrana* (Berisford 1982, Gargiullo et al. 1983), could ultimately be useful management tools. No models presently exist for use in an integrated pest management system (DeBarr et al. 1984).

Monitoring for *Dioryctria* spp. is simplified by pheromone cross-attraction among *D. amatella*, *D. clarioralis*, *D. disclusa*, and *D. merkeli*. Hanula et al. (1984b) reported the sex attractant of *D. disclusa* to be strongly attractive to *D. merkeli* and *D. clarioralis* in field tests. Traps baited with synthetic (Z)-9-tetradecenyl acetate can adequately monitor all three species. The strong inhibition to pheromone baited traps of *D. merkeli* and *D. disclusa* by *D. amatella* sex pheromone, (Z)-11-hexadecenyl acetate, requires seed orchard managers to monitor *D. amatella* separately from the other three sympatric species.

Hanula et al. (1984a) found male *Dioryctria* spp. more attracted to traps placed in the tops of loblolly pine, *Pinus taeda*, than to those placed at the base of the tree crown. Traps in taller trees were somewhat more effective than those in shorter trees. There was some evidence of trap competition at densities of 8 per 0.1 ha but not at densities of 4 per 0.1 ha or lower. DeBarr and Berisford (1981) report that up to 25 times as many *D. disclusa* males were collected in the upper crown than the lower crown of trees 9 to 15 meters tall. Traps above the canopy were not effective.

References

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Hanula, J.L., G.L. DeBarr, W.M. Harris, C.W. Berisford. 1984a. Factors affecting catches of male coneworms, *Dioryctria* spp. (Lepidoptera: Pyralidae), in pheromone traps in southern pine seed orchards. *Journal of Economic Entomology* 77:1449-1453.

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Dioryctria merkeli Mutuura & Munroe (Lepidoptera: Pyralidae)
A Coneworm

Sex Pheromones

The sex pheromone for *D. merkeli* has not been identified (DeBarr et al. 1984). However, males were attracted to pheromone traps baited with a blend of (*Z*/*E*)-9-tetradecenyl acetate (Meyer et al. 1984). Cameron (1981) reported that *D. disclusa* and *D. clarioralis* sex pheromone baited traps attracted *D. merkeli* in field tests, while *D. amatella* sex pheromone was not attractive.

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available		√
Current Operational Uses		
Monitoring	√	
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No baits are commercially available at this time.

Comments

Monitoring for *Dioryctria* spp. is simplified by pheromone cross-attraction among *D. amatella*, *D. clarioralis*, *D. disclusa* and *D. merkeli*. Hanula et al. (1984b) reported the sex attractant of *D. disclusa* to be strongly attractive to *D. merkeli* and *D. clarioralis* in field tests. Traps baited with synthetic (*Z*)-9-tetradecenyl acetate can adequately monitor all three species. Monitoring with pheromone traps could act as an early warning system for impending outbreaks of seed and cone pests (DeBarr et al. 1984).

Hanula et al. (1984a) found male *Dioryctria* spp. more attracted to traps placed in the tops of loblolly pine, *Pinus taeda*, than to those placed at the base of the tree crown. Traps in taller trees were somewhat more effective than those in shorter trees. There was some evidence of trap competition at densities of eight traps per 0.1 ha but not at densities of four or fewer per 0.1 ha.

References

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Dioryctria reniculelloides Mutuura & Munroe (Lepidoptera: Pyralidae) Spruce Coneworm

Sex Pheromones

(Z)-9-tetradecenyl acetate (Grant et al. 1987)

Grant et al. (1987) isolated the sex pheromone, (Z)-9-tetradecenyl acetate, from abdominal extracts of *D. reniculelloides* females. Electroantennogram bioassays and field tests confirm (Z)-9-tetradecenyl acetate to be the primary sex pheromone of *D. reniculelloides*.

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No baits are commercially available at this time.

Comments

In field tests conducted by Grant et al. (1987), catch in female-baited traps did not differ significantly from that in traps baited with 3μg of (Z)-9-tetradecenyl acetate. Attractiveness of the primary sex pheromone was significantly enhanced with the addition of 0.15 or 0.3 μg of (Z)-7-dodecenyl acetate. A three component lure, with the addition of (Z)-7-dodecenal, was competitive with female baited traps but not significantly different from the two component lure. Pheromone baited traps placed in the middle and upper crown of white (*Picea glauca*) and black (*P. mariana*) spruce were most effective at capturing *D. reniculelloides* males. No semiochemical is currently used to manage *D. reniculelloides*.

References

Grant, G.G., Y.H. Prévost, K.N. Slessor, G.G.S. King, R.J. West. 1987. Identification of the sex pheromone of the spruce coneworm, *Dioryctria reniculelloides* (Lepidoptera: Pyralidae). *Environmental Entomology*. 16:905-909.

Dioryctria resinosella Mutuura (Lepidoptera: Pyralidae)
Red Pine Shootmoth

Sex Pheromones

(*Z*)-9-tetradecenyl acetate (Grant et al. 1993)

(*Z*)-9-tetradecen-1-ol (Grant et al. 1993)

Grant et al. (1993) excised pheromone glands from *D. resinosella* females and isolated the compounds (*Z*)-9-tetradecenyl acetate and (*Z*)-9-tetradecen-1-ol. The authors conducted electroantennogram bioassays and identified these compounds as primary sex pheromones. In field tests, the lures baited with (*Z*)-9-tetradecenyl acetate, (*E*)-9-tetradecenyl acetate, (*Z*)-9-tetradecen-1-ol and (*Z*)-9-dodecenyl acetate in a μg ratio of 30:1.5:5:10 respectively, captured significantly more males than traps baited with (*Z*)-9-tetradecenyl acetate alone. This four-component lure is the most effective blend used to monitor *D. resinosella* populations.

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available		√
Current Operational Uses		
Monitoring	√	
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No baits are commercially available at this time.

Comments

Pheromones offer a convenient and species specific method for monitoring seed and cone pests to determine seasonal activity and relative population densities, and for providing early warnings of potential outbreaks (DeBarr and Berisford 1981, DeBarr et al. 1984). The use of pheromone traps in seed orchards should help prevent epidemic coneworm populations and high cone losses as seen in the past. Attraction of *D. banksiella* males to traps baited with the four-component lure may be a problem for monitoring *D. resinosella* populations because adults are difficult to distinguish. This could be problematic in areas near jack pine stands (Grant et al. 1993).

Grant et al. (1993) collected more insects from traps located in the upper canopy near the tops of trees.

References

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Acleris gloverana Walsingham (Lepidoptera: Tortricidae)
Western Blackheaded Budworm

Sex Pheromones

(*E*)-11,13-tetradecadienal (Gray et al. 1996)

The primary sex pheromone component of *A. gloverana* was identified as (*E*)-11,13-tetradecadienal from female pheromone glands using coupled gas chromatography-electroantennographic detection and gas chromatography-mass spectrometry. In field tests, *A. gloverana* males were most attracted to baits containing 1000 μg of (*E*)-11,13-tetradecadienal while lower and higher doses were significantly less attractive (Gray et al. 1996).

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No baits are commercially available at this time.

Comments

For adequate monitoring, optimal pheromone release rates must be assessed and field tested (Gray et al. 1996). Gray et al. (1996) recommended the Uni-trap (Phero Tech, Delta, BC) containing a large-capacity bucket for monitoring, because sticky traps became saturated with male moths after only a short time. However, no semiochemical management is currently in use.

References

Gray, T.G., R.F. Shepherd, G. Gries, R. Gries. 1996. Sex pheromone component of the Western Blackheaded Budworm, *Acleris gloverana* Walsingham (Lepidoptera: Tortricidae). *The Canadian Entomologist* 128:1135-1142.

Acleris variana (Fernald) (Lepidoptera: Tortricidae)
Eastern Blackheaded Budworm

Sex Pheromones

(*E*)-11,13-tetradecadienal (Gries et al. 1994)

The primary sex pheromone component of *A. variana* was identified as (*E*)-11,13-tetradecadienal using coupled gas chromatography-electroantennographic detection and gas chromatography-mass spectrometry. In field tests, (*E*)-11,13-tetradecadienal attracted *A. variana* males, and was more effective with increasing doses from 0.01 to 10 μg. Increases in pheromone quantity over 100 μg inhibited attraction (Gries et al. 1994).

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No baits are commercially available at this time.

Comments

For adequate monitoring, Gries et al. (1994) recommended the development of a sustained pheromone release rate throughout the *A. variana* flight period. No semiochemical is currently used to manage this pest.

References

Gries, G., J. Li, R. Gries, W.W. Bowers, R.J. West, P.D.C. Wimalaratne, G. Khaskin, G.G.S. King, K.N. Slessor. 1994. (*E*)-11,13-tetradecadienal: Major sex pheromone component of the eastern blackheaded budworm, *Acleris variana* (Fern.) (Lepidoptera: Tortricidae). *Journal of Chemical Ecology* 20(1):1-8.

Choristoneura fumiferana (Clemens) (Lepidoptera: Tortricidae)
Spruce Budworm

Sex Pheromones

(E/Z)-11-tetradecenals (Weatherston et al. 1971, Sanders and Weatherston 1976, Silk et al. 1980)

Other Compounds

Tetradecanal (Silk et al. 1980)

E-11-tetradecenyl acetate (Silk et al. 1980)

Silk et al. (1980) reported that the blend released by *C. fumiferana* females contains about 2% tetradecanal and very small amounts of E-11-tetradecenyl acetate. The acetate inhibits male response at low concentrations, but this effect is masked by the presence of tetradecanal (Alford et al. 1983, Sanders 1984). Sanders (1990) conducted wind tunnel studies where males responded more strongly to filter paper and rubber septa baited with female extract than to synthetic baits providing evidence for a missing component.

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available	√	
Current Operational Uses		
Monitoring	√	
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

Hercon Environmental Corp., Emigsville, PA—*C. fumiferana* lure and mating disruptant.

Grimble (1988) recommended the use of a lure with a continuous emission rate of 15.0 μg/day, for monitoring of endemic *C. fumiferana* populations, because trap catch can be easily influenced by poor timing of trap deployment or bad weather early in the flight season.

Comments

Control of *C. fumiferana* must start with predicting when endemic populations are likely to become epidemic by monitoring with pheromone traps (Grant 1991). Long term population studies (Sanders 1988), showed correlations between trap catch and late-instar larvae in the same year (r^2=66%) and with larvae in the following year (r^2=81%). Miller and McDougall (1973) reported r^2=98% for the relationship between moth catch and larval density in the following year. Sanders (1988) proposed the following criteria for predicting epidemic populations: three consecutive years of increasing trap catches or a threshold of 50 moths per sticky trap. Care must be taken when checking pheromone traps for *C. fumiferana* because other species are attracted to its pheromone blend. Problems could arise in distinguishing between *C. conflictana* and *C. fumiferana*, which have overlapping flight periods (Sanders 1993).

Lyons and Sanders (1993) described the North American spruce budworm pheromone trapping network as a system designed to incorporate historical pheromone trap catch data; geostatistics, to extrapolate from point data to contour maps for maximum spatial coverage; and GIS software for spatial analysis. Processing of the large annual accumulation of data incorporates computer-based GIS analysis to produce regional contour maps displaying budworm population levels each year. It allows trapping information to be combined with other point source information (e.g. larval estimates, egg counts or defoliation estimates) onto forest type maps. Ultimately, data from the pheromone trapping network may be used as a management tool to predict *C. fumiferana* outbreaks. Variation in lure potency, migrating moths, and unknown thresholds for baseline data needed for spatial analysis hinder development of predictive models.

Pheromone baited traps deployed at mid-crown or higher were most efficient at collecting males (Bergh et al. 1988). Sanders (1992) reported trap efficiency to be highest at 1.5 to 2.0 meters high with 40 meters between traps. Proper placement of traps helps monitor *C. fumiferana* at the beginning and end of the flight season and when population densities are low.

By examining mating status of males collected in pheromone traps in conjunction with insect net catches, the efficacy of pheromone disruption can be measured (Bergh et al. 1988). Sanders (1996) reported that, based on flight-tunnel studies with *C. fumiferana* males, time-averaged atmospheric concentrations of synthetic pheromone must be as high as 20 ng/m^3 to effectively disrupt mating. However, the effect of males following false trails, as observed in wind-tunnel experiments, will not adequately prevent mating (Sanders 1995).

Oral exudates from *C. occidentalis* and *C. fumiferana* larvae contain epideictic pheromones (Prokopy, 1981) and could theoretically be used to induce larval dispersal or to make larvae more vulnerable to conventional insecticides (Poirier and Borden 1995, 1996). Isolation and identification of any chemicals that mediate dispersal behavior and determination of the role natural foliage plays in this behavior is needed before a management strategy based on their use could be field tested (Poirier and Borden 1995, 1996).

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Choristoneura occidentalis Freeman (Lepidoptera: Tortricidae)

Western Spruce Budworm

Sex Pheromones

(E/Z)-11-tetradecenals (Silk et al. 1982)

(E/Z)-11-tetradecenyl acetates (Silk et al. 1982)

(E/Z)-11-tetradecenols (Silk et al. 1982)

The sex pheromone of *C. occidentalis* is a blend of 92:8 (E/Z)-11-tetradecenals; 89:11 (E/Z)-11-tetradecenyl acetates; and 85:15 (E/Z)-11-tetradecenols (Silk et al. 1982). These components are in a ratio of approximately 10:3:6 of Ald:Ac:OH respectively (Cory et al. 1982, Silk et al. 1982). Sweeney et al. (1990a) conducted flight-tunnel tests that support the hypothesis that this blend stimulates precopulatory behavior at long (>1 m) and short distances.

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available		√
Current Operational Uses		
Monitoring	√	
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No baits are commercially available at this time.

Triangular sticky traps are currently used and are as effective in wind tunnel tests as Pherocon 1CP traps, Dome traps, Double Cone traps and Kendall traps (Angerilli and McLean 1984). Sweeney and McLean (1990) found Uni-traps baited with 0.05% (E:Z) PVC lures (3 mm diam × 5 mm long) more effective than Delta Sticky traps. Trapping efficiency declined when Uni-traps baited with 0.05% (w:w) lure contained more than 250 moths, apparently because accumulated dead moths repelled live males. PVC lures formulated at 0.0005% (w:w) were judged ineffective because trapping efficiency declined after more than 50 male moths were collected, and trap catch declined significantly after 3 weeks of aging. Therefore, lure strength and cumulative trap catch both affect trapping efficiency, whereby the weaker lures may be more easily overridden by the repellent effect of accumulating dead moths. Sweeney and McLean (1990) report fewer males in a wind tunnel completed upwind flight to 0.5% (w:w) lure than to 0.05% (w:w) lure, thereby supporting evidence for an upper arrestment threshold (Roelofs 1978).

Comments

Sartwell et al. (1985) developed a pheromone monitoring system for *C. occidentalis* using inexpensive sticky traps and PVC lures formulated with a 92:8 blend of (E/Z)-11-tetradecenal at three low concentrations, 0.01, 0.001 and 0.0001%, to prevent trap saturation. Traps baited with the 0.0001% pheromone concentration could be directly related to defoliation, with the r^2 (coefficient of determination) between moth catch and defoliation in the subsequent year ranging from 76-98%.

Sweeney et al. (1990b) recommended using Uni-traps baited with 0.05% lure because they are sensitive at low densities, collect a wider range of moth densities than sticky traps, and may be used for more than one field season. They also stressed considering stand structure when attempting to correlate moth catch and larval density. Significant improvements were made in correlating trap catch with larval density by dividing the mean moth catch in unmaintained Uni-traps by either basal area or foliage biomass.

McLean et al. (1989) reported that *C. occidentalis* males respond to ω-fluorinated (E)-11-tetradecenal, a toxic pheromone analog, in wind-tunnel tests. This study shows that this formulation has considerable biological activity while still being toxic to *C. occidentalis*. Field tests for this pheromone analog will require toxicity testing on non target organisms, because other ω-fluorinated aldehydes are toxic to vertebrates (Pattison 1959).

Oral exudates from *C. occidentalis* and *C. fumiferana* larvae contain epideictic pheromones (Prokopy 1981) and conceivably could be used to induce larval dispersal or to make larvae more vulnerable to conventional insecticides (Poirier and Borden 1995, 1996). Isolation of chemical components inducing dispersal behavior and determination of the role natural foliage plays in this behavior is needed before a management strategy based on their use could be field tested (Poirier and Borden 1995, 1996).

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Choristoneura pinus Freeman (Lepidoptera: Tortricidae)
Jack Pine Budworm

Sex Pheromones

(E/Z)-11-tetradecenyl acetates (Silk et al. 1985)

(E/Z)-11-tetradecenyl alcohols (Silk et al. 1985)

The sex pheromone of *C. pinus* is a blend of (85:15) (E:Z)-11-tetradecenyl acetates (90%) and (85:15) (E:Z)-11-tetradecenyl alcohols (10%), and is as attractive as virgin females in field tests (Silk et al. 1985). Liebhold and Silk (1991) report *C. pinus maritima* males are attracted to the primary pheromone components of *C. pinus pinus*. Additional studies have indicted that the identified pheromone is not as effective as female moths and that it is not sufficiently effective for monitoring purposes (Silk et al. 1986). Work is currently in progress to identify missing pheromone components.

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No baits are commercially available at this time.

Comments

No semiochemical is currently used to manage *C. pinus*.

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Choristoneura rosaceana (Harris) (Lepidoptera: Tortricidae)
Obliquebanded Leafroller

Sex Pheromones

(Z/E)-11-tetradecenyl acetate (Hill and Roelofs 1979)

(Z)-11-tetradecenol (Hill and Roelofs 1979)

(Z)-11-tetradecenal (Vakenti et al. 1988)

The major sex pheromone component of *C. rosaceana* is (Z)-11-tetradecenyl acetate with (E)-11-tetradecenyl acetate and (Z)-11-tetradecenol as minor components (Hill and Roelofs 1979). Vakenti et al. (1988) identified an additional pheromone component, (Z)-tetradecenal, from female tip extracts that was strongly stimulatory in laboratory electroantennogram bioassays. In field tests, baits containing 3mg of 96.5:2:1.5 (Z)-11-teradecen-1-yl acetate, (*E*)-11-tetradecen-1-yl acetate, and (Z)-11-tetradecen-1-ol with 1% (Z)-tetradecenal added were significantly more attractive than traps baited with female *C. rosaceana* (Vakenti et al. 1988). Thomson et al. (1991) conducted field experiments comparing four different blends of four component lures in their ability to attract male *C. rosaceana.* The most attractive blend contained four components: (Z)-11-tetradecenyl acetate, (E)-11-tetradecenyl acetate, (Z)-11-tetradecenal and (Z)-11-tetradecenol in a 100:2:1:0.75 ratio respectively. The authors also reported possible regional differences in pheromone blends between British Columbia and Quebec. This would be an important consideration in blending a successful synthetic lure.

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No baits are commercially available at this time.

Comments

Monitoring *C. rosaceana* population dynamics could be important in estimating the density of the parasitoid *Meterous trachynotus* Vier (Hymenoptera: Braconidae). *M. trachynotus* is a bivoltine parasitoid overwintering in *C. rosaceana* larvae and attacking *C. fumiferana* in the spring. Adequate numbers of *C. rosaceana* must enter diapause either when *M. trachynotus* move from conifers to deciduous vegetation in mid-July (Maltais et al. 1989) or fewer parasitoids survive to attack *C. fumiferana* in spring. In field tests, lures (containing a 6 mg load of (*Z*)-11-tetradecenyl acetate, and (*E*)-11-tetradecenyl acetate (92:8%) in 1987 and containing a 10.5 mg load of (*Z*)-11-tetradecenyl acetate, (*E*)-11-tetradecenyl acetate, and (*Z*)-tetradecenol (92.2:2.9:4.9%) in 1988) was not as effective as *C. rosaceana* virgin females in attracting males to sticky traps (Delisle 1992).

(Z)-11-Tetradecenol is an essential component in making synthetic lures competitive with virgin females in Quebec (Delisle 1992). Delisle (1992) recommended lures baited with 5 mg of (Z)-11-tetradecenyl acetate, (E)-11-tetradecenyl acetate, and (*Z*)-11-tetradecenol in a 96.5:2:1.5 ratio respectively for *C. rosaceana* populations in Quebec.

Poirier and Borden (1991) reported that female *C. rosaceana* avoid oviposition sites near previously laid egg masses. Avoidance of the original site of egg masses continued even when eggs had been removed from that area. They suggest a pheromone is applied with each egg mass thereby reducing intra-specific competition. However, no semiochemical is currently used to manage *C. rosaceana*.

References

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Hyphantria cunea (Drury) (Lepidoptera: Arctiidae)
Fall Webworm

Pheromones

(Z,Z)-9,12-octadecadienal (Hill et al. 1982)

(Z,Z,Z)-9,12,15-octadecatrienal (Hill et al. 1982)

(Z,Z)-3,6-cis-9,10-epoxyheneicosadiene (Hill et al. 1982)

Hill et al. (1982) identified the pheromone blend for the two sympatric types of *H. cunea*. Both black-headed and red-headed types have been documented to share the same pheromone components. Ratios of the three components will differ in *H. cunea* populations in the United States and Russia.

Status	Yes	No
Experimental Quantities Available		√
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No baits are commercially available at this time.

Comments

No semiochemical is currently used to manage *H. cunea*.

References

Hill, A.S., B.G. Kovalev, L.N. Nikolaeva, W.L. Roelofs. 1982. Sex pheromone of the fall webworm moth, *Hyphantria cunea*. *Journal of Chemical Ecology*. 8:383-396.

Lambdina athasaria (Walker) (Lepidoptera: Geometridae)
Spring Hemlock Looper

Sex Pheromones

7-Methylheptadecane (Gries et al. 1994)

7,11-Dimethylheptadecane (Gries et al. 1994)

The major sex pheromone components of *L. athasaria* 7-methylheptadecane and 7,11-dimethylheptadecane were isolated from female pheromone glands and identified by gas chromatographic-electroantennographic detection and coupled gas chromatography/mass spectrometry. Field tests supported the laboratory results. Males were not attracted to sticky traps baited with 5,11-dimethylheptadecane or 7-methylheptadecane (100 μg) alone, but were attracted to a mixture of both compounds (100 μg each) (Gries et al. 1994).

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No baits are commercially available at this time.

Comments

No semiochemical is currently used to manage *L. athasaria.*

References

Gries, R., G. Gries, J. Li, C.T. Maier, C.R. Lemmon, K.N. Slessor. 1994. Sex pheromone components of the spring hemlock looper, *Lambdina athasaria* (Walker) (Lepidoptera: Geometridae). *Journal of Chemical Ecology* 20(10):2501-2511.

Lambdina fiscellaria fiscellaria Guenée (Lepidoptera: Geometridae)
Hemlock Looper

Sex Pheromones

(5*R*,11*S*)-5,11-Dimethylheptadecane (Gries et al. 1991)

2,5-Dimethylheptadecane (Gries et al. 1991)

The major sex pheromone components of *L. fiscellaria fiscellaria,* 5,11-dimethylheptadecane and 2,5-dimethylheptadecane were isolated and identified using flame ionization, electroantennographic detection and gas chromatography/ mass spectroscopy. In the field, males were attracted to sticky traps baited with 5,11-dimethylheptadecane alone (100 μg), and response was enhanced with the addition of 2,5-dimethylheptadecane (Gries et al. 1991). Li et al. (1993) reported that traps baited with (5*R*,11*S*)-5,11-dimethylheptadecane caught as many males as traps baited with all four stereoisomers. Li et al. (1993) concluded that females produce only the (5*R*,11*S*)-5,11-dimethylheptadecane isomer, and that males possess receptors for only that isomer.

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No baits are commercially available at this time.

Comments

West and Bowers (1994) reported that females exhibited a marking behavior by rubbing the terminal abdominal segments against laboratory vials where they were being held and that mated females were more likely to do so. Analysis of the marked substrate could yield compounds in addition to sex pheromones possibly associated with oviposition. Females were also observed calling at temperatures as low as 5 °C, and other abiotic factors such as wind, barometric pressure and rainfall could affect female calling or male response. Knowledge of *L. fiscellaria fiscellaria* behavior could aid in the development of monitoring and pest management strategies. For example, Gries et al. (1991) proposed mating disruption as a control for *L. fiscellaria fiscellaria.*

References

Gries, G., R. Gries, J.H. Borden, J. Li, K.N. Slessor, G.G.S. King, W.W. Bowers, R.J. West, E.W. Underhill. 1991. 5,11-Dimethylheptadecane and 2,5-Dimethylheptadecane: sex pheromone components of the geometrid moth, *Lambdina fiscellaria fiscellaria*. *Naturwissenschaften* 78:315-317.

Li, J., R. Gries, G. Gries, K.N. Slessor, G.G.S. King, W.W. Bowers, R.J. West. 1993. Chirality of 5,11-dimethylheptadecane, the major sex pheromone component of the hemlock looper, *Lambdina fiscellaria*. *Journal of Chemical Ecology* 19(6):1057-1062.

West, R.J., W.W. Bowers. 1994. Factors affecting calling behavior by *Lambdina fiscellaria fiscellaria* (Lepidoptera: Geometridae), under field conditions. *Environmental Entomology* 23(1):122-129.

Lambdina fiscellaria lugubrosa (Hulst) (Lepidoptera: Geometridae)
Western Hemlock Looper

Sex Pheromones

(5*R*, 11*S*)-5,11-Dimethylheptadecane (Gries et al. 1993)

(5*S*)-2,5-Dimethylheptadecane (Gries et al. 1993)

(7*S*)-7-Methylheptadecane (Gries et al. 1993)

The major sex pheromone components of *L. fiscellaria lugubrosa* 5,11-dimethylheptadecane, 2,5-dimethylheptadecane and 7-methylheptadecane were isolated from female pheromone gland extracts using gas chromatographic-electroantennographic analysis and gas chromatography/mass spectroscopy. In the field, males were attracted to sticky traps baited with 5,11-dimethylheptadecane alone (100 μg), and maximum response occurred with the addition of both 2,5-dimethylheptadecane and 7-methylheptadecane (Gries et al. 1993). 7-Methylheptadecane is produced by *L. fiscellaria fiscellaria*, but is not a pheromone component. The two- component lure for *L. fiscellaria fiscellaria* and the three- component lure for *L. fiscellaria lugubrosa* support the taxonomic division of these two subspecies.

Li et al. (1993) found that traps baited with (5*R*,11*S*)-5,11-dimethylheptadecane caught as many males as did traps baited with all four stereoisomers. The chirality of the synergistic sex pheromone components was also reported. (7*S*)-7-Methylheptadecane and (5*S*)-2,5-dimethylheptadecane increased male response to (5*R*, 11*S*)-5,11-dimethylheptadecane in electrophysiological studies or field bioassays, while (7*R*)-7-methylheptadecane and (5*R*)-2,5-dimethylheptadecane did not.

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No baits are commercially available at this time.

Comments

Evenden et al. (1995) examined the predictive capabilities of a pheromone-based monitoring system and determined that male moths are attracted to Unitraps baited with 10 μg of both isomeric 5,11-dimethylheptadecane and 2,5-dimethylheptadecane. Male moth catches correlated with larval and pupal counts within the same generation and predicted egg densities in the following generation. For accurate prediction of *L. fiscellaria lugubrosa* outbreaks pheromone traps could monitor male flight, but an early larval sample would be required before control measures might be implemented. Although the present model may predict subsequent egg populations, it may not be reliable for larval or pupal populations. For example, high mortality from parasitism may affect population dynamics and in turn the predictive capabilities of pheromone traps. No semiochemical is currently used to manage *L. fiscellaria lugubrosa*.

References

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Leucoma salicis Linnaeus (Lepidoptera: Lymantriidae)
Satin Moth

Sex Pheromones

3(*Z*)-*cis*-6,7-*cis*-9,10-di-epoxy-heneicosene (Gries et al. 1997)

The primary sex pheromone component of *L. salicis* was identified as 3(*Z*)-*cis*-6,7-*cis*-9,10-di-epoxy-heneicosene (leucomalure) from female pheromone glands using coupled gas chromatography-electroantennographic detection and gas chromatography-mass spectrometry. The identification of leucomalure was the first discovery of a di-epoxy sex pheromone in the Lepidoptera. In field tests, *L. salicis* males were attracted more to virgin females than to synthetic diastereomer blends of leucomalure (Gries et al. 1997).

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No baits are commercially available at this time.

Comments

The superior attractiveness of *L. salicis* females over leucomalure in field tests may be the result of unidentified and untested pheromone components. No semiochemical is currently used to manage this pest (Gries et al. 1997). This introduced species has the potential to become a serious pest in North America.

References

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Lymantria dispar (Linnaeus) (Lepidoptera: Lymantriidae)
Gypsy Moth

Sex Pheromone

(+)-Disparlure (7R,8S)-*cis*-7,8-epox-2-methyloctadecane (Bierl et al. 1970)

Disparlure was isolated from the last two abdominal segments of female *L. dispar* (Bierl et al. 1970). Disparlure is optically active but only the (+)-enantiomer is attractive. Males are inhibited progressively by increasing levels of the (-)-enantiomer (Plimmer et al. 1977).

Other Compounds

Olefin 2-methyl-*cis*-7-octadecene

The olefin is a biosynthetic precursor of disparlure that elicits variable behavioral responses. It suppresses male response to both females and synthetic pheromone when released from the same source (Cardé et al. 1973, Cardé et al. 1975, Odell et al. 1992). It may also increase male searching (Cardé et al. 1975). The presence of (-)-disparlure with the olefin further increases inhibition of attraction (Grant et al. 1996).

The olefin is a pheromone component of the closely related nun moth, *L. monacha*, where it acts as a synergist to (+)-disparlure, its major attractive pheromone component (Grant et al. 1996, Gries et al. 1996).

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available	√	
Current Operational Uses		
Monitoring	√	
Attack Disruption	√	
Spray Timing		√
Phenologic Models	√	
Trap Out	√	

Commercial Sources

Hercon Environmental Corp., Emigsville, PA—Hercon Disrupt, granulated flakes; Phero Tech, Inc., Delta, BC—*L. dispar* lure

A variety of techniques have been devised for releasing sufficient amounts of pheromone to monitor and to attempt to control outbreaks, including micro-dispensers suitable for aerial application (Schwalbe et al. 1983, Webb et al. 1988). Pherocon 1C sticky traps have been reported to be twice as efficient as USDA milk carton traps (Elkinton and Childs 1983), that decline in efficiency as they fill (Elkinton 1987). Traps stapled to the trunks of trees were more effective than those placed on branches. Beroza et al. (1974) reported that a 3-layer laminated plastic bait dispenser controlled release of pheromone for up to 120 days, allowing for a high release rate and more accurate monitoring of *L. dispar* populations. Schwalbe et al. (1979) reported the most effective formulation in reducing matings during peak male flight to be 1976 2% NCR released at 20 g disparlure/ha. The 1976 2% NCR formulation consisted of an aqueous suspension of plastic-coated, gelatin-walled capsules containing 2% disparlure in a 3:1 xylene: amyl acetate mixture. The capsules measured 50-250 μ diam, and the sticker was 1.1% RA-1645 (Monsanto Plastics and Resins). Leonhardt et al. (1992, 1993) found twine dispensers to be more effective than standard PVC laminates because they prolonged the pheromone release rate ($\geq$30 ng/h pheromone for a mean of 240 hours vs 80 hours for standard PVC laminate dispensers and residual pheromone content $\geq$100 μg after 16 weeks). Twine dispensers also were easier to use.

The effect of temperature on pheromone release rates and male moth catches was evaluated in the laboratory, greenhouse, and field for plastic (PVC) laminate dispensers, hollow fiber dispensers, PVC septum dispensers, and a semipermeable membrane covered, microporous reservoir dispenser. PVC laminate dispensers with 500 μg of (+)-disparlure with an initial release rate of 140-220 ng/h were the most effective dispensers tested and remained highly effective until the release rate dropped to <30 ng/h, with a pheromone content of <100 μg. Pheromone release rates were highly correlated with temperature, suggesting mean expected temperature is an important consideration when designing dispensers for field use (Leonhardt et al. 1990). Nation et al. (1993) found that pheromone lures required more frequent replacement and became less effective more rapidly during spring and early summer in Florida than in other regions of the country. A major challenge still exists to use pheromone traps to help forecast gypsy moth population trends (Grant 1991).

Pheromone-baited milk carton traps were used to assist in the assessment of efficacy of aerial sprays of gypsy moth NPV in Canadian trials by comparing catches between treated and check plots (Cunningham et al. 1997). Catches were lower in treated plots than in checks, but they were not as effective indicators of treatment effects as defoliation estimates and egg mass surveys.

Comments

Pheromone based management strategies for *L. dispar* are directed at mating disruption, mass trapping, survey, and monitoring (Hunter et al. 1993, Douce et al. 1994). Disruption is achieved by permeating the air with sex pheromones which renders males unable to locate females, or by mass trapping of flying males (Stevens and Beroza 1972, Beroza and Knipling 1972). Surveying and monitoring gypsy moth populations are critical steps in choosing appropriate management strategies.

Estimates of population size are generally based on egg mass density, although limited by inaccuracy at low densities and the high cost of sampling procedures (Wilson and Fontaine 1978, Kolodny-Hirsch 1986, Ravlin et al.1987, Liebhold et al. 1991, Carter et al. 1994a, Sharov et al. 1996). A method for evaluating the need to conduct egg mass surveys involves the use of male wing length (Carter et al. 1991), number of moths captured in pheromone traps, and defoliation maps (Carter et al. 1994b). Smaller moths collected in non defoliated areas may indicate the need for egg mass sampling because of migration from nearby populations. This method could be useful provided defoliation of <60% can be tolerated, which occurs frequently at an egg mass density of 2,471 per hectare (Gansner et al. 1985). Moore and Jones (1992) reported a more refined method for predicting population estimates by quantifying field egg hatch. In low density *L. dispar* populations, Carter and Ravlin (1995) report binomial egg mass sampling to be ineffective at predicting population size, even though this method greatly reduced sampling time. Male *L. dispar* mating potential can be successfully estimated with well placed disparlure baited traps. Traps placed next to large trees 1.5 m or less above the ground are reported to be most effective (Granett 1974). Male response to pheromone sources is affected by a variety of factors, including, ambient temperature (Charlton et al. 1993), proportion of females in the trap area (Elkinton and Cardé 1984), aerial density of male moths (Taylor et al. 1991), and pheromone concentration (Charlton et al. 1993).

The relationship between catch of male moths in pheromone baited traps and population density has been studied to calibrate population density estimates as opposed to standard egg-mass surveys. The results suggest that once the relationship between catch and population density estimates (by egg-mass survey) are calibrated for specific geographic areas, low-dose/low release pheromone-traps could be used to monitor gypsy moth population density (Thorpe et al. 1993).

Gage et al. (1990) discussed predicting next year's gypsy moth population densities based on catches in (+)-disparlure baited milk-carton traps. These data were analyzed and incorporated into a Geographic Information System (GIS), where male moth catch was found to be an indicator of defoliation the following year. This model can be used to predict degrees of risk (low, medium or high) in subsequent years. No attempt was made to include mapped forest biological or physiographic data in the model.

Sharov et al. (1995a) presented three methods to estimate boundary limits and geographic distributions of *L. dispar*: best classification (minimizing the number of grid cell misclassifications), first occurrence method, and logistic regression of log population counts versus distance perpendicular to population boundary. The study estimated these boundary limits from moths collected in pheromone baited traps and egg mass counts in Virginia and found the average spread rate from male moth counts to be 10.7-11.9 km/yr. The stability of small, isolated gypsy moth populations can be estimated using male moths captured in pheromone traps and population growth rates (Sharov et al. 1995b). Hohn et al. (1993) and Liebhold et al. (1995a) used a geostatistical model to predict gypsy moth infestations based on autocorrelation of canopy defoliation through space and time as opposed to predictions based on egg masses. While these models are not presently incorporated into management strategies, they offer an alternative approach to monitoring gypsy moth defoliation and ultimately may be able to predict gypsy moth outbreaks more precisely than traditional models.

Liebhold et al. (1995b) found no correlation between male moth catches in pheromone traps and defoliation at a local scale (10-20 km); however, certain trends indicated some association at a regional scale. Trap counts may still be best used to indicate defoliation at the leading edge of infestations. They concluded that egg mass counts or pupal counts under burlap bands are still better than pheromone traps for predicting regional defoliation.

Webb et al. (1990) concluded that, given the high cost of racemic disparlure (which is considerably less expensive that the (+)-enantiomer), its effective use as a mating disruptant was limited to low-level gypsy moth populations (≤15 egg masses per ha). Disruption of male gypsy moth orientation to female moths has potential as a viable management strategy, although the precise mechanism of disruption remains unknown (Kolodny-Hirsch and Webb 1993). One hectare plots treated with 500 g of racemic disparlure reduced pheromone trap catch of males by 95% and female mating success by 84% (Schwalbe and Mastro 1988). Leonhardt et al. (1996) successfully controlled low density *L. dispar* populations by annual aerial application of granulated flakes containing racemic disparlure at a rate of

75 g per hectare. One application of disparlure at 150 g per hectare continued to suppress populations for 3 years. Reardon et al. (1995) reviewed historical and current information on the use of mating disruption to manage gypsy moth.

Doane and Cardé (1973) reported that gypsy moth males may exhibit competitive responses, which can interfere with their searching behavior. For example, males encountering pheromone traps at the same time were reported to touch wing tips and, on most occasions, fly away. Further inquiry into male behavior in the presence of (+)-disparlure would allow for optimal release rates and placement of baits. Males require the presence of sex pheromone and additional tactile stimuli in the form of female abdominal scales to exhibit copulatory behavior (Charlton and Cardé 1989). Communication systems are disrupted with artificial disparlure used in management programs; however, at high densities the probability increases that stimulated males may encounter females.

Mass trapping as a means to control gypsy moth infestations is limited to small populations which are geographically isolated from other infestations. In these small populations, traps placed at high densities are able to catch enough males to contribute to reduced mating success of females.

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Malacosoma americanum (Fabricius) (Lepidoptera: Lasiocampidae)
Eastern Tent Caterpillar

Sex Pheromones

No sex pheromones have been isolated for *M. americanum*. Sample (1992) suggested that the sex pheromone of *M. americanum* may be similar in composition to that of the *Malacosoma* species *M. californicum* and *M. disstria*.

Trail Pheromones

5β-colestane-3,24-dione (Fitzgerald 1976)

5β-colestan-3-one (Fitzgerald 1976)

M. americanum caterpillars feed in groups and leave trail pheromones when exploring previously unvisited branches (Fitzgerald 1976). The pheromones allow the caterpillars to mark acceptable feeding sites for other group members. *M. americanum* caterpillars can distinguish between old and new pheromone trails and trails indicating food concentrations versus the return to the web route (Fitzgerald 1993, Peterson and Fitzgerald 1991, Costa 1997). Synthetic pheromones have been shown to draw caterpillars off natural trails under field conditions (Fitzgerald 1993).

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No baits are commercially available at this time.

Comments

No semiochemical is currently used to manage *M. americanum*.

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Malacosoma californicum (Packard) (Lepidoptera: Lasiocampidae) Western Tent Caterpillar

Sex Pheromones

(*E*)-5,(Z)-7-dodecadienal (Underhill et al. 1980)

The sex pheromone, (*E*)-5,(Z)-7-dodecadienal, has been isolated from female abdominal extracts. It was active in electroantennogram bioassays and attracted males to pheromone baited traps in field tests. Males were responsive to doses of 10 μg (*E*)-5,(Z)-7-dodecadienal, but were unresponsive to its corresponding alcohol 5,7-dodecadien-1-ol (Underhill et al. 1980).

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No baits are commercially available at this time.

Comments

No semiochemical is currently used to manage *M. californicum.*

References

Underhill, E.W., M.D. Chisholm, W. Steck. 1980. (*E*)-5, (*Z*)-7-dodecadienal, a sex pheromone component of the western tent caterpillar, *Malacosoma californicum* (Lepidoptera: Lasiocampidae). *The Canadian Entomologist* 112:629-631.

Malacosoma disstria Hübner (Lepidoptera: Lasiocampidae)
Forest Tent Caterpillar

Sex Pheromones

(Z)-5, (E)-7-dodecadienal (Chisholm et al. 1980)

(Z)-5, (E)-7-dodecadien-1-ol (Chisholm et al. 1980)

Electroantennogram responses to several acetates, aldehydes, and alcohols have been recorded from field collected adult *M. disstria* males. The principal sex pheromone component was identified as (Z)-5, (E)-7-dodecadienal using gas chromatography, mass spectrometry. The alcohol, (Z)-5, (E)-7-dodecadien-1-ol was identified as a secondary component. Males were most responsive to pheromone traps baited with the primary sex pheromone and the alcohol at ratios between 1:10 and 1:3 (Chisholm et al. 1980).

Trail Pheromones

5β-cholestan-3one (Fitzgerald and Webster 1993)

5β-Cholestan-3one has been isolated from abdominal extracts of fourth instar *M. disstria* larvae. Behavioral assays with synthetic pheromones showed 5β-cholestan-3one to be the primary trail pheromone for *M. disstria* and to be competitive with natural trails. Caterpillars were sensitive to pheromone concentration, preferring new trails to old ones. *M. disstria* responded to the trail pheromone of *M. americanum*, 5β-cholestan-3,24-dione, even though the compound was not present in *M. disstria* abdominal extracts (Fitzgerald and Webster 1993).

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No baits are commercially available at this time.

Comments

The use of sex pheromones in conjunction with biocontrol efforts offers some promise to control *M. disstria* (Smith and Strom 1993). Pheromone traps have been used to predict oviposition times of females through male moth catch, with three component lures (Chisholm et al. 1986) being more effective. Smith and Strom (1993) suggested incorporating sampling of late instars or pupae to more accurately predict optimal time for release of parasitoids such as *Trichogramma* spp.

Chisholm et al. (1986) tested mating disruption to control outbreaks of *M. disstria* using 5Z, 7*E*-dodecadienal, 5Z, 7Z-dodecadienal and 7Z-dodecenal. Baits emitting 5Z, 7*E*-dodecadienal (1 μg per hour), 5Z, 7Z-dodecadienal (0.1 μg per hour), and 7Z-dodecenal (0.1 μg per hour) can reduce male moth catch by about 50%. The authors recommend bait density to be at least 10 per 100 m^2 but preferably 20-50 per 100 m^2.

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Nepytia freemani Munroe (Lepidoptera: Geometridae)
Western False Hemlock Looper

Sex Pheromones

3*S*,13*R*-Dimethylheptadecane (Gries et al. 1993)

The major sex pheromone component of *N. freemani*, 3,13-dimethylheptadecane was isolated from female pheromone glands using coupled gas chromatographic-electroantennographic detection (EAD) and coupled gas chromatography and mass spectroscopy. In field tests, males were strongly attracted to sticky traps baited with 3,13-dimethylheptadecane (100 μg). Twelve other gland extracts were EAD-active and require structural elucidation, determination of their chirality if optically active, and field testing to determine the optimal pheromone blend of *N. freemani* (Gries et al. 1993).

King et al. (1995) examined the biological activity of the optical isomers of 3,13-dimethylheptadecane. They reported the major pheromone component in laboratory and field tests to be 3*S*,13*R*-dimethylheptadecane. The other stereoisomers 3*R*,13*R*-, 3*R*,13*S*-, and 3*S*,13*S*-dimethylheptadecane acted as synergists when added to the primary component and different combinations of isomers were equally attractive. This is the first time substitutionality of pheromone components has been reported. Current analytical techniques do allow for separation of optical isomers of (di)methylhydrocarbons, therefore it remains unknown whether females produce a four-component pheromone.

Status	Yes	No
Experimental Quantities Available		√
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No baits are commercially available at this time.

Comments

Gries et al. (1993) recommended the use of 3,13-dimethylheptadecane as a trap bait to monitor *N. freemani* populations.

References

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Orgyia pseudotsugata (McDunnough) (Lepidoptera: Lymantriidae) Douglas-fir Tussock Moth

Sex Pheromones

(Z)-6-heneicosen-11-one (Smith et al. 1975)

(E)-6-heneicosen-11-one (Smith et al. 1975)

(Z)6,(*E*)8-heneicosadien-11-one (Gries et al. 1997)

Smith et al. (1975) found that male *O. pseudotsugata* responded to both Z and E isomers of 6-heneicosen-11-one, although males were more strongly attracted to the synthetic Z isomer in laboratory tests. An additional pheromone component, (Z)6,(*E*)8-heneicosadien-11-one, was isolated from female pheromone gland extracts in subnanogram quantities and significantly increased trap catches when added to one of the original attractive compounds, (Z)-6-heneicosen-11-one (Gries et al. 1997).

Other Compounds

(Z)-6-heneicosen-11-ol has been shown to have a slightly inhibitory effect on pheromone response (Daterman et al. 1976).

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available	√	
Current Operational Uses		
Monitoring	√	
Attack Disruption	√	
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

Orsynex, Inc., Clifton, NJ—(*Z*)-6-heneicosen-ll-one

Comments

Shepherd et al. (1985a) found little correlation between pheromone trap catches or egg mass densities and defoliation in subsequent years. However, threshold density of 25 moths per trap or continuous increases in moth catches over 2 or 3 years indicates an impending *O. pseudotsugata* outbreak (Daterman et al. 1979, Shepherd et al. 1985b, Ravlin 1991). When high egg mass densities are likely, more intensive sampling can be conducted to quantify the populations (Shepherd et al. 1985a). Sower and Daterman (1977) reported that males were more responsive to traps baited with live females than to those baited with synthetic pheromone, and more males were caught as trap height increased above 1.5 m up to 18.3 m.

Control of *O. pseudotsugata* has been demonstrated by pheromone disruption by saturating infested areas with synthetic pheromone, thereby inhibiting the ability of males to locate suitable females. Aerial application of pheromone releasers has substantially reduced damage, even at high densities (Sower et al. 1983). Using this method, egg masses were reduced by 71% in plots treated with 8 g of pheromone per hectare and by 81% in plots treated with 25 g, compared with untreated plots. In a later study, Sower et al. (1990) found that pheromone-treated (by aerial application of pheromone-filled hollow fibers) plots at 25 g/hectare reduced the population level of the next generation by 74% for egg masses and 68% for larvae relative to untreated plots. Hulme and Gray (1994) reported that aerial or ground application of 72 g/hectare of (Z)-6-heneicosen-11-one saturated PVC beads prevented *O. pseudotsugata* males from finding and mating with females under experimental conditions. This experiment showed that application could be done with standard ground spray equipment.

Gries et al. (1997) reported (*Z*)6,(*E*)8-heneicosadien-11-one to be synergistic with (Z)-6-heneicosen-11-one in field tests. Commercial lures with both components may be more species specific than (Z)-6-heneicosen-11-one alone and provide a more effective tool for monitoring and mating disruption.

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Paleacrita vernata (Peck) (Lepidoptera: Geometridae)
Spring Cankerworm

Sex Pheromones

3(Z),6(Z),9(Z)-Nonadecatriene (Millar et al. 1990)

3(Z),6(Z),9(Z)-Eicosatriene (Millar et al. 1990)

6(Z),9(Z)-Nonadecadiene (Tentatively) (Millar et al. 1990)

Two sex pheromone components of *P. vernata* 3(Z),6(Z),9(Z)-nonadecatriene and 3(Z),6(Z),9(Z)-eicosatriene and a possible third, 6(Z),9(Z)-nonadecadiene, were identified from female abdominal tip extracts using gas chromatography, electroantennography, mass spectrometry, chemical tests, and comparison with standards. In field tests, males were attracted to sticky traps baited with an 8:2:1 ratio of 3(Z),6(Z),9(Z)-eicosatriene, 3(Z),6(Z),9(Z)-nonadecatriene and 6(Z),9(Z)-nonadecadiene. A two component lure in an 8:1 ratio of 3(Z),6(Z),9(Z)-eicosatriene to 3(Z),6(Z),9(Z)-nonadecatriene was as attractive as the three component lure. The interactions among the three compounds identified are not clear (Millar et al. 1990).

Status	Yes	No
Experimental Quantities Available		√
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No baits are commercially available at this time.

Comments

Results of trap comparison studies show sticky traps to be more effective than Hara cone traps. Because the Hara traps are reusable, further studies using pesticide strips to knock down captured males is desirable. The addition of 6Z,9Z-*cis*-3,4-epoxy-nonadecadiene, a pheromone component of some sympatric species, to synthetic lures inhibited male *P. vernata* response (Millar et al. 1990). No semiochemical is currently used to manage *P. vernata*.

References

Millar, J.G., M. Giblin, D. Barton, D.A. Reynard, G.B. Neill, E.W. Underhill. 1990. Identification and field testing of female-produced sex pheromone components of the spring cankerworm, *Paleacrita vernata* Peck (Lepidoptera: Geometridae). *Journal of Chemical Ecology* 16(12):3393-3409.

Semiothisa sexmaculata (Packard) (Lepidoptera: Geometridae)
A Looper

Sex Pheromones

(6Z,9Z-3*R*,4*S*)-epoxy-heptadecadiene (Gries et al. 1993)

The sex pheromone component of *S. sexmaculata*, (6Z,9Z)-*cis*-3,4-epoxy-heptadecadiene, was identified from female gland extracts using gas chromatographic (GC)-electroantennographic analysis, and GC-mass spectrometry. In field tests, males were attracted to traps baited with enantiomerically enriched 6Z,9Z-3*R*,4*S*-epoxy-heptadecadiene. Blends of (6Z,9Z)-*cis*-3,4-epoxy-heptadecadiene and (3Z,6Z,9Z)-heptadecatriene, a compound found in female gland extracts that elicited male electroantennogram activity, inhibited response of *S. sexmaculata* but strongly attracted a sympatric species *S. marmorata* (Gries et al. 1993).

Status	Yes	No
Experimental Quantities Available		√
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No baits are commercially available at this time.

Comments

Enantiomerically enriched 6Z,9Z-3*R*,4*S*-epoxy-heptadecadiene can be used in pheromone traps to monitor populations of *S. sexmaculata* (Gries et al. 1993).

References

Gries, G., R. Gries, E.W. Underhill, L. Humble. 1993. (6Z,9Z-3*R*,4*S*)-Epoxy-heptadecadiene: major sex pheromone component of the larch looper, *Semiothisa sexmaculata* (Packard) (Lepidoptera: Geometridae). *Journal of Chemical Ecology* 19(4):843-850.

Zeiraphera canadensis Mutuura & Freeman (Lepidoptera: Tortricidae)
Spruce Bud Moth

Sex Pheromones

(*E*)-9-tetradecenyl acetate (Silk et al. 1989)

Silk et al. (1989) isolated the sex pheromone, (*E*)-9-tetradecenyl acetate, from abdominal extracts of *Z. canadensis* females using gas chromatography (GC) and GC-mass spectrometry. Electro-antennogram bioassays and field tests confirm (*E*)-9-tetradecenyl acetate to be the primary sex pheromone of *Z. canadensis*.

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No baits are commercially available at this time.

Comments

Pheromone traps baited with (*E*)-9-tetradecenyl acetate were attractive to *Z. canadensis* males in field tests, and addition of 10% (Z)-9-tetradecenyl acetate or 10% (*Z*)-9-tetradecenol to 1 μg of the primary sex pheromone did not significantly affect trap catches ($P > 0.05$). Silk et al. (1989) concluded that lures containing between 1 and 100 μg of (E)-9-tetradecenyl acetate effectively trap *Z. canadensis*, although no dose-response relationship could be identified.

Two sympatric species, *Z. canadensis* and *Z. unfortunana*, are both attracted to pheromone traps baited with a blend of their respective primary sex pheromones (E)-9-tetradecenyl acetate and (E)-9-dodecenyl acetate (Silk et al. 1988, 1989). While Silk et al. (1989) reported traces of (E)-9-dodecenyl acetate isolated from pheromone gland extracts of *Z. canadensis*, its biological function is unknown. No semiochemical is currently used to manage *Z. canadensis*.

References

Silk, P.J., E.W. Butterworth, L.P.S. Kuenen, C.J. Northcott, E. Dunkelblum, E.G. Kettela. 1989. Identification of sex pheromone component of spruce budmoth *Zeiraphera canadensis*. *Journal of Chemical Ecology*. 15(10):2435-2444.

Silk, P.J., E.W. Butterworth, L.P.S. Kuenen, C.J. Northcott, E.G. Kettela. 1988. Sex pheromone of purplestriped shootworm *Zeiraphera unfortunana* Powell. *Journal of Chemical Ecology*. 14(5):1417-1425.

Zeiraphera unfortunana Powell (Lepidoptera: Tortricidae)
Purplestriped Shootworm

Sex Pheromones

(*E*)-9-dodecenyl acetate (Silk et al. 1988)

Silk et al. (1988) isolated the sex pheromone, (*E*)-9-dodecenyl acetate, from pheromone glands of *Z. unfortunana* females using gas chromatography (GC) and GC-mass spectrometry. Electroantennogram bioassays and field tests confirm (*E*)-9-dodecenyl acetate to be the primary sex pheromone of *Z. unfortunana*.

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No baits are commercially available at this time.

Comments

Pheromone traps baited with (*E*)-9-dodecenyl acetate were attractive to *Z. unfortunana* males in field tests, and addition of 10% (*Z*)-9-dodecenyl acetate to the primary sex pheromone did not affect mean trap catches. Silk et al. (1988) concluded from this study that lures containing between 1 and 10 μg of (*E*)-9-dodecenyl acetate effectively trap *Z. unfortunana* with dosage concentrations of 1-3 μg obtaining the best response.

Two sympatric species of *Zeiraphera*, *Z. canadensis* and *Z. unfortunana*, are both attracted to the same pheromone traps baited with a blend of their respective primary sex pheromones (E)-9-tetradecenyl acetate and (E)-9-dodecenyl acetate (Silk et al. 1988, 1989). However, no semiochemical is currently used to manage *Z. unfortunana*.

References

Silk, P.J., E.W. Butterworth, L.P.S. Kuenen, C.J. Northcott, E. Dunkelblum, E.G. Kettela. 1989. Identification of sex pheromone component of spruce budmoth *Zeraphera canadensis*. *Journal of Chemical Ecology*. 15(10):2435-2444.

Silk, P.J., E.W. Butterworth, L.P.S. Kuenen, C.J. Northcott, E.G. Kettela. 1988. Sex pheromone of purplestriped shootworm *Zeiaraphera unfortunana* powell. *Journal of Chemical Ecology*. 14(5):1417-1425.

Diprion similis (Hartig) (Hymenoptera: Diprionidae)
Introduced Pine Sawfly

Sex Pheromones

3,7-Dimethylpentadecan-2-ol propionate (Jewett et al. 1976)

Jewett et al. (1976) isolated the sex pheromone components of various diprionid sawflies and found them to be either the acetate or propionate esters of 3,7-dimethylpentadecan-2-ol (diprionol). In laboratory electroantennogram bioassays and field tests, *D. similis* males responded to the propionate form of diprionol. Kikukawa et al. (1982) reported that *D. similis* males were most strongly attracted to the chiral arrangement 2*S*,3*R*,7*R* of diprionol in field tests.

Status	Yes	No
Experimental Quantities Available		√
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No baits are commercially available at this time.

Comments

Pheromone traps for *D. similis* have been used successfully to delineate known infestations or detect new infestations (Thomas et al. 1982).

References

Jewett, D.M., F. Matsumura, H.C. Coppel. 1976. Sex pheromone specificity in the pine sawflies: interchange of acid moieties in an ester. *Science* 192:51-53.

Kikukawa, T., F. Matsumura, M.E. Kraemer, H.C. Coppel, A. Tai. 1982. Field attractiveness of chirally defined synthetic attractants to males of *Diprion similis* and *Gilpinia frutetorum*. *Journal of Chemical Ecology* 8(3):301-314.

Thomas, H.A., J.H. Ghent, C.G. Stone. 1982. Use of pheromone traps as a new technique in a large-scale survey of the introduced pine sawfly. *Bulletin of the Entomological Society of America* 28:303-304.

Neodiprion lecontei (Fitch) (Hymenoptera: Diprionidae)
Red-Headed Pine Sawfly

Sex Pheromones

3,7-Dimethylpentadecan-2-yl acetate (Jewett et al. 1976)

Jewett et al. (1976) isolated the acetate of 3,7-dimethylpentadecan-2-ol (diprionol) from *N. lecontei* and found it attractive to males in the field. In additional field tests, *N. lecontei* males were attracted to the acetate form of 2*S*,3*S*,7*S*-dimethylpentadecan-2-ol, and males were inhibited by the addition of the 2*S*,3*R*,7(*R*/*S*) acetate isomer. Traps baited with 15-30 μg of synthetic pheromone remained attractive for at least 6 weeks, although traps attracted the most males during the first week (Kraemer et al. 1981).

Status	Yes	No
Experimental Quantities Available		√
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No baits are commercially available at this time.

Comments

No semiochemical strategy is currently used to manage *N. lecontei*.

References

Jewett, D.M., F. Matsumura, H.C. Coppel. 1976. Sex pheromone specificity in the pine sawflies: interchange of acid moieties in an ester. *Science* 192:51-53.

Kraemer, M.E., H.C. Coppel, F. Matsumura, R.C. Wilkinson, T. Kikukawa. 1981. Field and electroantennogram responses of the red-headed pine sawfly, *Neodiprion lecontei* (Fitch), to optical isomers of sawfly sex pheromones. *Journal of Chemical Ecology* 7(6):1063-1072.

Neodiprion pratti banksianae Rohwer (Hymenoptera: Diprionidae)
Jack Pine Sawfly

Sex Pheromones

3,7-Dimethylpentadecan-2-ol acetate (Jewett et al. 1976)

Jewett et al. (1976) isolated the sex pheromone component of various diprionid sawflies to be either the acetate or propionate esters of 3,7-dimethylpentadecan-2-ol (diprionol). In field tests, *N. p. banksianae* males were attracted to the acetate form of 2*S*,3*S*,7*S*-dimethylpentadecan-2-ol, and attraction was improved with the addition of 2*S*,3*R*,7*R* acetate isomer in small proportions (6-20%). When the 2*S*,3*R*,7*R* acetate isomer exceeded 20% of the mixture, males were inhibited (Olaifa et al. 1984). The authors concluded that *N. p. banksianae* males use a mixture of two isomers 2*S*,3*S*,7*S* and 2*S*,3*S*,7*R*-dimethylpentadecan-2-yl acetate, and the most attractive combination in field tests was a 5:1 isomer ratio of 2*S*,3*S*,7*S* and 2*S*,3*S*,7*R*. They suggested that the second isomer (2*S*,3*R*,7*R* acetate) in low quantities may ensure mating isolation of *N. p. banksianae* from sympatric species.

Status	Yes	No
Experimental Quantities Available		√
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No baits are commercially available at this time.

Comments

No semiochemical is currently used to manage *N. p. banksianae*.

References

Jewett, D.M., F. Matsumura, H.C. Coppel. 1976. Sex pheromone specificity in the pine sawflies: interchange of acid moieties in an ester. *Science* 192:51-53.

Olaifa, J., T. Kikukawa, F. Matsumura, H.C. Coppel. 1984. Response of male jack pine sawfly, *Neodiprion pratti banksianae* (Hymenoptera: Diprionidae), to mixtures of optical isomers of the sex pheromone, 3,7-dimethylpentadecan-2-ol. *Environmental Entomology* 13:1274-1277.

Neodiprion sertifer (Geoffroy) (Hymenoptera: Diprionidae)
European Pine Sawfly

Sex Pheromones

3,7-Dimethylpentadecan-2-yl acetate (Jewett et al. 1976)

Jewett et al. (1976) isolated the acetate of 3,7-dimethylpentadecan-2-ol (diprionol) from *N. sertifer* and found it attractive to males in the field. In other field tests of optically active isomers, males were most strongly attracted to traps baited with the acetate of 2*S*,3*S*,7*S*-diprionol. The addition of small amounts of the acetate of 2*S*,3*R*,7*R*-diprionol enhanced trap catch, leading the authors to conclude that the *N. sertifer* sex pheromone contains both isomers (Kikukawa et al. 1983) Kraemer et al. (1983) reported similar results from field tests. Olaifa et al. (1987) found that males were attractive to a 5:0.003 mixture of (2*S*,3*S*,7*S*)-3,7-dimethylpentadecan-2-yl acetate (2*S*,3*S*,7*S*-A) and (2*S*,3*R*,7*R*-A or 2*S*,3*R*,7*R*/*S*-A. Contrary to North American results, field tests in Europe show an inhibitory effect with the addition of the 2*S*,3*R*,7*R*-A isomer to 2*S*,3*S*,7*S*-A (Anderbrant et al. 1992).

Status	Yes	No
Experimental Quantities Available		√
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No baits are commercially available at this time.

Comments

The basis for monitoring *N. sertifer* populations using pheromone traps exists although no program is currently operational. Studies have been conducted to examine the efficacy of pheromone traps under different environmental conditions. Weather factors, especially temperature, affect trap catch and ultimately population estimates. For instance, the threshold for *N. sertifer* flight has been reported to be above 11 °C, and increased wind velocity—to a point—has a positive effect on trap catch (Jönsson and Anderbrant 1993). In Central European field tests, more males were collected in sticky traps placed at 9.0-12.5 m into the crown than those placed at 2.5 to 0.5 m above the ground (Simandl and Anderbrant 1995).

Mating disruption of Swedish *N. sertifer* populations has been attempted. Males in pheromone baited traps were reduced by 95 to 100% in pine plantations in which (2*S*, 3*S*, 7*S*)-diprionyl acetate was released. These data support mating disruption as a potential control measure for *N. sertifer*, although its effects on population density were not examined because the population crashed (Anderbrant et al. 1995).

References

Anderbrant, O., J. Löfqvist, H.-E. Högberg, E. Hedenström. 1995. Development of mating disruption for control of pine sawfly populations. *Entomologia Experimentalis et Applicata* 74:83-90.

Anderbrant, O., J. Löfqvist, H.-E. Högberg, E. Hedenström, A.-B. Wassgren, G. Bergström, M. Bengtsson, G. Magnusson. 1992. Field response of the pine sawfly *Neodiprion sertifer* to the pheromone (2*S*,3*S*,7*S*)-diprionyl acetate and its stereoisomers. *Entomologia Experimentalis et Applicata* 62:169-181.

Jewett, D.M., F. Matsumura, H.C. Coppel. 1976. Sex pheromone specificity in the pine sawflies: interchange of acid moieties in an ester. *Science* 192:51-53.

Jönsson, P., O. Anderbrant. 1993. Weather factors influencing catch of *Neodiprion sertifer* (Hymenoptera: Diprionidae) in pheromone traps. *Environmental Entomology* 22(2):445-452.

Kikukawa, T., F. Matsumura, J. Olaifa, M.E. Kraemer, H.C. Coppel, A. Tai. 1983. Field evaluation of chiral isomers of the sex pheromone of the European pine sawfly, *Neodiprion sertifer*. *Journal of Chemical Ecology* 9(6):673-693.

Kraemer, M.E., H.C. Coppel, T. Kikukawa, F. Matsumura, H.A. Thomas, L.C. Thompson, K. Mori. 1983. Field and electroantennogram response to sex pheromone optical isomers by four fall-flying sawfly species (Hymenoptera: Diprionidae, *Neodiprion*). *Environmental Entomology* 12:1592-1596.

Olaifa, J., F. Matsumura, H.C. Coppel. 1987. Field response and gas-liquid chromatograph separation of optically active synthetic and natural pheromones in two sympatric diprionid sawflies, *Neodiprion nanulus nanulus* and *Neodiprion sertifer* (Hymenoptera: Diprionidae). *Journal of Chemical Ecology* 13(6):1395-1408.

Simandl, J., O. Anderbrant. 1995. Spatial distribution of flying *Neodiprion sertifer* (Hymenoptera, Diprionidae) males in a mature *Pinus sylvestris* stand as determined by pheromone trap catch. *Scandinavian Journal of Forest Research* 10:51-55.

REPRODUCTION PESTS

Hylobius pales (Herbst) (Coleoptera: Curculionidae)
Pales Weevil

Pheromones

No sex pheromone has been isolated for *H. pales*. Evidence for an apparent aphrodisiac pheromone, which induces male reproductive behavior, was reported by Schiffhauer (1983).

Host Compounds

Turpentine and ethanol are recognized as important cues in host location in a variety of pests infesting pines (Moeck 1970, Raffa and Hunt 1988). Pitfall traps baited with turpentine and ethanol have been effectively used in a monitoring program for *H. pales*. Higher levels of ethanol in lure mixtures were most effective (Rieske and Raffa 1991).

Kairomones

Phillips (1991) reported *H. pales* attraction to pine bolts infested with *Ips calligraphus* Germar and to synthetic *Dendroctonus* pheromones, frontalin and *exo*-brevicomin. Phillips (1991) postulates that *H. pales* exploits chemical signals from other species for recognition and host location.

Status	Yes	No
Experimental Quantities Available		√
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No baits are commercially available at this time.

Comments

No semiochemical is currently in use to manage *H. pales*.

References

Moeck, H.A. 1970. Ethanol as the primary attractant for the ambrosia beetle *Trypodendron lineatum* (Coleoptera: Scolytidae). *The Canadian Entomologist* 102:985-995.

Phillips, T.W. 1991. Attraction of *Hylobius pales* (Herbst) (Coleoptera: Curculionidae) to pheromones of bark beetles (Coleoptera: Scolytidae). *The Canadian Entomologist* 122:423-427.

Raffa, K.F., D.W.A. Hunt. 1988. Use of baited pitfall traps for monitoring pales weevil, *Hylobius pales* (Coleoptera: Curculionidae). *The Great Lakes Entomologist* 21:123-125.

Rieske, L.K., K.F. Raffa. 1991. Effects of varying ethanol and turpentine levels on attraction of two pine root weevil species, *Hylobius pales* and *Pachylobius picivorus* (Coleoptera: Curculionidae). *Environmental Entomology* 20(1):48-52.

Schiffhauer, D.E. 1983. Preliminary investigation of chemical communication in the pales weevil, *Hylobius pales* (Herbst). *M.S. thesis, University of Georgia;* 36 p.

Pachylobius picivorus (Germar) (Coleoptera: Curculionidae)
Pitch-eating Weevil

Pheromones

No pheromones have been isolated from *P. picivorus*.

Host Compounds

Phillips et al. (1988) reported *P. picivorus* attraction to sticky traps baited with turpentine. The addition of ethanol to trap baits did not enhance attraction.

Status	Yes	No
Experimental Quantities Available		√
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No baits are commercially available at this time.

Comments

No semiochemical is currently used to manage *P. picivorus*.

References

Phillips, T.W., A.J. Wilkening, T.H. Atkinson, J.L. Nation, R.C. Wilkinson, J.L. Foltz. 1988. Synergism of turpentine and ethanol as attractants for certain pine-infesting beetles. *Environmental Entomology* 17:456-462.

Matsucoccus resinosae Bean & Godwin (Homoptera: Margarodidae)
Red Pine Scale

Sex Pheromones

(2*E*,4*E*)-4,6,10,12-tetramethyl-2,4-tridecadien-7-one (Parks et al. 1986)

Males were attracted to crude hexane extracts from *M. resinosae* females in laboratory bioassays, and an apparent sex pheromone was isolated by Parks et al. (1986). The sex pheromone component of *M. resinosae*, (2*E*,4*E*)-4,6,10,12-tetramethyl-2,4-tridecadien-7-one, was identified from female extracts. The structure of the pheromone was identified from mass spectra and NMR spectra, and supported by synthesis of analogs **3**, (2*E*,4*E*)-4,6,11,12-tetramethyl-2,4-tridecadien-7-one, and **4**, (2*E*,4*Z*)-4,6,11,12-tetramethyl-2,4-tridecadien-7-one. In laboratory bioassays, males exhibited copulatory behavior when presented with dummy females treated with analog **3**, but were inhibited by those treated with analog **4** (Lanier et al. 1989).

Other Compounds

Males exposed to dodecanol, isolated from aeration solvent extracts of *M. resinosae* females, exhibited a wing-raising response, but the biological role of this behavior is unknown. It has been postulated that dodecanol could be released by mated females to inhibit copulatory behavior (Lanier et al. 1989).

Status	Yes	No
Experimental Quantities Available		√
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No baits are commercially available at this time.

Comments

No semiochemical is currently used to manage *M. resinosae*.

References

Lanier, G.N., Y.T. Qi, J.R. West, S.C. Park, F.X. Webster, R.M. Silverstein. 1989. Identification of the sex pheromone of three *Matsucoccus* pine bast scales. *Journal of Chemical Ecology* 15(5):1645-1659.

Park, S.C., J.R. West, L.P. Abrahamson, G.N. Lanier, R.M. Silverstein. 1986. Cross-attraction between two species of *Matsucoccus*, extraction, bioassay, and isolation of the sex pheromone. *Journal of Chemical Ecology* 12(3):609-617.

Pissodes strobi (Peck) (Coleoptera: Curculionidae)
White Pine Weevil

Pheromones

Grandisol *cis*-2-isopropenyl-1-methylcyclobutane-ethanol (Booth et al. 1983)

Grandisal *cis*-2-isopropenyl-1-methylcyclobutane-ethanal (Booth et al. 1983)

Both grandisol and grandisal have been isolated from *P. strobi* males but showed limited field activity. *P. strobi* showed little response in field studies, and there is no evidence that grandisol or grandisal acts as an aggregation pheromone (Phillips and Lanier 1986). Electroantennogram studies indicate that *P. strobi* males have receptors for those chemicals (Hibbard and Webster 1993).

Host Compounds

Carlson et al. (1971) found that *P. strobi* responded positively to limonene and negatively to α-pinene and myrcene in laboratory bioassays. No field studies have tested the attractiveness of *P. strobi* to limonene in the field.

Status	Yes	No
Experimental Quantities Available		√
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No baits are commercially available at this time.

Comments

No semiochemical is currently used to manage *P. strobi*.

References

Booth, D.C., T.W. Phillips, A. Claesson, R.M. Silverstein, G.N. Lanier, J.R. West. 1983. Aggregation pheromone components of two species of *Pissodes* weevils (Coleoptera: Curculionidae): Isolation, identification, and field activity. *Journal of Chemical Ecology* 9:1-12.

Carlson, R.L. 1971. Behavior of the sitka spruce weevil, *Pissodes stichensis* Hopkins (Coleoptera: Curculionidae), in Southern Washington. *Ph.D. Dissertation, University of Washington, Seattle, WA.*

Hibbard, B.E., F.X. Webster. 1993. Enantiomeric composition of grandisol and grandisal produced by *Pissodes strobi* and *P. nemorensis* and their electroantennogram response to pure enantiomers. *Journal of Chemical Ecology* 19(10):2129-2141.

Phillips, T.W., G.N. Lanier. 1986. Interspecific activity of semiochemicals among sibling species of *Pissodes* (Coleoptera: Curculionidae). *Journal of Chemical Ecology* 12:1587-1601.

Eucosma gloriola Heinrich (Lepidoptera: Tortricidae)
Eastern Pine Shoot Borer

Sex Pheromones

(*E*)-9-dodecenyl acetate (Grant et al. 1985)

(Z)-9-dodecenyl acetate (Grant et al. 1985)

Possible sex pheromone attractants of *E. gloriola* were field tested based on pheromone identification from an another *Eucosma* species, *E. sonomana*. *E. gloriola* males were most attracted to a mixture of (*Z*) and (*E*)-9-dodecenyl acetate in an optimal ratio between 9:1 and 8:2 (Grant et al. 1985).

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No baits are commercially available at this time.

Comments

No semiochemical is currently used to manage *E. gloriola*.

References

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Eucosma sonomana Kearfott (Lepidoptera: Tortricidae)
Western Pine Shoot Borer

Sex Pheromones

(*Z*)-9-dodecenyl acetate (Sower et al. 1979)

(*E*)-9-dodecenyl acetate (Sower et al. 1979)

E. sonomana females produce a sex pheromone blend of (*Z*)-9-dodecenyl acetate and (*E*)-9-dodecenyl acetate in a 3:1 ratio. Males are attracted to *Z:E* isomer blends ranging from 1:1 to 19:1 (Sower et al. 1979).

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available	√	
Current Operational Uses		
Monitoring		√
Attack Disruption	√	
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

Hercon Environmental Corp., Emigsville, PA—*E. sonomana* lure and disruptant, Hercon flakes, Disrupt; IPM Technologies, Portland, OR—*E. sonomana* lure.

Comments

Mating disruption using a 4:1 blend of (*Z*)-9-dodecenyl acetate and (*E*)-9-dodecenyl acetate has reduced *E. sonomana* infestations by 60 to 85% in ponderosa pine plantations (Overhulser et al. 1980, Sartwell et al. 1980, Sower et al. 1982). Williams et al. (1989) aerially treated pine plantations with dodecenyl acetate to reduce *E. sonomana* infestations. Taller trees were attacked more often than shorter trees in the same stand, and treated trees were associated with 66 to 85% fewer terminal shoot infestations. Yield simulation models predicted the impact of shoot-borer damage on different stands. From these models, Williams et al. (1989) concluded that a single treatment applied to the youngest stands was more cost effective than multiple treatments applied to older stands. Application of pheromone to larger areas is recommended to reduce per acre aerial application cost and provide an increased edge to center distance, thereby reducing reinfestations (Williams et al. 1989). Dewey et al.

(1985) showed that terminal infestations by *E. sonomana* were reduced from 50.9 to 1.6% after 2 years of treatment with synthetic pheromone in a ponderosa pine plantation. Sower and Mitchell (1994) report mating disruption in lodgepole pine stands was not effective enough to show a measurable increase in tree growth after 5 years of examination. They concluded that mating disruption did not sufficiently increase the vertical growth in lodgepole pines under the conditions of their study to justify treatment. However, treating larger areas to isolate plots from adjacent shoot borer habitat could make mating disruption more effective (Daterman 1990).

Daterman (1990) recommended Hercon Luretape (HLT) dispensers for aerial application over the use of pheromone formulated in polyvinylchloride (PVC) until protection against photodegradation can be provided.

References

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Rhyacionia buoliana Denis and Schiffermüller (Lepidoptera: Tortricidae) European Pine Shoot Moth

Sex Pheromones

(*E*)-9-dodecenyl acetate (Smith et al. 1974)

(*E*)-9-dodecenol (Gray et al. 1984)

Daterman (1972) bioassayed *R. buoliana* female sex pheromone by examining male responses in an air flow chamber. Males required a pheromone equivalent to 0.005-0.01 females to induce a direct response; response declined after repeated exposure. Daterman concluded that visual cues must be important in short-range mate location in combination with long-range chemical cues. Smith et al. (1974) identified the primary sex pheromone of *R. buoliana* to be (*E*)-9-dodecenyl acetate in laboratory and field tests. The pheromone mixture contains 1.1% of the *Z* isomer, and when increased to 3% of the mixture, it is inhibitory. Gray et al. (1984) isolated and identified (*E*)-9-dodecenol as an additional pheromone component and recommend a PVC lure (2.5 × 3 mm diameter rods) impregnated with (*E*)-9-dodecenyl acetate and (*E*)-9-dodecenol in a 97:3 ratio for optimum trapping of *R. buoliana* males.

Other compounds

Gray et al. (1984) reported that extracts from *R. buoliana* females contained (*E*)-9-dodecenyl acetate, (*E*)-9-dodecenol, dodecyl acetate, and dodecanol. The alcohol, (*E*)-9-dodecenol, enhanced attraction of males to traps when added to synthetic lures. Dodecanol acted as an inhibitor in field tests, when dodecyl acetate was absent from the lures.

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available	√	
Current Operational Uses		
Monitoring	√	
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

Hercon Environmental Corp., Emigsville, PA—*R. buoliana* lure; IPM Technologies, Portland, OR—*R. buoliana* lure.

Comments

For optimal survey results in forested areas, one white sticky trap should be allocated for every 4 acres or as many traps as resources will permit. Synthetic baits are more effective than live females in formulations with 5 percent active ingredient. Plastic dispensers 5 mm long and 3 mm in diameter mounted in adhesive traps sufficiently attract males from a distance of up to 198 m under optimal conditions (Daterman 1974).

The sex pheromone of *R. buoliana* is similar to that of *R. subtropica* Miller, and pheromone extracts of both species show strong reciprocal attraction. Baits for *R. buoliana* should be effective for survey and trapping of *R. subtropica*. The sex pheromone of *R. buoliana* has been shown to suppress the response of male *R. frustrana* to live females by 71.9% (Berisford and Hedden 1978). Male *R. frustrana* males responded weakly to the sex pheromone of *R. buoliana* in field tests (Berisford et al. 1979).

Daterman et al. (1972) reported on the inhibitory effect of *cis*-7-dodecenyl acetate on male *R. buoliana* response to pheromone baited traps. The authors discussed the potential of synthetic acetates in pest management. In a subsequent paper, Daterman et al. (1975) compared mating disruption using (*Z*)-9-dodecenyl acetate, the inhibitory isomer and the primary sex pheromone, (*E*)-9-dodecenyl acetate. They concluded that the primary pheromone was much more effective at mating disruption than the inhibitory compound.

Regan et al. (1991) proposed a linear regression model to predict *R. buoliana* pheromone trap catch based on heat unit accumulations from averaged maximum and minimum temperatures. The model, correlating degree-days (DD) with moth catch using a lower threshold of -2.2 °C, predicted requirements to be 1,712 DD for 10% catch, 1,958 DD for 50% catch, and 2,205 DD for 90% catch. The strong correlation between degree-days and moth catch can be useful for timing insecticidal sprays similar to those used to control *R. frustrana* (Gargiullo et al. 1985). Field testing optimal timing of insecticidal sprays is hindered by limited populations; therefore, no semiochemical is currently used to manage *R. buoliana* (Reagan et al. 1991).

References

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Rhyacionia frustrana (Comstock) (Lepidoptera: Tortricidae)
Nantucket Pine Tip Moth

Sex Pheromones

(*E*)-9-dodecen-1-yl acetate (Hill et al. 1981)

(*E*)-9,11-dodecadien-1-yl acetate (Hill et al. 1981)

Hill et al. (1981) reported two sex pheromone components (96:4) (*E*)-9-dodecen-1-yl acetate and (*E*)-9,11-dodecadien-1-yl acetate isolated from female gland extracts. Field tests showed that this combination of synthetics was highly attractive to males.

Other Compounds

Dodecen-1-ol acetate

(*E*)-9-dodecen-1-ol acetate

Dodecen-1-yl acetate

Hill et al. (1981) found evidence of dodecen-1-yl acetate, dodecen-1-ol acetate, and (*E*)-9-dodecen-1-ol acetate in female *R. frustrana* abdominal tips. None of these compounds were attractive.

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available	√	
Current Operational Uses		
Monitoring	√	
Attack Disruption		√
Spray Timing	√	
Phenologic Models	√	
Trap Out		√

Commercial Sources

Trécé, Inc., Salinas, CA—*R. frustrana* lure

Comments

The sex pheromone components, (*E*)-9-dodecen-1-yl acetate and (*E*)-9,11-dodecadien-1-yl acetate, are comparable to live females in attracting male *R. frustrana* to sticky traps. In field tests, extracts of female abdominal tips were more attractive than live females when the extract was replaced daily, except at high temperatures (Berisford and Brady 1972). Potential uses for sex pheromones include monitoring programs, trap-out programs, and communication disruption (Hill et al. 1981). Pheromone traps could also be useful in monitoring the end of pupal stages and the beginning of adult activity, indicating the optimal time to assess shoot damage for estimating population density (Ross 1990).

Five species in the genus *Rhyacionia*—*R. frustrana*, *R. bushnelli*, *R. rigidana*, *R. subtropica* and *R. buoliana*—share similar pheromone components and, in some cases, overlap in range. However, cross-attraction to pheromone extracts occurred among those species that were allopatric and had fewer hosts in common (Berisford et al. 1979). The asynchronous life cycles of *R. frustrana* and *R. rigidana* should be considered when controlling mixed tip moth populations (Berisford 1974). *Rhyacionia bushnelli* Busck, a sibling species to *R. frustrana*, occurs mostly in the midwestern United States (Powell and Miller 1978). Extracts from pheromone glands of *R. bushnelli* have the same relative percentages of the primary attractants for *R. frustrana*. Commercial baits and pheromone extracts from *R. frustrana* are highly attractive to *R. bushnelli* (C.W. Berisford and J.E. Pasek, unpublished data).

Extracts from female *R. frustrana* and *R. rigidana* mixed together in a 1:1 ratio completely inhibited male responses to sticky traps (Berisford and Brady 1973). Berisford (1973) reports that calling *R. frustrana* and *R. rigidana* females in close proximity inhibit conspecific male response, with *R. frustrana* more strongly inhibited. Male *R. frustrana* attraction to traps baited with live females was inhibited by 71.9% when the surrounding air was permeated with the sex pheromone of *R. buoliana* (*E*), 9 dodecenyl acetate (Berisford and Hedden 1978). The inhibitory effect *R. rigidana* (Berisford et al. 1974, Berisford 1977) and *R. buoliana* (Berisford and Hedden 1978) sex pheromones have on *R. frustrana* may be useful in controlling this pest.

Phenology models, based on degree days following initial emergence of *R. frustrana* adults (Haugen and Stephen 1984), are used in the South to predict optimal spray time for control of each of the three or four tip moth generations (Gargiullo et al. 1983, 1984, 1985). There are several sources of commercial baits for *R. frustrana* which may be used for population monitoring or spray timing.

References

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Rhyacionia neomexicana (Dyar) (Lepidoptera: Tortricidae)
Southwestern Pine Tip Moth

Sex Pheromones

(*E*/*Z*)-7-dodecenyl acetate (Niwa and Sower 1992)

(*E*/*Z*)-9-dodecenyl acetate (Niwa and Sower 1992)

In field tests, male moths were attracted to (*E*/*Z*)-7-dodecenyl acetate and especially to (*E*)-9-dodecenyl acetate (Jacobson and Jennings 1978). (*E*)-9-dodecenyl acetate was the most abundant compound in female abdominal washes. Two primary sex pheromone components (*E*)-9-dodecenyl acetate and (Z)-9-dodecenyl acetate have been identified, and an 80:20 ratio has been shown to be highly active in field trapping tests (Niwa and Sower 1992).

Other Compounds

The alcohols *E* and *Z* dodecenol were present in abdominal extracts of *R. neomexicana*, but their behavioral role is unknown (Niwa and Sower 1992).

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No baits are commercially available at this time.

Comments

No semiochemical is currently used to manage *R. neomexicana*. However, there is potential for at least monitoring for adult seasonal activity or regional distribution.

References

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Rhyacionia rigidana (Fernald) (Lepidoptera: Tortricidae)
Pitch Pine Tip Moth

Sex Pheromones

(*E,E*)-8,10-dodecadienyl acetate (Hill et al. 1976)

The compound (*E,E*)-8,10-dodecadienyl acetate was the only active chemical isolated from *R. rigidana* females, and it appears to be its only sex pheromone (Hill et al. 1976).

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No sources specifically for *R. rigidana*. However, the corresponding alcohol contained in the codling moth pheromone may be converted to the acetate.

Comments

Four species in the genus *Rhyacionia—R. frustrana, R. rigidana, R. subtropica* and *R. buoliana*—share similar pheromone components (i.e., 12 carbon acetates) and, in some cases, overlap in range. However, cross-attraction to pheromone baits occurred among those species that were allopatric and had fewer hosts in common (Berisford et al. 1979). The asynchronous life cycles of *R. frustrana* and *R. rigidana* should be considered when controlling mixed tip moth populations (Berisford 1974).

Extracts from female *R. frustrana* and *R. rigidana* mixed together in a 1:1 ratio completely inhibited male responses to sticky traps (Berisford and Brady 1973). Berisford (1973) reports that calling *R. frustrana* and *R. rigidana* females in close proximity inhibit conspecific male response, with *R. frustrana* more strongly inhibited. Catches of *R. frustrana* were sharply reduced by adding *R. rigidana* extracts to the lures. These data suggest sex pheromones of *R. rigidana* may be useful in controlling *R. frustrana* outbreaks, because it is considered a much more serious pest. No semiochemical is currently used to manage *R. rigidana*.

References

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Rhyacionia subtropica Miller (Lepidoptera: Tortricidae)
Subtropical Pine Tip Moth

Sex Pheromones

(*E*)-9-dodecenyl acetate (Roelofs et al. 1979)

The sex pheromone component of *R. subtropica*, (*E*)-9-dodecenyl acetate) has been isolated from female abdominal extracts and field tested (Roelofs et al. 1979). The corresponding alcohol, (*E*)-9-dodecen-1-ol, was present in female extracts, but decreased trap catch when added to pheromone traps.

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

Baits specifically for *R. subtropica* are not be available at this time, but they can be monitored effectively with baits for *R. buoliana*.

Comments

Berisford et al. (1979) report cross attraction of *R. subtropica* males to sticky traps baited with abdominal extracts of *R. buoliana* females. However, no semiochemical is currently used to manage *R. subtropica*.

References

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Rhyacionia zozana (Kearfott) (Lepidoptera: Tortricidae)
Ponderosa Pine Tip Moth

Sex Pheromones

(*E*)-9-dodecenyl acetate (Niwa et al. 1987)

(*E*)-9-dodecenol (Niwa et al. 1987)

The two sex pheromone components (*E*)-9-dodecenyl acetate and (*E*)-9-dodecenol in a 95:5 ratio have been shown to be active female sex pheromones via chemical analysis, electroantennograms, and field trapping (Sower et al. 1979, Niwa et al. 1987).

Status	Yes	No
Experimental Quantities Available	√	
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No baits are commercially available at this time.

Comments

Mating disruption of *R. zozana* has been demonstrated in the field and shown to be a potentially viable management tactic (Niwa et al. 1988, Kegley et al. 1995). Niwa et al. (1988) reported that mating disruption reduced damage from *R. zozana* larvae feeding on young pines, with 50% fewer damaged terminals in treated plots than in controls. The average yearly tree growth in infested terminals was approximately 5 cm less than in uninfested trees. The authors attributed the high degree of damage reduction through mating disruption of *R. zozana* to two factors: (1) many *Rhyacionia* species occur at low densities, and (2) treating relatively large plots (7-28 ha.) limited the effect of mated invading females from adjacent, untreated areas.

Kegley et al. (1995) reported effective control of *R. zozana* in Oregon using 156 pheromone impregnated 1/4 inch laminate tape lures tied to branches near the terminal shoot and spaced every 10 meters. There were no control plots used in this study because of the high value and low number of trees. This test plot was also treated with carbaryl to control *R. zozana* the previous year, which could partially explain the success of mating disruption in the following year.

References

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Monochamus titillator (Fabricius) (Coleoptera: Cerambycidae)
Southern Pine Sawyer

Pheromones

No pheromones have been isolated from *M. titillator*.

Host Compounds

Phillips et al. (1988) report *M. titillator* attraction to sticky traps baited with turpentine and ethanol released in adjacent dispensers or as a solution from the same dispenser. Species specific response to various combinations of host volatiles may indicate resource partitioning among sympatric species.

Status	Yes	No
Experimental Quantities Available		√
Commercial Quantities Available		√
Current Operational Uses		
Monitoring		√
Attack Disruption		√
Spray Timing		√
Phenologic Models		√
Trap Out		√

Commercial Sources

No baits are commercially available at this time.

Comments

No semiochemical is currently used to manage *M. titillator.*

References

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