Use of Pheromones to Disrupt Mating of Moth Pests in Area-Wide Management Programmes

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outline

- Nature of pheromone blends
- Overview of worldwide use
- Mechanisms and influence of formulation
- Does the complete pheromone blend need to be used?
- What features of the communication system work for or against successful disruption?
- Case studies
- Does area-wide mating disruption enhance its efficacy?

≈140,000 moth species

- Most all have a mate-finding system based on female release of pheromone—males locate females by following the pheromone plume upwind to her side.

≈140,000 moth species

- Miniscule quantities of pheromone mediate this process— females release only nanograms, or femtograms of pheromone per minute and this is diluted into a plume active for many meters downwind.

≈140,000 moth species

- The large majority of moth pheromones are termed **SCLP**s, or straight-chain lepidopteran pheromones, 10 to 18c in chain length, usually with 1-3 double bonds, and an either acetate, alcohol or aldehyde moiety. In the USA, these compounds in have greatly reduced registration protocols.

Does mating disruption work?

- Adoption by growers and managers—generally because current insecticide-based practices are ineffective, in some cases because of mandates to reduce use of neuroactive insecticides

Species	Principal Crop	Area (ha)	Region
Pectinophora gossypiella **pink bollworm**	cotton	55,000	U.S.A., Israel
Cydia pomonella **codling moth**	apple, pear, almond, walnut	120,000	U.S.A., Australia, E.U., South America
Grapholita molesta **oriental fruit moth**	peach, nectarine, apple, pear	50,000	U.S.A., Australia, E.U., South America
Lobesia botrana	grape	41,000	E.U.
Eupoecilia ambiguella	grape	32,000	E.U.
Endopiza viteana	grape	1,000	Canada, U.S.A.
Chilo suppressalis	rice	4,000	E.U.

Species	Principal Crop	Area (ha)	Region
leafrollers (Tortricidae)	tea, pear, apple, peach, grape	24,000	Japan, Australia, U.S.A., New Zealand
Synanthedon spp.	apricot, black currant, peach	5,000	Japan, U.S.A., New Zealand
Zeuzera pyrina	pear, olive	2,000	E.U.
Plutella xylostella	cabbage	2,000	Japan
Keiferia lycopersicella **tomato pinworm**	tomato	10,000	Mexico, U.S.A.
Lymantria dispar **gypsy moth**	deciduous forests	230,000	U.S.A.
others	vegetables, apple, peach, golf turf	27,000	Japan, U.S.A.

Total area of application as of 2010—770,000 hectares

- Effective for many moth families—Gelechiidae, Tortricidae, Pyralidae, Sesiidae, Cossidae, Erebidae

- Some important families not prominent in this list—Noctuidae—are they intractable because they are too migratory?

Witzgall, Kirsch & Cork, J Chem Ecol. 36:80-100, 2010

How does mating disruption work?

- And how does formulation influence efficacy?

1. Sensory impairment (=adaptation/habituation) Behavioral output the same: responsiveness eliminated or reduced; or threshold raised

- Many types of formulation likely effective
- Need not use “complete” pheromone—rather, partial blends, pheromone components plus antagonists
- Some species more readily impaired than others

2. Competition (=false trail following)

Time spent orienting to point sources of formulation diminishes time available for finding females

- Works with point-source formulations that are competitive with calling females
- Use "complete" pheromone
- Relative densities of calling females and competing point sources of pheromone important

3. Camouflage (females' plume "hidden" by pheromone from formulation)

- May be most effective at high atmospheric concentrations of disruptant and in disrupting plume following in cases where the male is far away from the female
- Probably some species are better able to navigate in an environment "rich" in synthetic pheromone
- Evidence of this if high rate of release lures are used

Types of formulation

Formulation	Density ha^{-1}	Application	Longevity	Mechanisms
Atomizer ("puffers")	<1 to Several	Hand placed on stake or hung on tree	Season long	Sensory interference; camouflage
Sealed plastic tube	Hundreds	Hand	Season long	Sensory interference; camouflage
Open-ended hollow fiber, Laminated plastic flakes	≈10,000	Specialized equipment, aerial	Weeks; season long	Sensory interference; camouflage; competition
Microcapsules	Many millions	Conventional spray	Days to several weeks	Sensory interference; camouflage
Attracticide (e.g., fibers with insecticide in sticker)	≈1000	Specialized equipment	Weeks	Direct toxicity; impairment of orientation; competition

Do species differ in their intrinsic susceptibility to mating disruption?

- Problematic to compare species because of differences in population density, crop foliage
- Notwithstanding, certain features of their communication system and mate-finding ecology should affect susceptibility

Female Traits

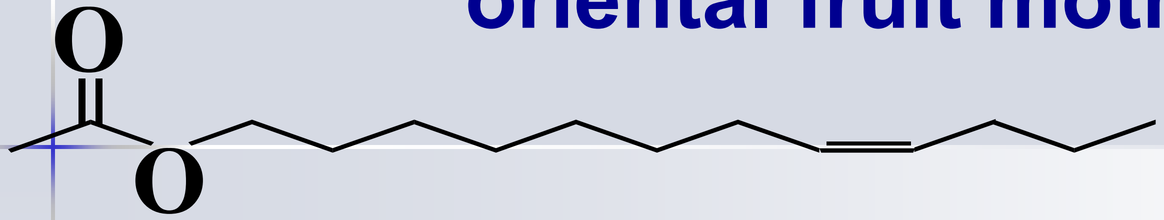
Higher susceptibility	Lower susceptibility
Low pheromone emission rate pink bollworm, **OFM**	High pheromone emission rate
Calling from within treated canopy	Calling at top of canopy or outside treated area pink bollworm
Calling rhythm imprecisely timed to males' rhythm of response pink bollworm	Calling rhythm well timed to males' rhythm of response
Low migratory tendency	High migratory tendency pink bollworm

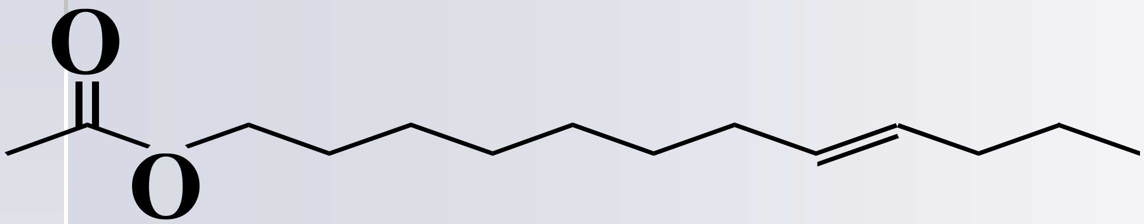
Male Traits

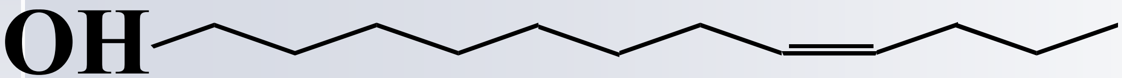
Higher susceptibility	Lower susceptibility
Readily habituated **OFM**	Difficult to habituate pink bollworm
Slow to dishabituate	Rapid dishabituation pink bollworm
Upwind flight inhibited by density of pheromone encountered in treated plots **OFM**, tomato pinworm	Able to orient to high concentrations of pheromone pink bollworm
Poor ability to orient along female-produced plumes within a background of pheromone from formulation	Able to orient along female-produced plumes within a background of pheromone from formulation
Rhythm of response imprecisely coordinated with females' rhythm of calling pink bollworm	Rhythm of response well coordinated with females' rhythm of calling
Males continually exposed to pheromone from formulation	Spend non-responsive periods in locations receiving little exposure to formulation pink bollworm
Males rely principally on pheromone for orientation and mating pink bollworm	Non-pheromonal cues (visual, tactile, or auditory) to facilitate orientation and mating **OFM**

Grapholita (=Cydia) molesta

oriental fruit moth







- **(*Z*)-8-dodecenyl acetate**
- **(*E*)-8-dodecenyl acetate**
- **(*Z*)-8-dodecen-1-ol**
- **0.1-0.2 ng released per hour**

OFM is easily disrupted

- Atmospheric puffers, hand-applied, sealed plastic ropes, hollow, open-ended plastic fibers, microcapsules all work
- Initial populations can be fairly high
- Principal concern is immigration of mated females from periphery

Successful area-wide programs in Tulbagh Valley of South Africa

- Extensive damage despite up to 13 applications of organophosphates

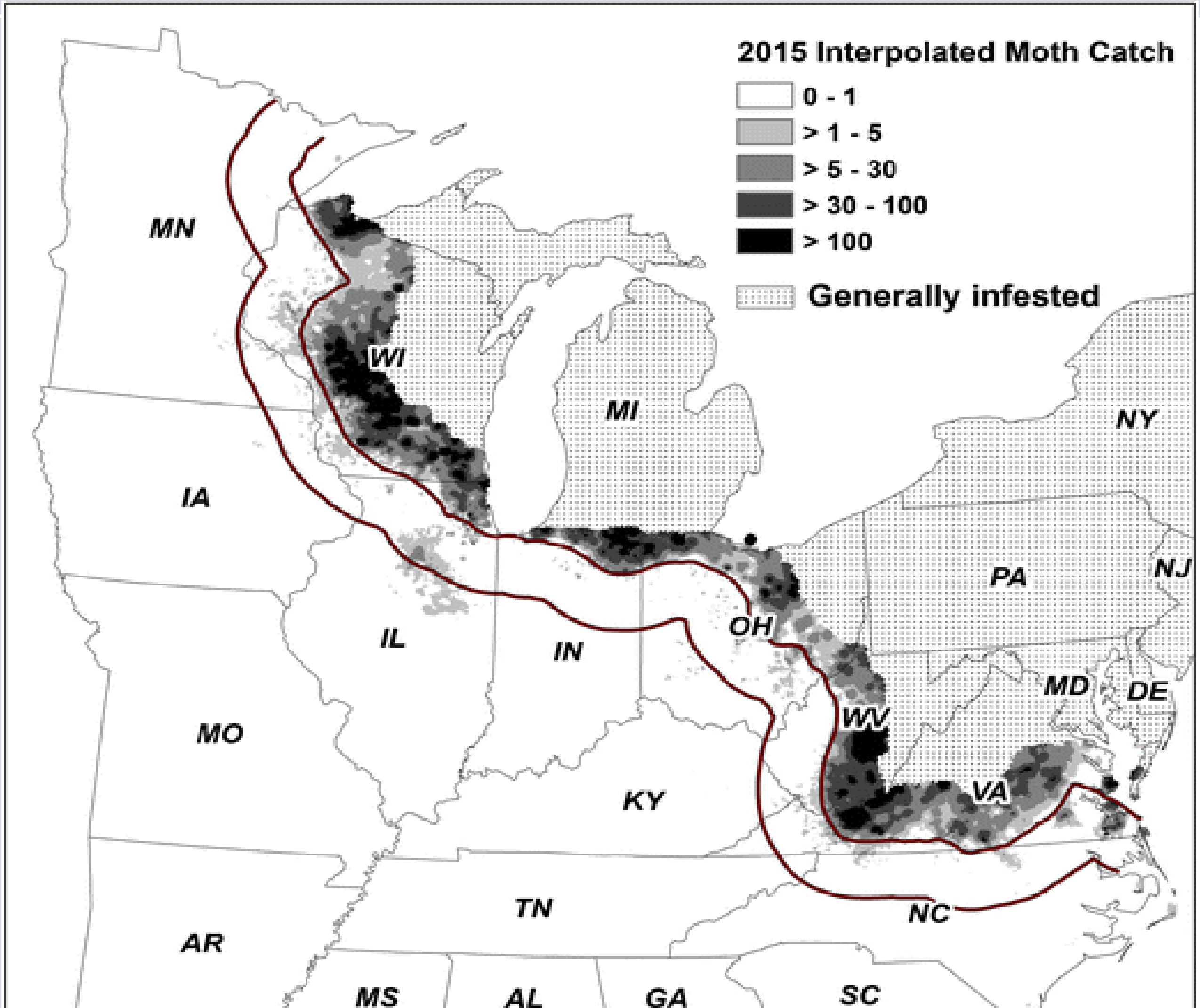
- In 1991/1992 entire 1,200 ha crop of peaches and nectarines, and to the five border rows of all plum, prune, apricot, almond, and pear orchards treated

- Shoot-tip damage in peaches dropped from an average of 49% to 0% in one year

Barnes & Blomefield . Technology Transfer in Mating Disruption. IOBC/wprs Bulletin 20(1), pp. 45–56, 1997

Gypsy moth is an invasive species to North America. Mating disruption has been used to stop or slow its spread from the northeast U.S. Crucial that populations are a low density before application of formulated pheromone.

capture of males in pheromone-baited traps used to pick vulnerable populations—70,000 traps used to survey density



- 182,000 ha now treated aerially yearly in 100 km band
- Slows the spread from 21 to 8 km yearly
- "disparlure" used for mating disruption is racemic and is about 1/10th as attractive as its (+) enantiomer—the natural pheromone.
- Clearly an are-wide approach

Lance et al. J Chem Ecol 42:590-605, 2016

Does the complete blend need to be used?

Eupoecilia ambiguella

- (*Z*)-9-dodecenyl acetate +12:Ac +18:Ac is best attractant

Addition of >0.1% (E)-9-dodecenyl acetate diminishes attraction

What formulation controls *Eupoecilia ambiguella*?

- Technical (*Z*)-9-dodecenyl acetate contains several % (*E*)-isomer
- Is not attractive
- Excludes competition as a mechanism when dispensed from point sources

Tomato pinworm moth
Keyferia lycopersicella
(E)-4-tridecenyl acetate

20-45+ applications of insecticide cocktails—5-84% tomato damage

IPM Program

Trumble & Alvarado-Rodriguez, *Agriculture, Ecosystems and Environment* 43, 267-284. 1993

- *Spodoptera exigua*
- *Helicoverpa zea*
- *Heliothis virescens*

- Avermectin
- *Bacillus thuringiensis*
- *Trichogramma* releases

winter planting

- IPM
- 6-30% damage
- $1200-2200 profit differential per ha

- Conventional
- 5-84% damage

- Works at high population levels
- Mechanisms of disruption undefined

Pink bollworm, *Pectinophora gossypiella*

- (Z,Z)-7,11-16:Ac
- (Z,E)-7,11-16:Ac

Rates of pheromone emission—pink bollworm

■ Calling female	0.3	ng min
■ Hollow, open-ended plastic fiber (Scentry)	1	ng min
■ Rubber septum (4 mg load, used in survey traps)	17	ng min
■ Sealed plastic "rope" (Shin-Etzu)	300	ng min

Parker Valley: 11,250 hectares in the Colorado River Desert cotton-growing region—isolated from other major cotton-growing areas

Parker Area-Wide Management Program

Treatment System	Hectares Treated 1990	1991	1992	1993
Rope (seaedl plastic tubes)	4,788	5,070	3,864	2,756
Open-ended fibers	12,339	12,628	24,919	16,558
Fibers + insecticide overspray	13,346	11,088	10,113	1,089
Insecticide	0	340	2,456	0

Staten et al. Successful area wide program to control pink bollworm by mating disruption pp. 383-396 In *Insect Pheromone Research. New Directions.* 1996.

Levels of crop protection achieved

YEAR	Larvae/100 cotton bolls	
	July 30	Sept 10
1989	3.6	28.4
1990	1.4	10.4
1991	0.1	3.7
1992	0.6	1.8
1993	0	0*

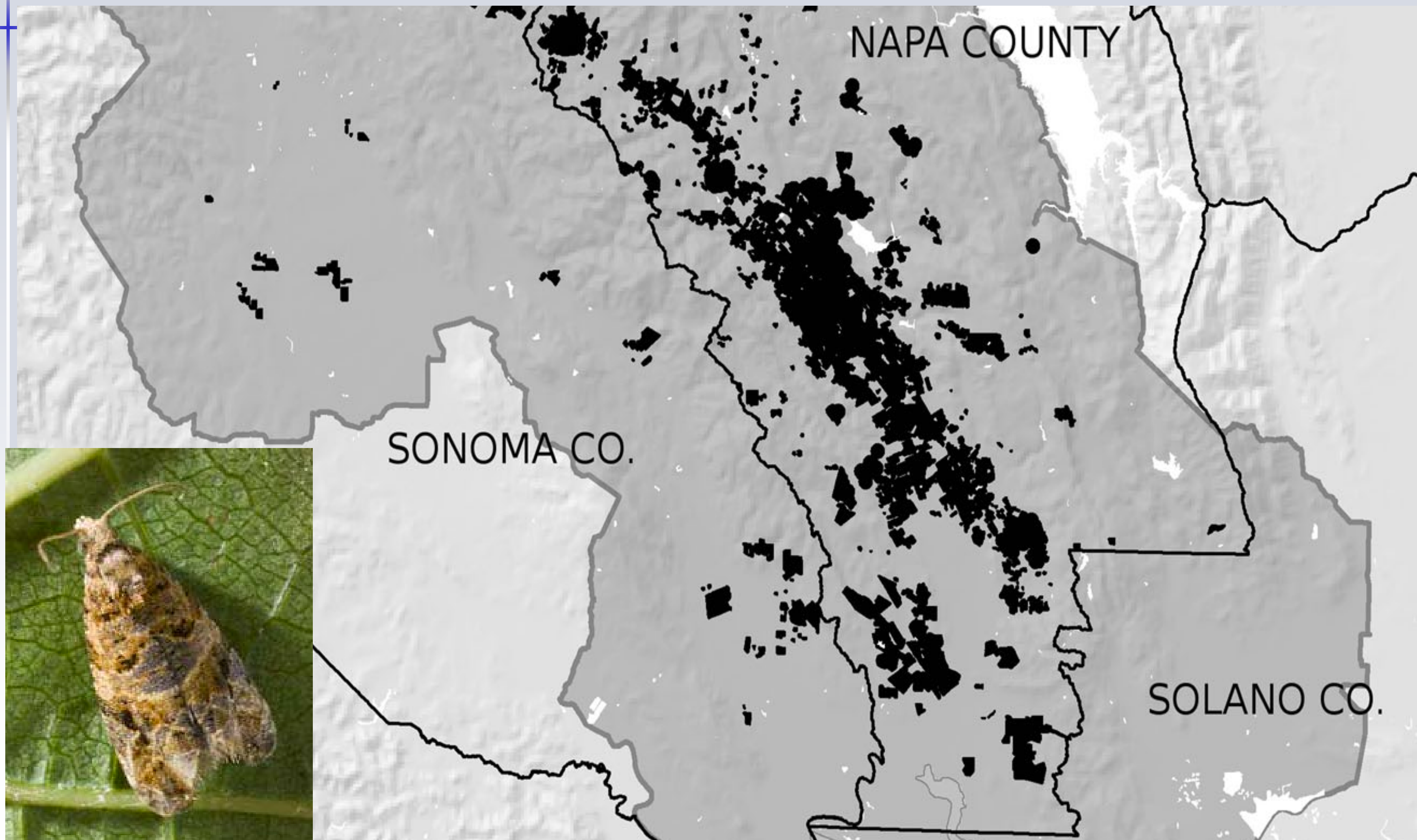
- *>10,000 bolls sampled

Area-wide efforts to eradicate PBW

- Beginning in 1994, multi-tool program to eliminate PBW from southwestern U.S. and northern Mexico
- Use of mating disruption, sterile moths, minimal use of insecticides, and in later years, Bt cotton
- By 2008, no PBW larvae could be found in southwestern U.S. and northern Mexico
- As PBW moths are highly dispersive, area-wide approach should have contributed to efficacy

Lance et al. J Chem Ecol 42:590-605, 2016

European grape vine moth (*Lobesia botrana*) eradication in northern California



- Initial infestations documented with pheromone traps, with over 100,000 males captured in Napa and Sonoma Counties in 2010, the year following discovery.
- 160 km^2 of commercial vineyards treated with disruptant and insecticides
- Number of trapped males dropped to 146 in 2011 and by 2014 only a single male was captured.
- By 2015 no mating disruption in use and no moths captured—and eradication declared

Lance et al. J Chem Ecol 42:590-605, 2016

Some final thoughts

- Integration with other IPM practices—usually not a "stand-alone" technology
- Formulation type/dose dictates the mechanism of disruption and, very likely, efficacy
- Species differ in susceptibility
- Population dynamics—especially migratory tendency—are clearly important

Some final thoughts

- Are-a-wide program, simply because of their size, should eliminate infiltration of mated females from outside of the treated area
- Area-wide programs also should promote success because they coordinate all pest control efforts
- The objective may be more either more effective management or eradication

If mating disruption works…

- Will resistance evolve?
- Can we predict mechanisms?
- Are there strategies to forestall resistance or restore efficacy?

Smaller tea tortrix, *Adoxophyes honmai*

- 63 : 31 : 4 : 2 blend
- Z9-14:Ac
- Z11-14:Ac
- E11-14:Ac
- 10-methyldodecyl acetate

Mating disruption in the smaller tea tortrix, *Adoxophyes honmai*

Mochizuki, F. *et al.* Appl. Entomol. Zool. 37: 299-304. (2002)

- 15 years of successful disruption using Z11-14:Ac, one of four blend components
- Breakdown of control in one region—crop damage and sentinel pheromone-baited traps capture males

Mating disruption in the smaller tea tortrix, *Adoxophyes honmai*

- Use of the 4-component blend restored efficacy
- One reason to use the complete blend—delay evolution of resistance

Additional (minor?) mechanisms

- Arrestment of upwind flight (at concentrations of pheromone above those produced by the female) Oriental fruit moth
- Advancement of males' rhythm of response (exposes males to other mechanisms before females commence calling) Pink bollworm
- Delay in mating (reduces fecundity)
- Promotes male movement out of treated area