

## Chemical Ecology

# Interactions Between *syn*- and *anti*-2,3-Hexanediol Lures on Trap Catches of Woodboring Beetles and Associates in Southeastern United States

D. R. Miller,<sup>1,2,4</sup> C. M. Crowe,<sup>1</sup> P. D. Mayo,<sup>2</sup> P. J. Silk,<sup>2</sup> and J. D. Sweeney<sup>2</sup>

<sup>1</sup>Southern Research Station, USDA Forest Service, 320 Green Street, Athens, GA 30602, USA, <sup>2</sup>Natural Resources Canada, Canadian Forest Service, Atlantic Forestry Center, 1350 Regent Street, P.O. Box 4000, Fredericton, NB E3B 5P7, Canada, and <sup>4</sup>Corresponding author, tel: (706) 559-4247, fax: (706) 559-4287, e-mail: [Daniel.Miller1@usda.gov](mailto:Daniel.Miller1@usda.gov)

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## Abstract

In 2016, we conducted three experiments to clarify the effects of 2,3-hexanediols isomers on trap catches of *Neoclytus acuminatus* (F.) (Coleoptera: Cerambycidae). We also noted the effects of the isomers on trap catches of other cerambycids and associated species of predators and competitors. Catches of *N. acuminatus* in traps baited with ethanol + *syn*-2,3-hexanediol + racemic 3-hydroxyoctan-2-one were reduced with the addition of *anti*-2,3-hexanediol, an attractant for *Curius dentatus* Newman (Coleoptera: Cerambycidae). A fourth experiment conducted in 2017 verified that racemic 3-hydroxyoctan-2-one increases catches of *N. acuminatus* in traps baited with ethanol + *syn*-2,3-hexanediol. The addition of *anti*-2,3-hexanediol increased catches of *Knolliana cincta* (Drury) (Coleoptera: Cerambycidae) in traps baited with ethanol + racemic 3-hydroxyoctan-2-one, whereas attraction of *Neoclytus scutellaris* (Olivier) to traps baited with ethanol + racemic 3-hydroxyhexan-2-one was reduced by *syn*-2,3-hexanediol. Trap catches of the beetle predators *Chariessa pilosa* (Forster), *Enoclerus ichneumonius* (F.), and *Madoniella dislocata* (Say) (Coleoptera: Cleridae) were affected by 2,3-hexanediol isomers, whereas other common predators were unaffected by the isomers. Attraction of the bostrichid *Xylobiops basilaris* (Say) (Coleoptera: Bostrichidae) was increased by the 2,3-hexanediols; the relative effect of the two isomeric blends was dependent on trap co-baits of 3-hydroxy-2-ketones. The two enantiomeric blends of 2,3-hexanediol had minimal effects on catches of most species of ambrosia beetles, whereas the 3-hydroxy-2-ketones affected trap catches of some species.

**Key words:** Cerambycidae, hardwood, detection, non-native, invasive

Hexanediols and hydroxyketones are two common chemical groups of pheromones used by woodboring beetles (Coleoptera: Cerambycidae), particularly species in the subfamily Cerambycinae (Hanks and Millar 2013, Millar et al. 2018). In the case of the red-headed ash borer *Neoclytus acuminatus* (F.), males release the aggregation pheromone (2*S*, 3*S*)-hexanediol from prothoracic glands (Lacey et al. 2004, 2007a; Ray et al. 2015; Hanks et al. 2019). Both sexes are attracted to traps baited with *syn*-2,3-hexanediol [racemic blend of (2*S*, 3*S*)-hexanediol and (2*R*, 3*R*)-hexanediol] (Lacey et al. 2004, 2009; Wong et al. 2012; Hanks and Millar 2013; Miller et al. 2015; Ray et al. 2015; Hanks et al. 2018, 2019). *anti*-2,3-Hexanediol [a racemic blend of the other two enantiomers (2*S*, 3*R*)-hexanediol and (2*R*, 3*S*)-hexanediol] is not attractive to *N. acuminatus* (Wong et al. 2012, Hanks and Millar 2013, Millar

et al. 2018, Hanks et al. 2019), and reduces attraction of beetles to traps baited with *syn*-2,3-hexanediol (Lacey et al. 2004, Hanks et al. 2019). In Georgia, traps baited with ethanol + *syn*-2,3-hexanediol were attractive to four other species of Cerambycidae as well as *Xylobiops basilaris* (Say) (Coleoptera: Bostrichidae) and *Chariessa pilosa* (Forster) (Coleoptera: Cleridae) (Miller et al. 2015).

3-Hydroxyhexan-2-one is another common pheromone of Cerambycinae species (Hanks and Millar 2013, Mitchell et al. 2015, Ray et al. 2015, Millar et al. 2018) although not attractive to *N. acuminatus* (Wong et al. 2012; Hanks and Millar 2013; Miller et al. 2015, 2017; Hanks et al. 2018). Adding racemic 3-hydroxyhexan-2-one to traps baited with *syn*-2,3-hexanediol generally results in lower catches of *N. acuminatus* (Wong et al. 2012; Miller et al. 2017; Hanks et al. 2018, 2019; Millar et al. 2018) but the

addition of another common cerambycine pheromone racemic 3-hydroxyoctan-2-one to those traps negates the interruptive effect (Miller et al. 2017).

Understanding the chemical ecology of beetle species within a community is necessary to develop effective semiochemical-based tools and strategies to detect these species, particularly for non-native invasive species (Borden 1989, Hanks and Millar 2016, Poland and Rassati 2019). The need for detection tools for *N. acuminatus* is most apparent due to its invasion and spread through Europe from North America (Keszthelyi 2021). The goal of this study was to discern the interacting effects of common cerambycine pheromones (racemic 3-hydroxyhexan-2-one, racemic 3-hydroxyoctan-2-one, *syn*- and *anti*-2,3-hexanediols) on catches of *N. acuminatus* and other long-horned beetles in ethanol-baited traps. One specific objective of our study was to determine the enhancement effect (if any) of 3-hydroxyoctan-2-one on catches of *N. acuminatus* and other Cerambycidae, and associated species (i.e., bark and ambrosia beetles, and associated predators) in traps baited with ethanol + *syn*-2,3-hexanediol. Our second objective was to determine the relative effects of *syn*- and *anti*-2,3-hexanediol on catches of *N. acuminatus* and other Cerambycidae, and associated species, in traps co-baited with ethanol and 3-hydroxyhexan-2-one and/or 3-hydroxyoctan-2-one.

## Materials and Methods

In 2016–2017, we conducted four trapping experiments in north Georgia to determine the effects of *syn*- and *anti*-2,3-hexanediol on catches of Cerambycidae and associated species (Table 1). All lures were obtained from Scotts Canada (Delta BC) (Table 2). All four experiments were conducted as randomized block designs with treatments varying by experiment (Table 3). The goal of experiment 1 was to verify that the addition of racemic 3-hydroxyoctan-2-one to traps baited with ethanol + *syn*-2,3-hexanediol would result in increases in trap catches of *N. acuminatus*. The goal of experiment 2 was to assess the interactive effects of *syn*-2,3-hexanediol, *anti*-2,3-hexanediol, and the blend of racemic 3-hydroxyoctan-2-one + racemic 3-hydroxyhexan-2-one on trap catches of Cerambycidae and associated species in ethanol-baited traps. In experiments 3 and 4, our focus was on the interactions between *syn*- and *anti*-2,3-hexanediol in traps baited with ethanol + 3-hydroxyoctan-2-one and ethanol + 3-hydroxyhexan-2-one, respectively. All traps were baited with ethanol because it enhances catches of many cerambycids such as *N. acuminatus* in traps baited with pheromones (Hanks et al. 2012, Handley et al. 2015, Miller et al. 2015).

Study methods were like those used in Miller et al. (2017) with modified 10-unit multiple-funnel traps (Miller et al. 2013a) hung on rope strung between trees and spaced 8–15 m apart. A strip (2.5 × 5.0 cm) of VaporTape II (Hercon Environmental Corp., Emigsville, PA) was attached under each trap canopy to discourage nest building by wasps. Collection cups on traps contained approximately 150 ml of ethanol-free Splash RV & Marine Antifreeze (propylene glycol and water) (SPLASH Products, St. Paul, MN) to kill and preserve captured insects (Miller and Duerr 2008). Voucher specimens were deposited in the University of Georgia Collection of Arthropods, Athens, GA.

SYSTAT (ver. 13) and SigmaStat (ver. 3.01) statistical packages (SYSTAT Software Inc., Point Richmond, CA) were used to analyze trap catch data. Data were transformed by  $\ln(Y + 1)$  as needed to achieve normality and homoscedasticity, verified by the Shapiro–Wilk and Bartlett's tests, respectively. Data for *N. acuminatus* in experiment 1 were analyzed by one-tailed paired *t*-test as the objective of the experiment was to verify that 3-hydroxyoctan-2-one would increase trap catches of *N. acuminatus* in traps baited with ethanol + *syn*-2,3-hexanediol. All

**Table 1.** Locations, coordinates, dominant tree species, and trapping dates for each of four experiments on flight responses of woodboring beetles to multiple-funnel traps baited with ethanol, 2,3-hexanediols, and 3,2-hydroxyketones

Experiment	Location	Coordinates	Tree species	Trapping dates
1	Oconee National Forest, Putnam Co., GA	33.240° N, 83.528° W	<i>Quercus alba</i> L., <i>Liquidambar styraciflua</i> L., <i>Pinus taeda</i> L.	28 Mar.–26 May 2017
2	Oconee National Forest, Greene Co., GA	33.740° N, 83.272° W	<i>P. taeda</i> , <i>Q. alba</i> , <i>L. styraciflua</i> , <i>Pinus echinata</i> Miller	5 May–6 July 2016
3	Clybel Wildlife Management Area, Jasper Co., GA	33.416° N, 83.740° W	<i>P. taeda</i> , <i>Q. alba</i> , <i>Carya tomentosa</i> , <i>Quercus falcata</i> Michaux	26 Apr.–7 June 2016
4	Clybel Wildlife Management Area, Jasper Co., GA	33.416° N, 83.740° W	<i>P. taeda</i> , <i>Q. alba</i> , <i>C. tomentosa</i> , <i>Q. falcata</i>	7 June–5 July 2016

**Table 2.** Description of lures used in the study

Code	Compound	Release rate <sup>a</sup>
E	Ethanol UHR	0.5 g/d at 23°C
sD	<i>syn</i> -2,3-hexanediol	1.5 mg/d at 20°C
aD	<i>anti</i> -2,3-hexanediol	1.5 mg/d at 20°C
K6	Racemic 3-hydroxyhexan-2-one	20–25 mg/d at 20°C
K8	Racemic 3-hydroxyoctan-2-one	20–25 mg/d at 20°C

All chemical purities >95%.

<sup>a</sup>Determined by manufacturer.

**Table 3.** Treatments used in four randomized block experiments testing the effects of ethanol, *syn*-2,3-hexanediol, *anti*-2,3-hexanediol, 3-hydroxyhexan-2-one, and 3-hydroxyoctan-2-one lures on catches of woodborers in north Georgia

Experiment	<i>n</i>	Treatments
1	10	1. EsD = ethanol UHR lure (E) + <i>syn</i> -2,3-hexanediol lure (sD) 2. EsD + K8 = E lure + sD lure + 3-hydroxyoctan-2-one lure (K8)
2	8	1. E = E lure 2. EsD = E lure + sD lure 3. EaD = E lure + <i>anti</i> -2,3-hexanediol lure (aD) lure 4. EK = E lure + K8 lure + 3-hydroxyhexan-2-one (K6) lure 5. EsDaD = E lure + sD lure + aD lure 6. EsDK = E lure + sD lure + K6 lure + K8 lure 7. EaDK = E lure + aD lure + K6 lure + K8 lure 8. ALL = E lure + sD lure + aD lure + K6 lure + K8 lure
3	10	1. EK8 = E lure + K8 lure 2. EK8 + sD = E lure + K8 lure + sD lure 3. EK8 + aD = E lure + K8 lure + aD lure 4. ALL = E lure + K8 lure + sD lure + aD lure
4	8	1. EK6 = E lure + K6 lure 2. EK6 + sD = E lure + K6 lure + sD lure 3. EK6 + aD = E lure + K6 lure + aD lure 4. ALL = E lure + K6 lure + sD lure + aD lure

*n* = number of replicate blocks.

other data in experiment 1 were analyzed by two-tailed paired *t*-test. Data in experiments 2–4 were analyzed by mixed-model analysis of variance (ANOVA) with treatment as the fixed factor. For species with a significant treatment effect, means in experiments 2–4 were compared using the Holm-Sidak multiple-comparison test ( $\alpha = 0.05$ ). The Holm-Sidak test controls the overall experiment-wise error rate at 0.05 (Glanz 2005). Additionally, data in experiment 2 were analyzed by mixed-model ANOVA using the following model factors: 1) *syn*-2,3-hexanediol treatment (sD); 2) *anti*-2,3-hexanediol treatment (aD); 3) 3-hydroxyoctan-2-one + 3-hydroxyhexan-2-one lure (K); 4) sD × aD; 5) sD × K; 6) aD × K; and 7) sD × aD × K. Data in experiments 3 and 4 were analyzed by mixed-model ANOVA using the following factors: 1) *syn*-2,3-hexanediol treatment (sD); 2) *anti*-2,3-hexanediol treatment (aD); and 3) sD × aD. For any given species, the total number of insects caught in an experiment is denoted by *N*.

## Results

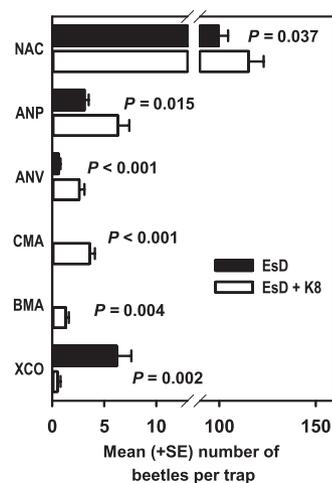
### Longhorned Beetles (Coleoptera: Cerambycidae)

In experiment 1, 3-hydroxyoctan-2-one increased catches of *N. acuminatus* in traps baited with ethanol + *syn*-2,3-hexanediol

but decreased catches of *Xylotrechus colonus* (F.) (*N* = 2,149 and 67, respectively) (Fig. 1). Increases in catches were also noted for *Anelaphus parallelus* (Newman), *Anelaphus villosus* (F.), *Clytus marginicollis* Castelnau & Gory, and *Bellamira scalaris* (Say) (*N* = 94, 32, 36, and 13, respectively). There were no treatment effects on trap catches of *Anelaphus pumilus* (Newman), *Cyrtophorus verrucosus* (Olivier), *Euderces pini* (Olivier), *Knulliana cincta* (Drury), and *Neoclytus mucronatus* (F.) (Table 4).

In experiment 2, catches of *N. acuminatus* were affected by the *syn*-2,3-hexanediol and ketone blend treatments with significant interactions with *anti*-2,3-hexanediol and the ketone blend (Table 5). All treatments with pheromones increased trap catches of *N. acuminatus* compared to traps baited with ethanol alone (Fig. 2A). The largest catches of *N. acuminatus* were in traps baited with ethanol + *syn*-2,3-hexanediol with reductions caused by the addition of *anti*-2,3-hexanediol and/or the ketone blend. The *anti*-2,3-hexanediol + ketone blend did not reduce trap catches of *N. acuminatus* any more than *anti*-2,3-hexanediol or the ketone blend alone. Catches of *Curius dentatus* Newman were affected by *anti*-2,3-hexanediol and the ketone blend but not *syn*-2,3-hexanediol, with a significant interaction between the ketone blend and *anti*-2,3-hexanediol (Table 5). Beetle catches were greater in traps baited with ethanol + *anti*-2,3-hexanediol (with or without *syn*-2,3-hexanediol) than in traps baited with ethanol + ketone blend (with or without *syn*-2,3-hexanediol) (Fig. 2B).

The ketone blend treatment affected catches of *N. mucronatus*, *Neoclytus scutellaris* (Olivier), *A. pumilus*, and *B. scalaris* (Say) in experiment 2 (Table 5). In addition, catches of *N. scutellaris* were affected by *anti*-2,3-hexanediol, whereas those of *N. mucronatus* were affected by *syn*-2,3-hexanediol and the interaction of the ketone blend and *syn*-2,3-hexanediol (Table 5). A similar response profile was exhibited by *N. mucronatus*, *N. scutellaris*, and *A. pumilus* with catches of all three species highest in all traps containing the ketone blend, regardless of the hexanediol treatments (Fig. 2C–E). Similarly, catches of *B. scalaris* were greatest in three of the four treatments with the ketone blend (Fig. 2F). *syn*-2,3-Hexanediol had a positive effect on catches of *N. mucronatus* but not those of *N. scutellaris* or *A. pumilus* (Fig. 2C–E). Catches of *Xylot. colonus* and *Elaphidion mucronatum* (Say) (*N* = 153 and 42, respectively) in experiment 2



**Fig. 1.** Effects of adding 3-hydroxyoctan-2-one (K8) to traps baited with ethanol + *syn*-2,3-hexanediol (EsD) on mean trap catches of the cerambycids *Anelaphus parallelus* (ANP), *A. villosus* (ANV), *Bellamira scalaris* (BMA), *Clytus marginicollis* (CMA), *Neoclytus acuminatus* (NAC), and *Xylotrechus colonus* (XCO) in north Georgia (experiment 1). *P* = significance level for paired *t*-test.

**Table 4.** Total beetle numbers (*N*), mean ( $\pm$ SE) number of beetles per trap, and *t* and *P* values (paired *t*-test) for species that exhibited no treatment effects in experiment 1

Family and species	<i>N</i>	Mean $\pm$ SE	<i>t</i> <sub>9</sub>	<i>P</i>
Cerambycidae				
<i>Anelaphus pumilus</i>	44	2.2 $\pm$ 0.3	0.375	0.716
<i>Cyrtophorus verrucosus</i>	81	4.1 $\pm$ 0.7	0.332	0.748
<i>Eudercus pini</i>	10	0.5 $\pm$ 0.2	0.000	0.394
<i>Knulliana cincta</i>	12	0.6 $\pm$ 0.2	1.500	0.168
<i>Neoclytus mucronatus</i>	10	0.5 $\pm$ 0.2	0.391	0.705
Cleridae				
<i>Chariessa pilosa</i>	120	6.0 $\pm$ 0.5	1.427	0.187
<i>Pyticeroidea laticornis</i>	16	0.8 $\pm$ 0.3	1.732	0.117
Curculionidae				
<i>Cyclorhipidion bodoanum</i>	43	2.2 $\pm$ 0.5	1.530	0.160
<i>Hylocurus rudis</i>	22	1.1 $\pm$ 0.3	1.714	0.121
<i>Monarthrum fasciatum</i>	19	1.0 $\pm$ 0.2	0.519	0.616
<i>Monarthrum mali</i>	339	17.0 $\pm$ 1.6	2.055	0.070
<i>Stenoscelis brevis</i>	429	21.5 $\pm$ 2.5	1.731	0.118
<i>Xyleborinus saxesenii</i>	329	16.5 $\pm$ 1.5	0.146	0.887
<i>Xylosandrus compactus</i>	165	8.3 $\pm$ 0.9	0.573	0.580
<i>Xylosandrus crassiusculus</i>	1,152	57.6 $\pm$ 6.8	0.000	1.000
<i>Xylosandrus germanus</i>	14	0.7 $\pm$ 0.2	1.562	0.153
Passandridae				
<i>Catogenus rufus</i>	34	1.7 $\pm$ 0.3	1.260	0.239
Trogossitidae				
<i>Temnoscheila virescens</i>	18	0.9 $\pm$ 0.2	2.250	0.051
<i>Tenebroides</i> spp.	118	5.9 $\pm$ 0.5	0.930	0.377

**Table 5.** ANOVA significance values (*P*) for effects of *syn*-2,3-hexanediol (sD), *anti*-2,3-hexanediol (aD), 3,2-hydroxyketone blend (K), and all treatment interactions on trap catches of Bostrichidae, Cerambycidae, Cleridae and Trogossitidae (Coleoptera), and Reduviidae (Hymenoptera) in experiment 2

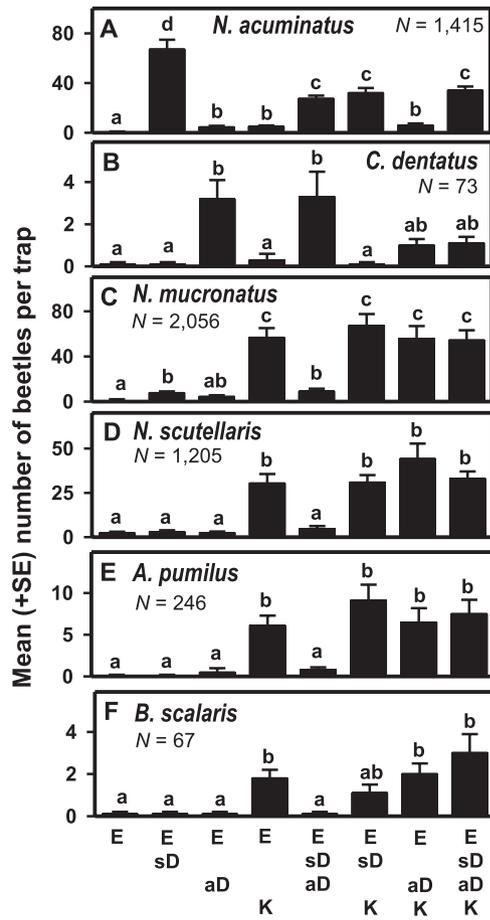
Family and species	<i>P</i>						
	sD	aD	K	sD $\times$ aD	sD $\times$ K	aD $\times$ K	sD $\times$ aD $\times$ K
Bostrichidae							
<i>Xylobiops basilaris</i>	<0.001	0.021	0.524	0.097	0.070	0.065	0.212
Cerambycidae							
<i>Anelaphus pumilus</i>	0.061	0.495	<0.001	0.883	0.708	0.076	0.505
<i>Bellamira scalaris</i>	0.709	0.144	<0.001	0.196	0.709	0.144	0.196
<i>Curius dentatus</i>	0.931	<0.001	0.036	0.902	0.902	0.022	0.423
<i>Neoclytus acuminatus</i>	<0.001	0.313	0.048	<0.001	<0.001	0.948	<0.001
<i>Neoclytus mucronatus</i>	0.002	0.621	<0.001	0.154	0.013	0.145	0.289
<i>Neoclytus scutellaris</i>	0.297	0.034	<0.001	0.915	0.124	0.550	0.316
Cleridae							
<i>Chariessa pilosa</i>	<0.001	0.007	0.032	0.134	<0.001	0.370	0.761
<i>Enoclerus ichneumonius</i>	0.016	0.080	<0.001	0.055	0.037	0.159	0.055
<i>Madoniella dislocata</i>	<0.001	0.317	0.001	0.038	0.001	0.194	0.225
Curculionidae							
<i>Dryoxylon onoharaense</i>	0.507	0.518	<0.001	0.089	0.697	0.023	0.759
<i>Monarthrum mali</i>	0.735	0.010	0.019	0.112	0.370	0.165	0.711
<i>Xyleborinus saxesenii</i>	0.194	0.865	<0.001	0.526	0.680	0.030	0.192
<i>Xyleborus</i> spp.	0.024	0.227	<0.001	0.777	0.402	0.799	0.239
<i>Xylosandrus crassiusculus</i>	0.353	0.982	<0.001	0.635	0.982	0.174	0.757
Trogossitidae							
<i>Temnoscheila virescens</i>	0.714	0.349	<0.001	0.986	0.937	0.489	0.551
Reduviidae							
<i>Apiomerus crassipes</i>	0.720	0.465	<0.001	0.984	0.409	0.793	0.168

*F* values presented in Supp Table (online only).

were unaffected by lure treatments ( $F_{7,49} = 1.649$ ,  $P = 0.144$  and  $F_{7,49} = 1.583$ ,  $P = 0.163$ , respectively); mean ( $\pm$ SE) trap catch = 2.4  $\pm$  0.3 and 0.7  $\pm$  1.0, respectively.

There were significant effects of *syn*-2,3-hexanediol on trap catches of *N. acuminatus* in experiments 3 and 4 (Table 6). In addition, catches were affected by *anti*-2,3-hexanediol and the interaction between

*syn*-2,3-hexanediol and *anti*-2,3-hexanediol in experiment 3 with traps co-baited with 3-hydroxyoctan-2-one but not in experiment 4 with traps co-baited with 3-hydroxyhexan-2-one. Catches of *N. acuminatus*



**Fig. 2.** Interaction of *syn*-2,3-hexanediol (sD), *anti*-2,3-hexanediol (aD), and 3,2-hydroxyketone blend (K) on catches of the cerambycids *Neoclytus acuminatus* (A), *Curius dentatus* (B), *N. mucronatus* (C), *N. scutellaris* (D), *Anelaphus pumilus* (E), and *Bellamira scalaris* (F) in traps baited with ethanol (E) in north Georgia (experiment 2).

in traps baited with ethanol + 3-hydroxyoctan-2-one (experiment 3) or ethanol + 3-hydroxyhexan-2-one (experiment 4) were increased with the addition of *syn*-2,3-hexanediol (Fig. 3A and E). The addition of *anti*-2,3-hexanediol reduced catches of *N. acuminatus* in traps baited with ethanol + 3-hydroxyoctan-2-one + *syn*-2,3-hexanediol (Fig. 3A) but not those in traps baited with ethanol + 3-hydroxyhexan-2-one + *syn*-2,3-hexanediol (Fig. 3E). Catches of *Xylot. colonus* (Fig. 3B and F) were affected by *syn*-2,3-hexanediol in experiment 3 (Table 6) but not in experiment 4 ( $F_{3,21} = 0.971, P = 0.425$ ). Adding *anti*-2,3-hexanediol to traps baited with ethanol + 3-hydroxyoctan-2-one significantly increased catches of *Xylot. colonus* (Fig. 3B).

Catches of *K. cincta* in experiment 3 were affected by *anti*-2,3-hexanediol (Table 6) with the highest numbers in traps baited with ethanol + 3-hydroxyoctan-2-one + *anti*-2,3-hexanediol, with or without *syn*-2,3-hexanediol (Fig. 3C). In experiment 4, responses by *N. scutellaris* were affected by *syn*-2,3-hexanediol lure treatments (Table 6) with catches in traps baited with ethanol + 3-hydroxyhexan-2-one reduced by the addition of *syn*-2,3-hexanediol, regardless of the presence of *anti*-2,3-hexanediol (Fig. 3G). Catches of *N. mucronatus* were affected by *syn*-2,3-hexanediol in experiment 3 but not in experiment 4 (Table 6); the Holm-Sidak multiple-comparison test was unable to separate treatment means in experiment 3. There was no treatment effect on trap catches of *E. mucronatum* ( $N = 42$ ) in experiment 4 ( $F_{3,21} = 0.371, P = 0.775$ ); mean ( $\pm$ SE) trap catch =  $1.3 \pm 0.3$ .

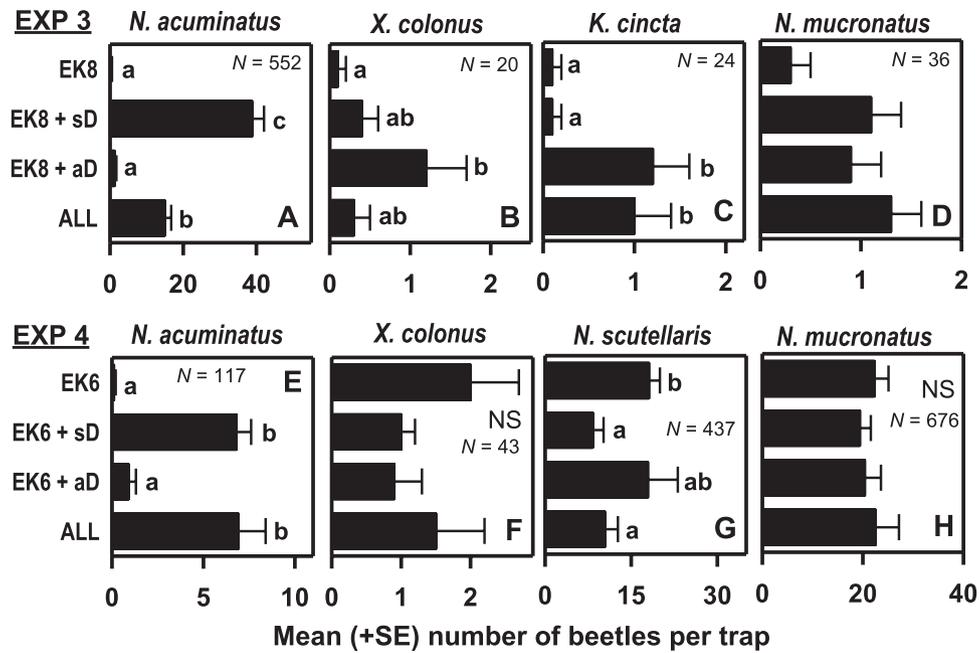
**Bark and Ambrosia Beetles (Coleoptera: Curculionidae)**

In experiment 1, 3-hydroxyoctan-2-one increased catches of *Cnestus mutilatus* (Blandford) and *Hypothenemus rotundicollis* Woods & Bright ( $N = 862$  and  $107$ , respectively) in traps baited with ethanol + *syn*-2,3-hexanediol but decreased catches of *Dryoxylon onoharaense* (Murayama) and *Xyleborus* spp. ( $N = 501$  and  $N = 42$ , respectively) (Fig. 4). There were no treatment effects on trap catches of *Cyclorhipidion bodoanum* (Reitter), *Hylocurus rudis* (LeConte), *Monarthrum fasciatum* (Say), *Monarthrum mali* (Fitch), *Stenoscelis brevis* Boheman, *Xyleborinus saxesenii* (Ratzeburg), *Xylosandrus compactus* (Eichhoff), *Xylosandrus crassiusculus* (Motschulsky), and *Xylosandrus germanus* (Blandford) (Table 4).

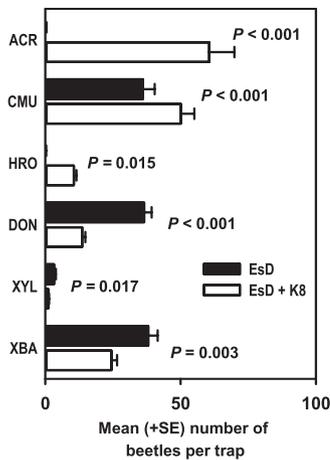
**Table 6.** ANOVA values for effects of *syn*-2,3-hexanediol treatment (sD), *anti*-2,3-hexanediol treatment (aD), and the interaction between the two treatments on trap catches of Bostrichidae, Cerambycidae, Cleridae, and Curculionidae in experiments 3 and 4

Species	Experiment	sD		aD		sD × aD	
		F <sup>a</sup>	P	F <sup>a</sup>	P	F <sup>a</sup>	P
<b>Bostrichidae</b>							
<i>Xylobiops basilaris</i>	3	63.52	<0.001	7.199	0.012	5.251	0.030
	4	17.98	<0.001	19.07	<0.001	4.537	0.045
<b>Cerambycidae</b>							
<i>Knulliana cincta</i>	3	0.216	0.646	15.65	<0.001	0.216	0.646
<i>Neoclytus acuminatus</i>	3	405.8	<0.001	4.668	0.040	22.89	<0.001
	4	135.4	<0.001	1.331	0.262	2.454	0.132
<i>Neoclytus mucronatus</i>	3	5.400	0.028	2.400	0.133	0.600	0.445
	4	0.227	0.638	0.112	0.741	0.236	0.632
<i>Neoclytus scutellaris</i>	4	18.06	<0.001	0.203	0.657	1.562	0.225
<i>Xylotrechus colonus</i>	3	0.886	0.355	3.147	0.087	5.287	0.029
<b>Cleridae</b>							
<i>Chariessa pilosa</i>	3	38.34	<0.001	0.088	0.769	0.155	0.696
<b>Curculionidae</b>							
<i>Cnestus mutilatus</i>	4	0.492	0.491	2.340	0.141	7.535	0.012

<sup>a</sup>df = 1, 27 in experiment 3; df = 1, 21 in experiment 4.



**Fig. 3.** Interaction of *syn*-2,3-hexanediol (sD) and *anti*-2,3-hexanediol (aD) on catches of the cerambycids *Neoclytus acuminatus* (A, E), *Xylotrechus colonus* (B, F), *Knolliana cincta* (C), *N. mucronatus* (D, H), and *N. scutellaris* (G) in traps baited with ethanol + 3-hydroxyoctan-2-one (EK8) (experiment 3) or ethanol + 3-hydroxyhexan-2-one (EK6) (experiment 4) in north Georgia. For each species, means followed by the same letter are not significantly different at  $P \leq 0.05$  (Holm-Sidak multiple-comparison test). NS =  $P > 0.05$ .



**Fig. 4.** Effects of adding 3-hydroxyoctan-2-one (K8) to traps baited with ethanol and *syn*-2,3-hexanediol (EsD) on mean trap catches of the beetles *Cnestus mutilatus* (CMU), *Dryoxylon onoharaense* (DON), *Hypothenemus rotundicollis* (HRO), *Xyleborus* spp. (XYL), and *Xylobiops basilaris* (XBA), and the assassin bug *Apiomerus crassipes* (ACR) in north Georgia (experiment 1). P = Significance level for paired t-test.

In experiment 2, the ketone blend affected catches of *Xyle. saxesenii*, *Xylos. crassiusculus*, *D. onoharaense*, *M. mali*, and *Xyleborus* spp. (Table 5). Catches of *Xyleborus* spp. were also affected by *syn*-2,3-hexanediol, whereas those of *M. mali* were affected by *anti*-2,3-hexanediol; catches of *D. onoharaense* and *Xyle. saxesenii* were affected by the interaction between *anti*-2,3-hexanediol and the ketone blend (Table 5). All traps baited with treatments that included the ketone blend caught more *Xyle. saxesenii* than traps baited solely with ethanol (Fig. 5A). A similar response profile was noted for *Xylos. crassiusculus* with catches in traps baited with ethanol + ketone blend greater than those in traps baited solely with ethanol (Fig. 5B). In contrast, the ketone blend reduced catches of *D. onoharaense*

in all treatments containing *anti*-2,3-hexanediol (Fig. 5C). Treatment effects on mean catches of *M. mali* and *Xyleborus* spp. were not discernible with the Holm-Sidak test (Fig. 5D and E).

Catches of the ambrosia beetles *Cn. mutilatus*, *Cyc. bodoanum*, and *Ambrosiodmus* spp. ( $N = 1,554$ , 122, and 67, respectively) in experiment 2 were not affected by lure treatments ( $F_{7,49} = 1.933$ ,  $P = 0.084$ ;  $F_{7,49} = 0.416$ ,  $P = 0.888$ ; and  $F_{7,49} = 0.611$ ,  $P = 0.744$ , respectively); mean ( $\pm$ SE) trap catch =  $24.3 \pm 2.2$ ,  $1.9 \pm 0.3$ , and  $1.0 \pm 0.2$ , respectively. Similarly, catches of the bark beetles *Hypothenemus* spp. and the snout weevil *S. brevis* ( $N = 97$  and 2,265, respectively) were unaffected by lure treatments in experiment 2 ( $F_{7,49} = 1.828$ ,  $P = 0.103$  and  $F_{7,49} = 0.897$ ,  $P = 0.516$ , respectively); mean ( $\pm$ SE) trap catch =  $1.5 \pm 0.2$  and  $35.4 \pm 2.2$ , respectively.

Hexanediol treatments had no effect on trap catches of all Curculionidae in experiment 3 and most Curculionidae in experiment 4 (Table 7). In experiment 4, catches of *Cn. mutilatus* were affected by the interaction between *syn*-2,3-hexanediol and 3-hydroxyhexan-2-one (Table 6) with catches in traps baited with ethanol + 3-hydroxyhexan-2-one + *syn*-2,3-hexanediol greater than those in traps baited with all four compounds (Fig. 6D).

#### Beetle Predators and Associates

In experiment 1, 3-hydroxyoctan-2-one decreased catches of the bostrichid *X. basilaris* ( $N = 624$ ) in traps baited with ethanol + *syn*-2,3-hexanediol (Fig. 4). In experiment 2, *X. basilaris* was affected by both *syn*- and *anti*-2,3-hexanediol; no other factor was significant (Table 5). Catches of *X. basilaris* in traps baited with five of the six combinations that included *syn*- and/or *anti*-2,3-hexanediol were greater than those in traps baited with ethanol alone (Fig. 7A). Catches of *X. basilaris* in experiments 3 and 4 were affected by all three model factors (Table 6). In experiment 3, traps baited with *syn*-2,3-hexanediol (with or without *anti*-2,3-hexanediol) caught the most *X. basilaris* and those without any hexanediol caught the least (Fig. 6A). In experiment 4, the addition of either or both hexanediol

blends to traps were baited with ethanol + 3-hydroxyhexan-2-one increased catches of *X. basilaris* (Fig. 6C).

In experiment 1, 3-hydroxyoctan-2-one increased catches of the assassin bug *Apiomerus crassipes* (F.) (Hemiptera: Reduviidae) ( $N = 608$ ) in traps baited with ethanol + *syn*-2,3-hexanediol (Fig. 4). Catches of *C. pilosa*, *Pyticeroides laticornis* (Say) (Coleoptera: Cleridae), *Catogenus rufus* (F.) (Coleoptera: Passandridae), *Temnoscheila*

*virescens* (F.), and *Tenebroides* spp. (Coleoptera: Trogossitidae) were unaffected by lure treatments in experiment 1 (Table 4).

In experiment 2, catches of *Ap. crassipes* and *T. virescens* were only affected by the ketone blend (Table 5) with catches of both species significantly greater in traps baited with the ketone blend than in those without the blend (Fig. 7B and C). *Madoniella dislocata* (Say) (Coleoptera: Cleridae) and *C. pilosa* were both affected by *syn*-2,3-hexanediol and the ketone blend, and the interaction between the two (Table 5). There was a significant effect of *anti*-2,3-hexanediol for *C. pilosa* but not for *Ma. dislocata*, whereas the interaction between the ketone blend and *syn*-2,3-hexanediol was significant for *Ma. dislocata* but not for *C. pilosa* (Table 5). The highest catches of both species were in traps baited with ethanol + *syn*-2,3-hexanediol (with or without *anti*-2,3-hexanediol) (Fig. 7D and E). Traps baited with ethanol + *syn*-2,3-hexanediol + *anti*-2,3-hexanediol had greater catches than those baited with ethanol + *syn*-2,3-hexanediol + ketone blend for *C. pilosa* but not *Ma. dislocata*. Catches of *C. pilosa* but not *Ma. dislocata* were greater in all traps that included the ketone blend than in traps baited with ethanol alone.

Catches of *Enoclerus ichneumonius* (F.) (Coleoptera: Cleridae) in experiment 2 were affected by *syn*-2,3-hexanediol, the ketone blend, and the interaction between *syn*-2,3-hexanediol and the ketone blend (Table 5). Beetle catches were significantly greater in traps baited with ethanol + *syn*-2,3-hexanediol + *anti*-2,3-hexanediol than in all other treatments, except traps baited with ethanol + *syn*-2,3-hexanediol (Fig. 7F). Adding the ketone blend to traps baited with ethanol + *syn*-2,3-hexanediol + *anti*-2,3-hexanediol significantly reduced catches of *En. ichneumonius*. Catches of *Tenebroides* spp. in experiment 2 ( $N = 343$ ) were unaffected by lure treatments ( $F_{7,49} = 0.779, P = 0.608$ ); mean ( $\pm$ SE) trap catch =  $5.4 \pm 0.4$ .

In experiment 3, catches of *C. pilosa* were affected by *syn*-2,3-hexanediol (Table 6) with the greatest catches in traps baited with ethanol + 3-hydroxyoctan-2-one + *syn*-2,3-hexanediol (with or without *anti*-2,3-hexanediol) (Fig. 6B). Hexanediol treatment had no effect on catches of *Ap. crassipes* in experiments 3 and 4 ( $N = 326$  and  $74$ , respectively) ( $F_{3,27} = 0.942, P = 0.434$  and  $F_{3,21} = 0.238, P = 0.869$ , respectively); mean ( $\pm$ SE) trap catch =  $8.2 \pm 0.07$  and  $2.3 \pm 0.3$ . Similarly, catches of *T. virescens* in experiment 4 and *Tenebroides* spp. in experiment 3 ( $N = 284$  and  $76$ , respectively) were unaffected by lure treatments ( $F_{3,21} = 0.337, P = 0.799$  and  $F_{3,27} = 0.123, P = 0.946$ , respectively); mean ( $\pm$ SE) trap catch =  $8.9 \pm 0.7$  and  $1.9 \pm 0.2$ , respectively.

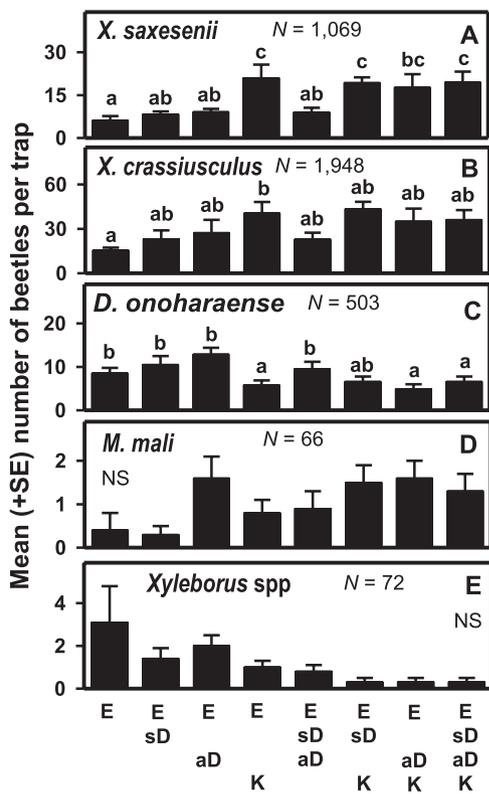
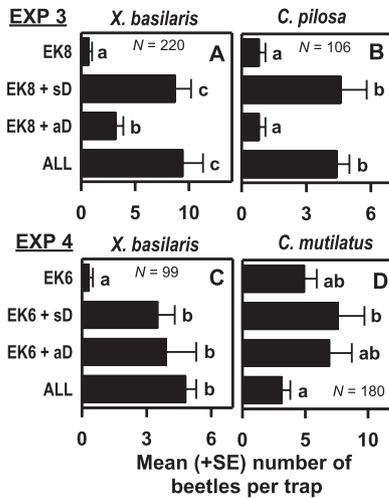


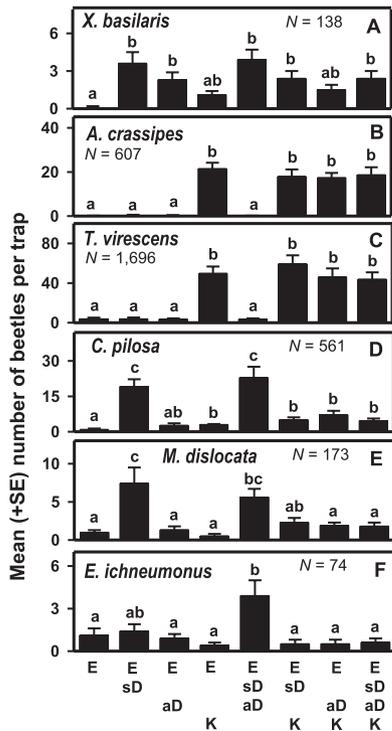
Fig. 5. Interactions of *syn*-2,3-hexanediol (sD), *anti*-2,3-hexanediol (aD), and 3,2-hydroxyketone blend (K) on catches of the ambrosia beetles *Xyleborinus saxesenii* (A), *Xylosandrus crassiusculus* (B), *Dryoxylon onoharaense* (C), *Monarthrum mali* (D), and *Xyleborus* spp. (E) in traps baited with ethanol (E) in north Georgia (experiment 2). NS =  $P > 0.05$ .

Table 7. Total beetle numbers (N), mean ( $\pm$ SE) number of beetles per trap, and F and P values (ANOVA) for Curculionidae species that exhibited no treatment effects in experiments 3 (df = 3, 27) and 4 (df = 3, 21)

Species	Experiment	N	Mean $\pm$ SE	F	P
<i>Ambrosiodmus</i> spp.	3	43	1.1 $\pm$ 0.2	2.130	0.120
<i>Cnesinus strigicollis</i>	4	49	1.5 $\pm$ 0.3	0.433	0.732
<i>Cnestus mutilatus</i>	3	1,024	25.6 $\pm$ 1.7	0.528	0.667
<i>Cyclorhipidion bodoanum</i>	3	41	1.0 $\pm$ 0.2	1.478	0.243
<i>Dryoxylon onoharaense</i>	3	97	2.4 $\pm$ 0.3	1.295	0.296
	4	261	8.2 $\pm$ 0.9	1.540	0.233
<i>Hypothenemus</i> spp.	3	327	8.2 $\pm$ 0.7	2.515	0.080
<i>Monarthrum fasciatum</i>	4	35	1.1 $\pm$ 0.5	1.374	0.278
<i>Monarthrum mali</i>	3	81	2.0 $\pm$ 0.3	0.648	0.591
	4	45	1.4 $\pm$ 0.3	0.973	0.424
<i>Stenoscelis brevis</i>	3	67	1.7 $\pm$ 0.2	0.012	0.998
<i>Xyleborinus saxesenii</i>	3	241	6.0 $\pm$ 0.5	1.409	0.262
	4	94	2.9 $\pm$ 0.3	0.610	0.616
<i>Xylosandrus crassiusculus</i>	3	1,558	39.0 $\pm$ 3.0	0.084	0.968
	4	1,041	32.5 $\pm$ 3.2	1.138	0.357



**Fig. 6.** Interaction of *syn*-2,3-hexanediol (sD) and *anti*-2,3-hexanediol (aD) on catches of *Xylobiops basilaris* (A, C), *Chariessa pilosa* (B), and *Cnestus mutilatus* (D) in traps baited with ethanol + 3-hydroxyoctan-2-one (EK8) (experiment 3) or ethanol + 3-hydroxyhexan-2-one (EK6) (experiment 4) in north Georgia. For each species, means followed by the same letter are not significantly different at  $P \leq 0.05$  (Holm-Sidak multiple-comparison test). NS =  $P > 0.05$ .



**Fig. 7.** Interactions of *syn*-2,3-hexanediol (sD), *anti*-2,3-hexanediol (aD) and 3,2-hydroxyketone blend (K) on catches of the assassin bug *Apiomerus crassipes* (A), and the predatory beetles *Tennoscheila virescens* (B), *Chariessa pilosa* (C), *Madoniella dislocata* (D), *Enoclerus ichneumonius* (E) and *Tenebroides* spp. (F) in traps baited with ethanol (E) in north Georgia (experiment 2).

## Discussion

Species-specific pheromone communication channels allow insects to maintain reproductive isolation with minimal risks of injury or death (Wyatt 2003). Such channels may be defined by unique pheromones or pheromone blends used by different species, as well as by

interruptive effects of one species' pheromone on the response of another species to its own pheromone (Greenfield and Karandinos 1979, Borden 1982, Miller 1991, Cardé and Haynes 2004, Bacquer et al. 2015, Allison and Cardé 2016, Silva et al. 2017). Even with simple chemical motifs such as 3,2-hydroxyketones or 2,3-hexanedioles as the pheromone basis for cerambycine species of Cerambycidae, channel separation can be achieved with the addition of minor pheromone components enhancing or interrupting beetle responses (Hanks et al. 2019, Silva et al. 2020).

We found evidence of pheromone channel separation among some cerambycid species captured in our study. We remind the reader that all lure combinations used in this study included an ethanol lure to act as a stressed host volatile and enhance longhorn beetle response to pheromones. However, to improve the flow of discussion of interacting effects of 3,2-hydroxyketones and 2,3-hexanedioles on trap catches, we have omitted the explicit mention of ethanol.

Traps baited with *syn*-2,3-hexanediol caught the most *N. acuminatus* (Fig. 2A, 3A, and 3B), whereas traps baited with *anti*-2,3-hexanediol caught the most *Cu. dentatus* (Fig. 2B). Adding *syn*-2,3-hexanediol to traps baited with *anti*-2,3-hexanediol had no effect on catches of *Cu. dentatus* (Fig. 2B), whereas adding *anti*-2,3-hexanediol to traps baited with *syn*-2,3-hexanediol (Fig. 2A) reduced catches of *N. acuminatus*. The contrasting effects of *syn*- and *anti*-hexanedioles on the behavior of *N. acuminatus* and *Cu. dentatus* were reported by Lacey et al. (2004) and Hanks et al. (2019) who showed that *N. acuminatus* produce *syn*-hexanediol only. The pheromones produced by *Cu. dentatus* are unknown at this time.

Hexanedioles can also help to separate the pheromone channels of other cerambycid species. Catches of *K. cincta* in traps baited with racemic 3-hydroxyoctan-2-one increased with the addition of *anti*-2,3-hexanedioles suggesting *R,S*- or *S,R*-2,3-hexanediol, or both may be components of its pheromone blend. Adding *syn*-2,3-hexanedioles to traps baited with racemic 3-hydroxyoctan-2-one + *anti*-2,3-hexanedioles did not interrupt catches of *K. cincta* (Fig. 3C). However, adding *syn*-2,3-hexanediol to traps baited with racemic 3-hydroxyhexan-2-one reduced catches of *N. scutellaris* (Fig. 3G) but not *N. mucronatus* (Fig. 3H) as in Millar et al. (2018). Both *N. mucronatus* and *N. scutellaris* use 3-hydroxyhexan-2-one as a pheromone (Lacey et al. 2007b; Miller et al. 2015, 2017; Mitchell et al. 2015; Ray et al. 2015; Millar et al. 2018; Hanks et al. 2019). Attraction of *Xylot. colonus* to one of its pheromones, *syn*-2,3-hexanediol (Lacey et al. 2009, Hanks and Millar 2013, Mitchell et al. 2015) was reduced by 3-hydroxyoctan-2-one (Fig. 1).

There was little evidence of any separation of pheromone channels for other cerambycid species. Traps baited with the hydroxyketone blend were attractive to *N. mucronatus*, *N. scutellaris*, *A. pumilus*, and *B. scalaris* with no effect from 2,3-hexanediol blends (Fig. 2C-F). 3-Hydroxyhexan-2-one is a pheromone for *A. pumilus* (Miller et al. 2015, Mitchell et al. 2015, Millar et al. 2018) and Miller et al. (2017) found interruption for *A. pumilus* to traps baited with ethanol + *syn*-2,3-hexanediol + 3-hydroxyhexan-2-one from the addition of 3-hydroxyoctan-2-one. Catches of *A. parallelus*, *A. villosus*, *Cl. marginicollis*, and *B. scalaris* in traps baited with ethanol + *syn*-2,3-hexanediol all increased with the addition of 3-hydroxyoctan-2-one (Fig. 1). Pheromone production has not yet been determined for *A. villosus*, *A. parallelus*, *Cl. marginicollis*, and *B. scalaris* although attraction of *A. villosus* and *A. parallelus* to ethanol + *syn*-2,3-hexanediol, and attraction of *Cl. marginicollis* to 3-hydroxyoctan-2-one have been documented (Hanks and Millar 2013; Miller et al. 2015, 2017). The identification of minor components may be important in separating these species (Hanks et al. 2019, Meier et al. 2020).

Channel separation for some of these species likely requires consideration of temporal patterns of activity (Hanks et al. 2012, 2014; Hanks and Millar 2013; Rassati et al. 2021). In Illinois, Mitchell et al. (2015) found seasonal and diel variation in pheromone-based behaviors among seven cerambycid species that all use 3-hydroxyhexan-2-one as their pheromone, separating the communication channels of these species. The same type of separation pattern has been demonstrated for pheromone communication channels in other taxa such as Lepidoptera (Greenfield and Karandinos 1979, Liénard and Löfstedt 2016).

Other parameters to separate channels may include spatial patterns of behaviors and host preferences (Hanks and Wang 2017). The preferred larval hosts for *Cl. marginicollis* are pines, whereas most of the other species develop in hardwood shrubs and trees, particularly oaks (*Quercus* spp.) and hickories (*Carya*); larval development for a few species such as *Xylot. colonus* can occur in pines and hardwoods (Lingafelter 2007). For those species that feed as adults, food preferences are known for only a few species and include flower pollen, leaves, needles, and twigs (Solomon 1995; U.S. Department of Agriculture [USDA] 1985; Graham et al. 2012). Ultimately, reproductive isolation with minimal injury from interspecific interference can likely still occur through proximal cues such as contact pheromones and acoustic, tactile, and visual signals (Wang 2002, Lu et al. 2007).

The role of 3-hydroxyoctan-2-one in the chemical ecology of *N. acuminatus* is unclear. We found that the addition of 3-hydroxyoctan-2-one to traps baited with ethanol + *syn*-2,3-hexanediol increased catches of *N. acuminatus* in a fashion consistent with data in Miller et al. (2017). Yet, 3-hydroxyoctan-2-one is not a known pheromone for *N. acuminatus* (Lacey et al. 2004, Ray et al. 2015, Hanks et al. 2019). It is possible that 3-hydroxyoctan-2-one may be released as a short-range pheromone in response to proximal chemical, tactile, acoustic, or visual cues. Alternatively, it might be an example of eavesdropping by individuals of one species on the channel used by individuals of a different species (Wyatt 2003). As adults, cerambycids require oviposition sites as well as feeding sites such as flowers, leaves, needles, or twigs (for those that feed as adults) (Solomon 1995, USDA 1985, Graham et al. 2012, Hanks and Wang 2017). Selection should favor individuals that can locate such resources in a timely manner. Tracking the channel of another species in conjunction with their own might get *N. acuminatus* adults closer to superior feeding and/or oviposition sites, large or rich enough to satisfy numerous species.

Additionally, cerambycids may be eavesdropping on channels of other species to find feeding, or oviposition sites, even in the absence of their own pheromones (Silva et al. 2017). Unlike Wong et al. (2012), Hanks and Millar (2013), and Millar et al. (2018), we found a low level of attraction by *N. acuminatus* to traps baited with *anti*-2,3-hexanediol and/or the ketone blend even in the absence of *syn*-2,3-hexanediol (Fig. 2A). Traps baited with ethanol + *syn*-2,3-hexanediol (with and without *anti*-2,3-hexanediol) caught more *N. mucronatus* than traps baited solely with ethanol (Fig. 2C). Traps baited with the ketone blend were attractive to *B. scalaris*, possibly as a pheromone or eavesdropping on pheromone channels of other species (Fig. 2F); pheromones have not yet been identified for *B. scalaris*.

Numerous species of bark and woodboring beetles eavesdrop on pheromone channels of other species, either to avoid interspecific interactions or to exploit them as kairomones. In western United States, two sympatric species of pine bark beetles, *Ips paraconfusus* Lanier and *Ips pini* (Say) (Coleoptera: Curculionidae), exhibit strong species specificity in their pheromone blends as well as

strong interspecific interruption in attraction (Birch and Wood 1975; Birch et al. 1977, 1980). In contrast, various species of pine sawyers, *Monochamus* spp. are attracted to pheromones produced by bark beetles, likely serving as kairomones that indicate the likelihood of high-quality oviposition sites for *Monochamus* spp. (Miller et al. 2013b, 2016). Similarly, the bark beetle *Ips avulsus* is attracted to ipsenol, a pheromone produced by the sympatric species *Ips grandicollis* but not *I. avulsus* (Allison et al. 2012). Acting as a kairomone, ipsenol provides *I. avulsus* with information allowing quick access to host material for colonization. In both cases, such sites tend to be unpredictable and ephemeral.

Ambrosia beetles are broadly attracted to traps baited with ethanol (Miller and Rabaglia 2009). Adults and larvae feed on ambrosia fungi selectively cultivated in galleries located in host material containing a high concentration of ethanol (Ranger et al. 2018). As in Miller et al. (2015), ambrosia beetles in our study seemed to be largely unaffected by 2,3-hexanediols although several species were affected by 3,2-hydroxyketones. As in Miller et al. (2015), catches of *D. onoharaense* in ethanol-baited traps were reduced by the addition of 3-hydroxyoctan-2-one (Fig. 4). In the present study, the ketone blend had a positive effect on catches of *Xyle. saxesenii* and *Xylos. crassiusculus* but negative effect on catches of *D. onoharaense* (Fig. 5A–C). In the Russian Far East, catches of several species of ambrosia beetles in ethanol-baited traps were reduced by 3-hydroxyoctan-2-one although there was no effect on catches of *Xyle. saxesenii* (Sweeney et al. 2016). In Italy, ambrosia beetles were largely unaffected by a lure blend that included *syn*-2,3-hexanediol and 3,2-hydroxyketones (Marchioro et al. 2020).

Catches of the twig beetle *H. rotundicollis* in traps baited with ethanol + *syn*-2,3-hexanediol increased with the addition of 3-hydroxyoctan-2-one (Fig. 4). Miller et al. (2015) noted that catches of *H. rotundicollis* in ethanol-baited traps were increased by the addition of either *syn*-2,3-hexanediol or 3-hydroxyoctan-2-one. In our study, attraction to 2,3-hexanediols was also noted for the bostrichid *X. basilaris*, another wood feeding species (Fig. 3A and C) with some interruption caused by 3-hydroxyoctan-2-one (Fig. 4). Similar results for *X. basilaris* were found in Miller et al. (2015) although there was some attraction to 3-hydroxyhexan-2-one. Our data provide a few insights into host use by a few non-cerambycid species that breed in woody tissues as well as support in adding lures for hardwood cerambycids in ethanol-based trapping programs for detection of exotic species of ambrosia beetles.

Predators have a clear benefit in eavesdropping on pheromone channels of their prey (Wyatt 2003). Miller et al. (2017) previously noted the attraction of various predatory species to cerambycid pheromones, particularly the hydroxyketones. In our study, specificity in attraction to traps baited with ethanol + *syn*-2,3-hexanediol was exhibited by the clerid predators *C. pilosa* (Fig. 6B and 7D) and *Ma. dislocata* (Fig. 7E), whereas others such as the bee assassin bug *Ap. crassipes* and the trogossitid *T. virescens* were attracted to traps baited with the ketone blend (Fig. 7A and B). The clerid *En. ichneumonius* was strongly attracted to traps baited with ethanol + *syn*-2,3-hexanediol + *anti*-2,3-hexanediol but interrupted by the ketone blend. The selection pressures causing these patterns are unknown but likely involve differences in prey and feeding sites.

A complete understanding of the chemical ecology of cerambycids will require consideration of all ecological factors and selection pressures, much of which may vary geographically with changes in forest composition. In addition to interspecific interactions between resource competitors, the activities of predators may exert selection pressure on communication channels used by bark and wood boring beetles (Raffa 2011).

## Supplementary Data

Supplementary data are available at *Environmental Entomology* online.

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