Mating Disruption for Managing *Prionus californicus* (Coleoptera: Cerambycidae) in Hop and Sweet Cherry

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Abstract

Larvae of *Prionus californicus* Motschulsky feed on the roots of many woody perennial plants and are economically important pests of hop *Humulus lupulus* L. (Urticales: Cannabaceae) and sweet cherry *Prunus avium* (L.) (Magnoliopsida: Rosaceae) in the United States Pacific Northwest and Intermountain West. Adult males are strongly attracted to a volatile sex pheromone, (3R,5S)-3,5-dimethyldodecanoic acid, produced by females. Here, we summarize the results of field experiments evaluating the synthetic pheromone in a blend of all four possible stereoisomers as a means for managing *P. californicus* in hop yards and sweet cherry orchards by mating disruption (MD). Mean capture of male beetles was lower, in all 3 yr of the study, from plots in commercial hop yards and sweet cherry orchards treated with synthetic *P. californicus* pheromone than from similar, untreated plots. Although trap catch was lower in sweet cherry, relative differences between trap catches from MD and nonmating disruption plots were similar to that seen in hop yards. The number of *P. californicus* larvae recovered from plots in hop yards treated for three consecutive growing seasons with synthetic pheromone was lower than in similar plots that were not treated with the pheromone or treated with the soil fumigant ethoprop. Our research demonstrates that deployment of synthetic *P. californicus* pheromone effectively reduces mate-finding by males, can effectively reduce larvae populations in pheromone-treated hop yards, and thus, has excellent potential for managing *P. californicus* in hop, sweet cherry, and perhaps in other crops where it or *Prionus* species are pests.

Key words: pest management, pheromone, 3,5-dimethyldodecanoic acid, root-borer

The California prionus, *Prionus californicus* Motschulsky, is broadly distributed throughout western North America where it feeds on roots of trees, woody shrubs, and vines (Linsley 1962). Adults are large (25–55 mm), crepuscular beetles that are active from late June through early September in the U.S. Pacific Northwest and Intermountain West (Barbour et al. 2006, Alston et al. 2007). Adults do not feed, and therefore live only 2–3 wk (Barbour et al. 2006). Females deposit 150–200 eggs in soil near the base of living host plants and the larvae feed on the roots for 3–5 yr before pupating (Linsley 1962, Bishop et al. 1984). As they feed, larvae prune smaller roots and bore into larger roots and crowns resulting in reduced plant growth due to decreased nutrient uptake and moisture stress (Alston et al. 2010). Heavy infestations of the larvae cause wilting, yellowing, and death of individual limbs, vines/bines, or even entire plants (Bishop et al. 1984, Solomon 1995). Its broad host range includes many woody agricultural, ornamental, and native plants (Solomon 1995). In the U.S. Pacific Northwest and Intermountain West, *P. californicus* is a serious pest of hop *Humulus lupulus* L. (Urticales: Cannabaceae) and sweet cherry *Prunus avium* (L.), (Magnoliopsida: Rosaceae) (Bishop et al. 1984, Alston et al. 2007).

Management options for *P. californicus* in hop and sweet cherry are few and generally consist of a combination of cultural and insecticidal methods. Cultural control entails completely removing the crowns and roots of plants from heavily infested hop yards and cherry orchards, and then either fallowing soil or planting to a nonhost for ≥3 yr between host-crop plantings. Alternatively, removal of infested plant material in the fall can be followed by a preplant soil fumigation the following spring. Neither option is highly effective or economically sustainable. Larvae in fallowed hop yards may persist by feeding on the buried portion of hop trellis poles and
other woody debris remaining after removal of hop crowns (J.D.B., personal observation). Larvae in infested Utah cherry orchards are known to persist as long as 5 yr in an alfalfa rotation crop (M.P., personal observation). These observations suggest that alfalfa, and perhaps other crops, may not provide an effective nonhost rotation crop. Fumigation is prohibitively expensive (> $900/ha for chemical costs alone; Galinato and Tozer 2016). Fallowing is undesirable, particularly in hop because the trellis system upon which the hops are grown limits the options for producing an alternative crop, and it is not economical to remove and later replace the trellis system (> $4,940/ha for labor alone; Galinato and Tozer 2016). Finally, the organophosphate soil insecticide ethoprop (Mocap EC, Bayer Crop Science, Research Triangle Park, NC) is labeled for management of *P. californicus* in hop, but the efficacy of this chemical is unknown and its use poses a threat to wildlife (Patterson 2003) and is a health hazard for farm workers (Amen and Stratton 1991). No insecticides are labeled for control of *P. californicus* in sweet cherry, and experiments with the systemic insecticide, imidacloprid (Admire Pro, Bayer Crop Science), found no effect on older larvae within woody roots and crowns (Alston et al. 2010). Thus, there is a great need for new, sustainable, management tactics for *P. californicus* in hop and sweet cherry production.

Female *P. californicus* produce a volatile sex pheromone, (3R,5S)-3,5-dimethyl-3-decanoic acid, to which males are strongly attracted (Cervantes et al. 2006, Rodstein et al. 2009). Males respond equally well to a synthetic blend of all four of the possible stereoisomers of the compound, which is more economical to produce than the pure (3R,5S) stereoisomer (Rodstein et al. 2011). Sex pheromones have been used effectively to manage insect pests by hindering mating, either by mass trapping (removing males from the population) or by mating disruption (inundating the habitat with synthetic pheromone such that males cannot locate mates; Millar 2007, Witzgall et al. 2010). As far as we are aware, pheromones methods used to date to manage large beetles in crops consist of aggregation pheromones that attract both sexes. Here, we summarize large plot field research evaluating pheromone-based management of *P. californicus* in hop yards and sweet cherry orchards by mating disruption using a sex pheromone that attracts only males, and document subsequent reduction of larvae numbers in mating disrupted hop yards.

**Materials and Methods**

**Capture of Males in Mating and Nonmating Disrupted Plots: Hop**

We compared capture of *P. californicus* males in mating disrupted (MD) versus nonmating disrupted (NMD) plots in commercial hop yards (≥ 65 ha each) in Idaho (2011–2013) and Washington (2011 and 2012). *Prionus californicus* males were monitored using pheromone-baited pitfall (2011) or panel traps (2012 and 2013) beginning in late June of each year. In each year, three fields in each state with high trap captures were selected for experiments. Pitfall traps were made from 1.9-liter plastic funnels (model 3864, Hutzler Mfg. Co., Inc., Canaan, CT) and 1.9-liter plastic jars (model 55-650C, General Bottle Supply Company, Los Angeles, CA) with threaded lids. The funnel spout was shortened to produce a 35-mm-diameter opening. A 7.5-cm hole was drilled into the center of the jar lid and the funnel glued to the lid so that the jar could be attached with the spout inside the jar. In Idaho, the assembled traps were buried between hop rows so that the funnel rim was flush with the ground and growers avoided cultivation in areas where pit fall traps were located. In Washington, growers required pitfall traps to be placed in hop rows. Panel traps consisted of black corrugated plastic, 1.2-m tall x 0.3-m wide (Alpha Scents AST0031; West Linn, OR) with the supplied collection jar replaced by our pitfall trap basins described above. Using panel traps allowed us to place traps in the hop rows to avoid interference with cultivation and other farming operations. Preliminary studies showed the panel traps performed as well as pitfall traps (J. D. B., unpublished data). Panel traps and funnels used in pitfall and panel trap basins were not coated with fluon since trap catches in preliminary experiments were generally high and we were not comparing trap catch among different cerambycid species (see Graham et al. 2010). Pitfall and panel traps were baited with monitoring lures, consisting of 5 × 7.5-cm press-seal bags (# 01-816-1A, Fisher Scientific, Santa Clara, CA) and containing 0.1 mg of synthetic *P. californicus* sex pheromone (3,5-dimethyl-3-decanoic acid in ethanol). Monitoring lures were suspended ~15 cm over pitfall traps with a stiff wire inserted into the ground immediately adjacent to the trap and were suspended from the center opening of panel traps using a paper clip. The 0.1-mg lures are more attractive than an actual female, but we reasoned they would provide a conservative estimate of mating disruption potential (Maki et al. 2011, Rodstein et al. 2011). Lures in surrogate female traps were replaced weekly to assure consistent pheromone release rates. Monitoring traps were checked twice weekly and MD treatments were established in selected fields within 1 wk of when first capture of *P. californicus* males indicated that beetle flight had begun.

Hop plants in a hop yard are grown on a wire and cable trellis supported about 5.5 m above the ground by vertical poles established in a regular grid with poles 9.1 m apart. Plants are grown in rows 4.55 m apart with alternating rows of hop plants in and between pole rows, with 1.1 m between plants within rows. In 2011, using the standard 9.1-m grid of poles supporting the hop trellis, we established three MD plots and one NMD plot in each of the three Idaho and Washington hop yards (replicates) selected for the study. Plots were seven poles wide (55 m) by 21 poles long (182 m). Each MD plot was treated with 63, 126, or 246 Isomate (Pacific Biocontrol Corporation, Vancouver, WA) style dispensers per hectare. Each dispenser contained 50 mg of synthetic *P. californicus* pheromone. Dispensers were stapled to trellis poles, taking care not to puncture the dispensers, or twisted securely around trellis strings, 1–1.5 m above the ground. NMD plots contained no pheromone dispensers. There was a 91-m buffer between MD and NMD plots and at least 18 m between NMD plots. To avoid problems with carry-over effects of treatments, pheromone dispensers were recovered from MD plots at the end of each growing season and no field was used in two consecutive years.

Based on 2011 results, the experimental design was changed in 2012 and 2013 to three hop yards in each state comparing one MD plot containing 246 Isomate lures per hectare with one NMD plot. Field and plot size and selection were as 2011, except there were two plots per yard with at least 91 m between plots. In all years, MD treatments were not assigned randomly to plots but were assigned so that NMD and lower concentration MD plots were upwind of each other. Male beetles were collected twice weekly until trap catches in preliminary experiments were generally high and we were not comparing trap catch among different cerambycid species (see Graham et al. 2010). Pitfall and panel traps were baited with monitoring lures, consisting of 5 × 7.5-cm press-seal bags (# 01-816-1A, Fisher Scientific, Santa Clara, CA) and containing 0.1 mg of synthetic *P. californicus* sex pheromone (3,5-dimethyl-3-decanoic acid in ethanol). Monitoring lures were suspended ~15 cm over pitfall traps with a stiff wire inserted into the ground immediately adjacent to the trap and were suspended from the center opening of panel traps using a paper clip. The 0.1-mg lures are more attractive than an actual female, but we reasoned they would provide a conservative estimate of mating disruption potential (Maki et al. 2011, Rodstein et al. 2011). Lures in surrogate female traps were replaced weekly to assure consistent pheromone release rates. Monitoring traps were checked twice weekly and MD treatments were established in selected fields within 1 wk of when first capture of *P. californicus* males indicated that beetle flight had begun.

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species occurring in the Western United States have 11 or 13 antennae segments (Linsley 1962).

Capture of Males in MD and NMD Plots: Sweet Cherry

Trials were conducted from 2011 to 2013 in 10 sweet cherry orchards ranging in size from 0.2 to 1.7 ha in Perry and Willard, Utah (Box Elder County). Five of the orchards were used in >1 yr; however, none were treated with MD and then converted to NMD in a subsequent year. One orchard was treated with MD in all 3 yr, two orchards received MD dispensers in two consecutive years, and two orchards served as NMD controls in two consecutive years. The remaining five orchards were used in only 1 yr of the study. Orchards served as replicates; across the 3 yr, a total of 10 replicates were treated with MD dispensers, and seven replicates served as NMD controls.

The distance between MD and NMD orchards ranged from 0.3 to 5.8 km, and for those ≤1.6 km apart, MD-treated orchards were upwind of NMD orchards (Utah Climate Center, Orchard Weather Data, Perry, Sumida Farm: https://climate.usur.usu.edu/station-stuff.php). Isolate dispensers, the same as those used in hops, were placed at a rate of 246 dispensers/ha in late June or early July (20 June 2011; 2 July 2012; and 9 July 2013). Dispensers were stapled to tree trunks 10–20 cm above the soil line or placed on the ground near the trunk base.

In each orchard, four pitfall traps were placed in tree rows (at least five rows apart) in a rectangular pattern. MD dispensers were deployed on the same date as traps (2011) or 1 wk later (2012 and 2013). Traps were composed of 13.2- or 18.9-liter plastic buckets buried in the ground so that the rim was 2.5 to 5.0 cm above the soil line. The bucket handle was held upright by a plastic cable tie secured through a hole drilled in the bucket side. Pheromone lures serving as surrogate females were attached to the top of bucket handles with metal binder clips (2-cm wide). A 30.5-cm diameter aluminum funnel (Universal black light trap; Bioquip Products Inc., Rancho Domingo, CA) was placed on the bucket rim to guide the insects into the bucket.

Two pheromone lures were compared: 0.1 mg of synthetic *P. californicus* pheromone in press-seal bags as per hop experiments and commercial lures containing 30 mg of synthetic *P. californicus* pheromone (Contech Enterprises Inc., Victoria, BC, Canada). Two traps per orchard were baited with each lure type. Traps were checked weekly for 10–12 wk through mid-to late September. During each check, male beetles were collected and lures rotated clockwise to the next trap position. About 30-mg lures were replaced every 4 wk, and 0.1-mg lures were replaced weekly (2011 and 2012) or biweekly (2013). Beetles were identified as *P. californicus* as described above.

Recovery of Larvae From Crowns and Roots in MD and NMD Plots: Hop

Larvae recovery experiments were conducted in Idaho hop yards with field selection and plot arrangement as previously described with the following modifications. Three fields (replications) were selected in 2013 and three plots established in each field. One MD plot containing 246 dispensers/ha and one NMD plot were established as described for male capture experiments. An additional NMD plot treated 7- to 10-d postharvest with ethoprop (Mocap EC) at 4.7 liter/ha (3.36 kg ai/ha) was established to compare control provided by MD and the standard in-season insecticide management option. This plot arrangement was repeated in the same fields for three consecutive years through 2015 with all treatments in the same locations each year. Pheromone dispensers in MD plots were removed immediately before harvest each growing season and replaced with fresh dispensers each summer in mid-June before the *P. californicus* flight had begun. This multi-season replication of the same plots was necessary to reliably detect differences in larvae number between treated and untreated plots because of the 3- to 5-yr life-span of *P. californicus* larvae.

In fall of 2015, we destructively sampled MD and NMD plots using a tractor-mounted cylinder borer (30-cm dia. × 30-cm deep) to remove hop crowns, roots, and associated soil from 15 hills per plot. Borer contents were transferred to 18.9-liter buckets and transported to our laboratory where soil was sifted through a 0.3175-cm mesh hardware cloth screen, the roots and crowns dissected, and all *P. californicus* larvae.  

Data Analyses

The hypotheses for male capture and larvae recovery experiments were that fewer males would be captured and fewer larvae recovered from MD plots than from NMD plots, respectively. If ethoprop applied postharvest effectively controls *P. californicus* larvae, numbers of larvae in control (NMD) plots also should be higher than those in ethoprop-treated plots.

Because of the large number of '0' means from MD plots in male capture experiments, we used the nonparametric Friedman's test to compare the mean number of males captured per four traps over all sample days for each state, blocked by sample day and replicate (field). In experiments with more than two treatments, means were separated using the Ryan-Einot-Gabriel-Welsch Q multiple comparison test (REGWQ) to control the maximum experiment-wise error rate (SAS Institute 2009). For male capture experiments, we also calculated reduction of males captured in surrogate female traps as percentage trap shutdown: \(1 - x/y\) × 100, where \(x\) is the number of males caught in each MD treatment and \(y\) is the number of males caught in the NMD (control) plots. Percentage trap shutdown was quantified by averaging percentage trap shutdown values for the fields in each state for each sampling period. Sampling periods in which no beetles were captured in control traps were eliminated from analyses. Larvae recovery experiments were analyzed by two-way analysis of variance for the effect of MD and NMD treatments on the number of larvae per hop crown recovered using field as a replicate. Means were separated by Student’s Protected LSD test.

Results

Capture of Male Beetles in MD Versus NMD Plots: Hop

The number of males captured by surrogate female traps (0.1-mg lure) in NMD (control) plots from both states peaked in early August of 2011, and mid-July of 2012 and 2013 (Fig. 1). After mid-August, trap catches in both states declined rapidly. This decrease represents the natural decline of the beetle population and was not due to decreasing pheromone concentration, since surrogate female lures were replaced weekly. The total number of beetles captured each year was 506 (235 Idaho; 271 Washington) in 2011, 882 (696 Idaho; 235, Washington) in 2012, and 1,261 in Idaho in 2013. More beetles were captured from NMD plots than from MD plots over most of the trapping period (Fig. 1).

In each of the 3 yr, mean capture of male beetles was significantly reduced in MD as compared to NMD plots in Idaho (Fig. 2A–C: 2011, \(Q_{2,115} = 75.65, P < 0.0001\); 2012, \(Q_{2,119} = 142.04, P < 0.0001\); 2013, \(Q_{2,167} = 103.80, P < 0.0001\)) and Washington (Fig. 2D and E: 2011, \(Q_{2,123} = 57.97, P < 0.0001\); 2012, \(Q_{2,191} = 20.82, P < 0.0001\)).
In Idaho, although fewer males were captured in 2011 from MD than NMD plots, male capture did not differ among plots treated with 63, 126, or 246 MD dispensers/ha (Fig. 2A). In the similar experiments in Washington in 2011, however, capture of males among disrupted plots decreased with increasing dispenser rate (Fig. 2D). For MD plots, capture of males was lowest with 246 dispensers/ha, intermediate with 126 dispensers/ha, and highest with 63 dispensers/ha. Although the total number of *P. californicus* males captured in respective MD and NMD plots was similar from Idaho and Washington in 2011, a higher percentage of beetles was captured from MD plots in Washington (42%) than in Idaho (7%), most of the increase coming from plots treated with fewer pheromone dispensers/ha. As a result, percentage trap shutdown in Washington hop yards was only 55 and 76%, respectively, from plots treated similarly. It is possible that the differences between the Idaho and Washington results in this experiment result from differences in the beetles’ access to pitfall traps that were placed in the relatively open area between hop rows in Idaho hop yards and in the close cover of the hop understory of hop rows in Washington hop yards. Percentage trap shutdown with 246 pheromone dispensers per ha was 94 and 97% for Washington and Idaho, respectively.

In 2012 and 2013, when all MD plots were treated with 246 dispensers per ha, the mean number of males caught in MD plots was ≤2, for both states, while the mean number from NMD plots was 9.5 in Washington in 2012 (Fig. 2E), and 19 to >45 males in Idaho in 2012 (Fig. 2B) and 2013, respectively (Fig. 2C). Mean percentage trap shutdown ranged from 83 to 98%.

**Capture of Male Beetles in MD Versus NMD Plots: Sweet Cherry**

As in experiments with hop, more *P. californicus* were captured from NMD plots in Utah sweet cherry orchards over much of the trapping period (Fig. 3A–C) and trap capture peaked in mid-July across all 3 yr. More beetles were captured in 2011 (total, X ± SEM = 281, 2.9 ±
0.85), than in 2012 (54, 0.6 ± 0.13) or 2013 (161, 1.3 ± 0.37) (Q1, 318 = 9.4083, P < 0.0091). Mean trap capture of males (Fig. 3D–F) was higher in NMD than in MD plots for each year of the study (2011: Q1, 95 = 15.2069, P < 0.0001, 2012: Q1, 95 = 15.2105, P < 0.0001, 2013: Q1, 95 = 18.00, P < 0.0001) and was >11 times higher in NMD than MD orchards across the 3 yr (3.38 ± 0.69 vs. 0.26 ± 0.05, Q1, 318 = 47.5152, P < 0.0001). Traps baited with 30-mg lures captured more males than traps baited with 0.01-mg lures in 2011 (Q1, 95 = 17.2857, P < 0.0001) and 2012 (Q1, 95 = 8.0667, P = 0.0045), but not in 2013 (Q1, 95 = 1.1905, P = 0.2792). Over all 3 yr, capture was 2.7 times higher in traps baited with 30- than 0.1-mg synthetic pheromone (2.24 ± 0.55 vs. 0.86 ± 0.22, Q1, 115 = 22.5625, P < 0.0001). Percentage trap shutdown (Fig. 4) only in NMD than in MD plots for each year of the study (2011: Q1, 95 = 17.2857, P < 0.0001) and 2012 (Q1, 95 = 8.0667, P = 0.0045), but not in 2013 (Q1, 95 = 1.1905, P = 0.2792). Over all 3 yr, capture was 2.7 times higher in traps baited with 30- than 0.1-mg synthetic pheromone (2.24 ± 0.55 vs. 0.86 ± 0.22, Q1, 115 = 22.5625, P < 0.0001). Percentage trap shutdown (Fig. 4) over the 3 yr ranged from 81 to 95% across treatment and lure rates and was similar for 0.1- and 30-mg lures (2011: Q1, 26 = 3.664, P = 0.0557, 2012: Q1, 15 = 1.1049, P = 0.2932, 2013: Q1, 15 = 1.3568, P = 0.2441).

**Recovery of Larvae From Hop Crowns and Roots in MD and NMD Plots**

The mean number of *P. californicus* larvae recovered per hop crown from MD plots treated for three consecutive years with 246 *P. californicus* pheromone dispensers per hectare (0.20 ± 0.09; Fig. 5) was significantly lower than from untreated and ethoprop-treated plots (F4,126 = 5.07, P = 0.0076). There was no difference between the number of larvae recovered from the NMD (1.04 ± 0.25) control and ethoprop-treated plots (1.00 ± 0.28).

**Discussion**

Our findings support those of an earlier experiment in hop conducted in smaller plots (342 and 1,296 m²; Maki et al. 2011) and confirm that use of synthetic sex pheromone for mating disruption is a potentially viable management option for *P. californicus* in hop. Using 246 dispensers/ha with 0.1-mg trapping lures, we demonstrated a mean percentage trap shutdown of 92% across hop yards in Idaho and Washington and sweet cherry orchards in Utah over 3 yr. Although the numbers of male beetles captured in sweet cherry were an order of magnitude less than that in hop, relative differences between trap catches from MD and NMD plots were similar, and percentage trap shutdown was therefore similarly high. Our results suggest that dispenser rates of <246/ha with 50-mg Isomate dispensers such as used...
in our experiments may not provide reliable percentage trap shutdown; however, research has not been conducted to directly compare reduction in trap shutdown to larvae infestation levels. Our research does show a fivefold reduction of larvae in plots treated for three consecutive years with \textit{P. californicus} sex pheromone at a rate of 246 dispensers/ha compared with insecticide treated and nontreated plots. Taken together these results indicate that mating disruption can be an effective method for managing \textit{P. californicus} in hops and sweet cherry. These results also demonstrate that the use of ethoprop applied postharvest is ineffective for \textit{P. californicus} management.

The life history traits of \textit{P. californicus} should render it particularly suitable for management by mass trapping and mating disruption (see Millar 2007, Witzgall et al. 2010). The adults are nonfeeding, and therefore, short-lived. Consequently, adults are under strong selection pressure to find mates before exhausting...
their limited energy reserves. Since the adult activity period is only 6–8 wk/yr, pheromone dispensers and lures need only have an effective field life of about 8 wk. The beginning of the adult flight period is easily detected with pheromone-baited traps so that mass-trapping or mating disruption can be deployed accurately to maximize their impact and minimize costs. Finally, the long generation time of this species (3–5 yr) should slow recovery of local populations that have been suppressed by these tactics and repeated annual applications of mass trapping and/or mating disruption could dramatically reduce population densities to levels below the economic injury level, with populations subsequently maintained at low levels with little management effort.

Our results support the use of the *P. californicus* sex pheromone as a mating disruption tool to reduce populations of the beetle in agricultural crops. Pheromone-based management strategies are likely to be adopted by hop and sweet cherry growers because they are high value crops, grown on limited acreage, and current management alternatives for *P. californicus* are uneconomical, impractical, or ineffective (see Introduction and Results). Commercial costs associated with management of *P. californicus* by mating disruption are not currently known. However, commercial sources for similar, existing pheromone dispensers indicate a cost of $65–$123 per ha for dispensers alone at 264 dispensers/ha (J D B., personal observation) This price range appears to be competitive with the approximately $192/ha costs of applying ethoprop, the currently labeled insecticide ethoprop (Mocap) as per the current label, or left untreated for *P. californicus* (UTC).

While additional research is needed to address these and other questions, such semiochemical-based management strategies have proven to be both highly successful and cost effective for managing other large beetle species that are important pests via mass trapping (Hallett et al. 1999, Oelschlager et al. 2002, Soroker et al. 2005, Faleiro 2006) and have shown potential for effective management via mating disruption (Koppenhofer et al. 2005, Wenninger and Averill 2006). This is the first study that we are aware of documenting control of a long-lived beetle species by mating disruption using a sex pheromone as opposed to mass-trapping using an aggregation pheromone. If *P. californicus* can be managed effectively with pheromone-based tactics in hop and sweet cherry, these methods also may be used to manage this insect in other crop systems, such as apple (*Malus* spp.) and peach (*Prunus persica* (L.)) where it can be a significant pest (Bishop et al. 1984, Solomon 1995, Alston et al. 2010, Agnello et al. 2018). Furthermore, our previous research has demonstrated that males of several other *Prionus* species, including species that are important pests in other crops, are highly attracted to the pheromone of *P. californicus* or to one or more of its isomers (Barbour et al. 2011). This finding suggests that the structures of female-produced pheromones may be highly conserved among closely related species in the subfamily Prioninae and that other pest species in this subfamily may be suitable targets for pheromone-based management. Dutcher and Bactawar (2016) found the *P. californicus* pheromone can be used to effectively monitor and manage *P. laticollis* and *P. imbricornis* by mass trapping via an attract-and-kill strategy in U.S. pecan orchards. Agnello et al. (2018) have shown the *P. californicus* sex pheromone has potential for management of *P. laticollis* in New York apple orchards and Wickham et al. (2016) found the *P. californicus* sex pheromone to be attractive to *Dorythesthes granulosus*, which is a pest of sugar cane in China.

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