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Pheromone Lure and Trap Color Affects Bycatch in Agricultural Landscapes of Utah

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ABSTRACT

Aerial traps, using combinations of color and attractive lures, are a critical tool for detecting and managing insect pest populations. Yet, despite improvements in trap efficacy, collection of non-target species ("bycatch") plagues many insect pest surveys. Bycatch can influence survey effectiveness by reducing the available space for target species and increasing trap screening time, especially in areas where thousands of insects are captured as bycatch in a given season. Additionally, bycatch may negatively impact local non-target insect populations, including beneficial predators and pollinators. Here, we tested the effect of pheromone lures on bycatch rates of Coccinellidae (Coleoptera), Apoidea (Hymenoptera), and non-target Lepidoptera. Multicolored (primarily yellow and white) bucket traps containing a pheromone lure for capturing one of three survey target species, *Spodoptera litura* (Fabricius), *S. littoralis* (Boisduval), or *Helicoverpa armigera* (Hübner), were placed in alfalfa and corn fields, and compared to multicolored traps without a pheromone lure. All-green traps with and without *H. armigera* lures were employed in a parallel study investigating the effect of lure and trap color on bycatch. Over 2,600 Coccinellidae representing seven species, nearly 6,400 bees in 57 species, and more than 9,000 non-target moths in 17 genera were captured across 180 traps and seven temporal sampling events. Significant effects of lure and color were observed for multiple taxa. In general, non-target insects were attracted to the *H. armigera* lure and multicolored trap, but further studies of trap color and pheromone lure specificity are needed to better understand these interactions and to minimize non-target captures.

KEY WORDS: beneficial insects, bumble bees, lady beetles, non-target, bycatch

Insect traps are important tools for monitoring pest populations in surveys and integrated pest management (IPM) programs. Traps can help detect invasions by novel pest species, the onset of seasonal pest activity, determine the range and intensity of pest infestations, and track changes in pest populations, all which help inform decision making for pest management (Knodel et al. 1995). Traps typically use olfactory (chemical) and/or visual cues or stimuli to attract pest insects. Therefore, traps are ideally specific to the species being monitored, thus reducing the amount of handling time per trap and limiting the cost of trap monitoring and maintenance, while increasing the chance of early detection (Adams et al. 1989, Pair et al. 1989, Weber and Ferro 1991). Guerrero et al. (2014), for example, found that more male *Helicoverpa* moths were captured in bucket than sticky traps, and that sticky traps required more processing time than bucket traps. To further maximize trap effectiveness, trap design and trap color are often paired with specific pheromone or floral scent lures to attract target pests. For example, Haynes et al. (2007) found that male eastern tent caterpillar moths (*Malacosoma americanum*, Fabricius) were more attracted to orange delta traps baited specifically with a 9:1 blend of (E,Z)-5,7-dodecadienal and (E,Z)-5,7-dodecadienol than to other combinations of trap design, color, blend ratios, and loading dose.

Despite attempts to improve monitoring efficacy for target species, insect traps catch many non-target insects, including beneficial and rare species (Spears and Ramirez 2015). In particular, white or yellow traps attract larger numbers of lady beetles (Coccinellidae), honey bees (*Apis mellifera*, Linnaeus) and native bees, including different species of bumble bees (*Bombus* spp.) and sweat bees (e.g., *Lasioglossum* spp.), than darker colored traps (Hamilton et al. 1971, Gross and Carpenter 1991, Meagher and Mitchell 1999, Clare et al. 2000, Weber et al. 2005, Mori and Evendon 2013, Kemp and Cottrell 2015). Similarly, Asian ladybird beetle traps (semitransparent blue) catch higher numbers of bees and are thus more effective for monitoring bee diversity than yellow Japanese beetle traps (Stephen and Rao 2005).

Many insects are equipped with photoreceptors and may rely on color to find flower resources (Briscoe and Chittka 2001). It is not surprising then that non-target insects are attracted to some monitoring traps of a particular color. Pheromone blends, however, are usually designed to be species-specific, even though congeners and unrelated species may still be strongly attracted to the lures (Landolt et al. 2006, Keathley et al. 2013, Guerrero et al. 2014, Kelly et al. 2015). Some predators have also evolved to detect these pheromones and may use them to identify and locate prey (Zhu et al. 1999, Verheggen et al. 2007). Although there have been many efforts to increase trap and pheromone specificity and decrease capture of non-target insects (e.g., Fleischer et al. 2005, Martín et al. 2013, Mori and Evenden 2013, Panzavolta et al. 2014), some trap and lure combinations are so attractive to beneficial insects that they become unacceptable pest management tools (Aurelian et al. 2015). In general, knowledge of pheromone lure effects on non-target insects is lacking for most species-specific blends, particularly those used during nationwide invasive pest surveys supported by the Cooperative Agricultural Pest Survey (CAPS) program (http://caps.ceris.purdue.edu) (Spears and Ramirez 2015).

The objectives of this study were to investigate the effects of pheromone lures and lure-trap color interactions on bycatch of lady beetles, bees, and non-target moths collected during invasive pest surveys in an agricultural landscape in Utah.

Materials and Methods

Lure Effects on Bycatch. Insect pheromone traps were placed near each of 15 alfalfa and 15 corn fields in Cache, Box Elder, Weber, Utah, and Millard counties, UT (Fig. 1), as part of an early-detection survey for invasive field crop pests following national CAPS guidelines (CAPS 2014). Four multicolored (green canopy, yellow funnel, and white bucket) Unitraps (International Pheromone Systems, Cheshire, UK) were installed along the roadside edge of each field, corresponding to one trap per field for each of the target pests old world bollworm (*Helicoverpa armigera*, Hübner, OWB), cotton cutworm (*Spodoptera litura*, Fabricius, CWW), Egyptian cottonworm (*S. littoralis*, Boisduval, ECW), and a control (i.e., no pheromone lure) (n = 30 fields; n = 4 traps per field; n = 120 traps in total). Traps within the same field were separated by 20 meters and were placed 1.5 meters above the ground (CAPS 2014). A Hercon Vaportape II insecticide strip (Hercon Environmental Corporation, Emigsville, PA) containing 10% dimethyl 2,2-dichlorovinyl phosphate and a small cellulose sponge was placed in each bucket to quickly kill captured insects and to absorb rain or irrigation water, respectively (Guerrero et al. 2014). A pheromone lure was placed inside the lure basket of the trap canopy for each respective survey species. The OWB rubber septum lure (provided by the USDA APHIS Otis Methods Lab) is composed of three compounds, Z-11-hexadecenal aldehyde (Z11-16Ald), Z-9-hexadecenal aldehyde (Z9-16Ald), and butylated hydroxytoluene, the former two of which are loaded into the lure dispenser in a 97:3 ratio, respectively (Venette et al. 2003; Sullivan and Molet 2007; Guerrero et al. 2014; van Kretschmar et al. 2014). In previous work, the OWB lure has not been considered to be species-specific, as *H. zea* has had attraction to this blend (Sullivan and Molet 2007). The CWW and ECW laminate pheromone lures (USDA APHIS Otis Methods Lab) are composed of two compounds, Z,E-9,11-tetradecenyl acetate (Z9E11-14Ac) and Z,E-9,12-tetradecenyl acetate (Z9E12-14Ac), which are loaded into the lure dispenser in a 7:1 (for CWW) and 200:1 (for ECW) ratio, respectively (Venette et al. 2003, Ellis 2004, Sullivan 2007a, 2007b).

Traps were placed in fields on 20 May and removed on 30 August 2014, providing time to collect trap contents over seven dates. Trap contents were collected every two weeks, lures were replaced every 28 days for OWB, and every 84 days for CWW and ECW, and insecticide strips were replaced every two weeks, following pest monitoring protocols (CAPS 2014). Collected insects were returned to the lab and stored in a freezer for later processing and identification.

Lure and Color Effects on Bycatch. To test for interactions between trap color and pheromone lure effects on bycatch, we specifically selected the OWB lure because in previous surveys lady beetles and pollinators were regularly observed in traps baited with this lure (L. R. Spears, personal observation). Therefore, two additional traps (n = 30 fields; n = 60 traps in total) were placed in each of the fields previously described: an all-green trap containing an OWB lure and an unbaited all-green trap (green control). These traps were then compared to the multicolored traps baited with an OWB lure or used as a control in the previous study. Green traps were modified by painting the outside of multicolored traps with American Accents® Ultra Cover hunter green paint (Rust-Oleum Corporation, Vernon Hills, IL) that closely resembles the green canopy of the multicolored trap. Traps were painted, as opposed to purchasing commercially available all-green traps, due to budget constraints. The same collection methods described previously (see *Lure Effects on Bycatch*) were followed for these traps.

Specimen Identification. All moths were removed from traps and sent to the Washington State Department of Agriculture regional Lepidoptera screening lab where they were screened for target and non-target moth species. Most non-target moths were identified to genus or species, although many specimens were too degraded to identify efficiently and were enumerated simply as non-target Lepidoptera. Although it is well known that *H. zea* is attracted to the *H. armigera* lure (OWB) (Sullivan and Molet 2007), we treated *H. zea* as a non-target during this study, as this species was not the intended target species. Remaining specimens, primarily lady beetles and bees, were pin-mounted and labeled. Lady beetles were identified to species at the Utah Plant Pest Diagnostic Lab at Utah State University and bees were identified to species at the USDA-ARS Pollinating Insect Research Unit in Logan, Utah. Voucher specimens were deposited in their respective identifying lab.

Data Analysis. Two separate analyses were conducted to test (a): pheromone lure (and control) effects and (b) main and interaction effects of the OWB lure (and control) and trap color (multicolored vs. all-green) on bycatch. For both analyses, we used a general linear mixed model with repeated measures. An unstructured covariance matrix was used to model repeated measures across seven temporal sampling events (i.e., date of trap collection). Bycatch abundance was the dependent variable; the independent variables were pheromone lure, trap color, and sampling event (and their interactions). Crop type was not treated as a potential predictor variable in the models, as alfalfa (and corn) fields were usually surrounded in all directions by other crop types. Response variables were ln-transformed ($x + 0.05$) to meet assumptions of normality. For main effects, pairwise mean comparisons were adjusted for family-wise Type I errors using the Tukey-Kramer method. Pairwise comparisons for significant interactions were examined with stepdown Bonferroni adjustments. Analyses were carried out in SAS/STAT software Version 9.3 in the SAS System for Windows (PROC GLIMMIX, SAS Institute 2013). Follow-up two sample t-tests were performed to compare the control to the pheromone lures separately (PROC TTEST, SAS Institute 2013). Significance for all tests was set at $\alpha < 0.05$.

Results

Diversity of Bycatch. Across all traps, a total of 2,613 lady beetles (Coccinellidae) were collected, belonging to three genera and seven species (Table 1). The most commonly collected species was *Hippodamia convergens* (Guérin-Méneville), comprising 62% of the lady beetles collected. *Coccinella septempunctata* (Linnaeus) was the second most abundant species comprising 23% of the Coccinellidae collected, while five taxa (*C. novemnotata,* Herbst; *C. transversoguttata*, Faldermann; *Harmonia axyridis,* Pallas; *Hi. sinuata*, Mulsant; and *Hi. tredecimpunctata*, Linnaeus) made up 15% of lady beetle captures.

We collected a total of 6,399 bees, belonging to at least five families, 25 genera, and 57 species (Table 1). The most commonly collected genera were *Agapostemon,* comprising 24% of the total bee catch, followed by *Apis* (20%), *Lasioglossum* (14%), and *Bombus* (13%). The two most commonly collected taxa were *Ap. mellifera* and *Ag. angelicus* (Cockerell) */ texanus* (Cresson), each of which comprised 20% of the total capture (female *Ag. angelicus* and *Ag. texanus* are not morphologically distinguishable and were pooled for this analysis).

A total of 9,053 non-target moths were collected, belonging to more than five families and 17 genera/species (Table 1). Moths collected in bucket traps are often devoid of identifying scales, so many non-target specimens were not identified to species, especially the Microlepidoptera (e.g., Tortricidae, Gelechiidae, Elachistidae). The three most captured taxa were *Helicoverpa zea* (Boddie) (24% of total moth captures), *Plagiomimicus spumosum* (Grote) (19%), and *Anarta decepta* (Grote) (18%).

Lure Effects on Bycatch. Lady beetles, bees, and non-target moths were attracted to the OWB lure (lady beetles: $F_{3,609} = 3.48$, $P = 0.02$; bees: $F_{3,609} = 7.96$, $P < 0.01$; moths: $F_{3,609} = 716.22$, $P < 0.01$) (Fig. 2). Specifically, the OWB lure increased lady beetle, bee, and non-target moth captures by 23%, 110%, and over 2000%, respectively, over the control (all Tukey-Kramer comparisons: $P \leq 0.01$). Non-target moths were also influenced by the CWW lure, relative to the control, yet the actual difference between means of the control and treated group was small (i.e., 0.18 moths) (Fig. 2) (Tukey-Kramer: $P = 0.02$). Follow-up two sample t-tests confirmed that the OWB lure increased lady beetle (albeit a marginally significant trend), bee, and non-target moth captures over the control (lady beetles: $t_{418} = -1.84$, $P = 0.07$; bees: $t_{418} = -3.77$, $P < 0.01$; moths: $t_{418} = -28.56$, $P < 0.01$). The CWW lure also attracted more non-target moths over the control ($t_{418} = -3.74$, $P < 0.01$).

When beetle genera were analyzed separately, we found that *Hippodamia* was captured more frequently in traps baited with the OWB lure than in control traps, and drove the observed OWB lure effects on lady beetles as a whole, rather than *Coccinella* (*Hippodamia*: $F_{3,609} = 5.66$, $P < 0.01$, Tukey-Kramer: $P < 0.01$; *Coccinella*: $F_{3,609} = 0.79$, $P = 0.50$, Tukey-Kramer: $P = 0.96$). Similarly, *Agapostemon*, *Bombus*, and *Lasioglossum* were more abundant in traps baited with the OWB lure than in control traps (*Agapostemon*: $F_{3,609} = 3.10$, $P = 0.03$, Tukey-Kramer: $P = 0.03$; *Bombus*: $F_{3,609} = 31.02$, $P < 0.01$, Tukey-Kramer: $P < 0.01$; *Lasioglossum*: $F_{3,609} = 17.34$, $P < 0.01$, Tukey-Kramer: $P < 0.01$). We observed no significant effect of any lure on *Apis* ($F_{3,609} = 0.92$, $P = 0.43$). We found that *H. zea* was the most abundant non-target moth species and was strongly attracted to the OWB lure ($F_{3,609} = 655.83$, $P < 0.01$), a result that has been previously observed (Sullivan and Molet 2007). Moreover, the remaining non-target moths (i.e., *Anarta*, *Chrysoteuchia*, and *Plagiomimicus*) were also more strongly attracted to the OWB lure than to the control (all $P < 0.01$; all Tukey-Kramer comparisons: $P < 0.01$). Genus-level analyses, however, did not reveal which genera drove the response to the CWW lure (all Tukey-Kramer comparisons: $P > 0.05$).

There were seasonal differences in bycatch (lady beetles: $F_{6,203} = 17.24$, $P < 0.01$; bees: $F_{6,203} = 12.55$, $P < 0.01$; moths: $F_{6,203} = 12.49$, $P < 0.01$), but only non-target moths varied by season (sampling event) and pheromone lure (lady beetles: $F_{18,609} = 1.34$, $P = 0.16$; bees: $F_{18,609} = 0.89$, $P = 0.6$; moths: $F_{18,609} = 6.1$, $P < 0.01$). Bees were more abundant early-summer, whereas lady beetles were more abundant mid-summer. Non-target moths were more abundant mid-summer, but only in traps baited with the OWB lure (mean values not shown).

Lure and Color Effects on Bycatch. Lady beetles, bees, and non-target moths responded to the main effects of sample date, trap color, and OWB lure (all P values < 0.01), yet these effects were often compounded with interactions. Lady beetles and bees varied by sample date and trap color (lady beetles: $F_{6,609} = 10.32$, $P < 0.01$; bees: $F_{6,609} = 9.18$, $P < 0.01$). Specifically, lady beetle captures were greater during mid-summer and especially in multicolored traps (Fig. 3). Bees were more abundant in early summer in multicolored traps, but their abundances were consistently low across the survey periods in all-green traps (Fig. 3). Moths varied by sample date and OWB lure ($F_{6,609} = 16.63$, $P < 0.01$). Specifically, moths were more abundant in traps baited with the OWB lure during mid-summer than in early or late summer, yet their abundances were similar across the survey periods in control traps (mean values not shown). Further, the combination of the OWB lure and multicolored trap increased capture rates of bees and non-target moths (bees: $F_{1,609} = 8.73$, $P < 0.01$; moths: $F_{1,609} = 72.07$, $P < 0.01$) more than multicolored traps without, and all-green traps with, an OWB lure (Fig. 4). Bees, however, were attracted to the multicolored traps even when the OWB lure was not used. The interaction between trap color and OWB lure was not significant for lady beetles ($F_{1,609} = 1.74$, $P = 0.19$) as it was for bees and non-target moths, but a similar trend was noted (Fig. 4). For all taxa, the three-way interaction was not significant (all $P > 0.05$).

All of the major non-target insect genera were affected by trap color, with all-green traps capturing fewer insects than multicolored traps (all main effects of color: $P \leq 0.02$; all Tukey-Kramer comparisons: $P < 0.01$).

Discussion

Many of the non-target insects we examined in this study responded to the pheromone lure used for monitoring the invasive old world bollworm (OWB) (*H. armigera*). No study has, to our knowledge, examined the effects of the OWB lure on non-target insects, despite the nearly nationwide use of this lure during annual invasive pest detection surveys. Many studies, however, have shown that some non-target insects are attracted to pheromone-baited traps, including species that are closely related and not related to the target pest (Gross and Carpenter 1991, Malo et al. 2001). Indeed, it is well-documented that *H. zea*, which we considered to be a non-target species in our study, is strongly attracted to the *H. armigera* lure (OWB) of which it is closely related to (Sullivan and Molet 2007). In addition, Meagher et al. (2008) found that native *Spodoptera* species were attracted to pheromones that were designed for exotic *Spodoptera* species and Meagher and Mitchell (1999) found that *Bombus* spp. were common in traps baited with *S. frugiperda* lures. More generally, studies have revealed that chemical communication is an important component of lady beetle, bee, and moth behavior (reviewed in Howard and

Blomquist 2005). It is clear that lady beetles detect olfactory cues that are associated with prey (e.g. Alhmedi et al. 2010). A well-known case is their attraction to (E)-β-farnesene, an alarm pheromone that is emitted by aphids when attacked by a predator (Francis et al. 2004). Similarly, bees use chemical cues to find floral resources or to attract other members of the colony (Howard and Blomquist 2005), and moths use chemical cues to find mates and are attracted to some host plant volatiles (Nesbitt et al. 1980, Li et al. 2005, Zhang et al. 2012). As previously mentioned, the OWB lure is composed of three compounds, Z-11-hexadecenal aldehyde (Z11-16Ald), Z-9-hexadecenal aldehyde (Z9-16Ald), and butylated hydroxytoluene (Sullivan and Molet 2007; van Kretschmar et al. 2014). Butylated hydroxytoluene has been used extensively as a preservative in food products, but some studies have shown that hexadecenal compounds are sex pheromone components of skin and carpet beetles (Coleoptera: Dermestidae) (e.g., Cross et al. 1977, Olson et al. 2013). Other studies show that cephalic labial gland secretions of *Bombus* contain many compounds related to hexadecenal (e.g., Meulemeester et al. 2011). It is unknown at this time exactly what lure component(s) these insects were responding to, or if they were responding to the release rates of these compounds instead (Meagher and Mitchell 1999). What was striking is that the two non-target insects that were not attracted to the OWB lure, *A. mellifera* and *C. septempunctata*, are also exotic species. Two possibilities are that some native species are strongly attracted to unfamiliar scents or conversely that these exotic species are capable of disregarding chemical cues emitted by species that originate from similar geographic areas. *H. armigera*, *A. mellifera*, and *C. septempunctata* are native to parts of Europe and Asia. There are examples in the literature of (usually native) species responding differently to native and introduced species (e.g., McQuillan and Hingston 1999, Pizzatto and Shine 2009, Polo-Cavia et al. 2010), yet continuing research is warranted on the ecological patterns and processes that affect exotic species encountering familiar environmental cues in an (somewhat) evolutionary unfamiliar landscape.

Our results further indicated that all of the major non-target insect taxa responded significantly to trap color. Other studies report that trap color affects capture of lady beetles, bees (especially bumble bees), and moths (e.g., Hendrix and Showers 1990, Gross and Carpenter 1991, Meagher and Mitchell 1999, Clare et al. 2000, Stephen and Rao 2005, Weber et al. 2005, Mori and Evendon 2013, Kemp and Cottrell 2015). Specifically, lady beetles have a low response rate to green wavelengths (490-530 nm) (Rodriguez-Saona et al. 2012, Jiuxuan et al. 2013; Kemp and Cottrell 2015). Bees, in general, are attracted to yellow wavelengths (550-580 nm), although how bees respond to color is still being studied, as color preferences can vary among Apidae (Stephen and Rao 2005). Finally, some moths are attracted to white and/or yellow, particularly the fall armyworm (*S. frugiperda*, J.E. Smith) -- a pest that is closely related to two of the target pests in our commodity survey (Mitchell et al. 1989, Pair et al. 1989, Meagher 2001). Conversely, all-green traps have resulted in a reduction in moth captures. Indeed, this is partly the reason why multicolored traps are still being used during exotic moth surveys. Although we did not quantify fluorescence and infrared spectral attributes of these traps, many studies suggest that yellow or white traps attract large numbers of non-targets because these colors either mimic food (flowers) resources or contrast more strongly against background foliage than green-colored traps (e.g., Haynes et al. 2007; but see Rao and Ostroverkhova 2015).

Bucket traps are the approved trap for monitoring many invasive moth pests due to the effectiveness of the trap over other trap types and also due to identification needs. In general, bucket traps are easy to handle and cost effective, offer a high trap capacity and easy catch removal, and their canopy helps to provide high quality specimens for identifiers by protecting specimens from inclement weather. Conversely, sticky traps capture a limited number of moths and require more processing time to avoid damaging insect specimens (Guerrero et al. 2014). While it is important to use the most effective survey tools for monitoring destructive, invasive pests (Dodds et al. 2010), it is also critical to reduce insect bycatch for at least two reasons. First, non-target captures can compromise monitoring efforts by reducing the available space for target species and increasing trap screening time (Adams et al. 1989, Pair et al. 1989, Weber and Ferro 1991). Increasing the specificity of traps and pheromone lures would reduce the amount of handling time monitoring programs must devote to sorting and identifying trap contents. Second, incidental captures of beneficial insects may interfere with ecosystem services, such as pollination and natural pest control (Aurelian et al. 2015, Spears and Ramirez 2015). Fisheries bycatch has led to negative impacts on marine ecosystems (e.g., Read et al. 2006, Lewison et al. 2014), and it is possible that similar effects could happen to terrestrial insect systems. However, no study has been published on this topic.

It has long been known that pheromone-baited traps attract more than the intended targets, and a concerted effort has been made to increase trap and pheromone specificity and decrease capture of non-target insects (e.g., Fleischer et al. 2005; Martín et al. 2013; Meagher and Mitchell 1999; Mori and Evenden 2013; Panzavolta et al. 2014). Yet, there is still much to be learned about which trap features can be modified to minimize bycatch of beneficial insects. Reducing the time that traps are in the field, using specific trap colors during certain times of the summer, or strategically placing traps in areas with known low populations of beneficial insects may further help minimize incidental captures. To our knowledge, these strategies are not currently being used. Despite the benefits of reducing bycatch, however, we understand that some trap features cannot be compromised because they are critical to attracting target species to traps. Since compilations of regional bycatch may help expand our knowledge of trap effects on non-target species and insect ecology more generally (Spears and Ramirez 2015), we recommend that bycatch data be processed and made available to other researchers through a centralized online depository, such as the Global Biodiversity Information Facility (www.gbif.org).

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Table 1. Abundance[a] and diversity of bycatch captured during CAPS monitoring of invasive pests in an agricultural landscape in Utah.

Order	Family	Species	Abundance
Coleoptera	Coccinellidae	*Coccinella septempunctata* (Linnaeus, 1758)	601
		Coccinella novemnotata (Herbst, 1793)	15
		Coccinella transversoguttata (Faldermann, 1835)	86
		Harmonia axyridis (Pallas, 1773)	73
		Hippodamia convergens (Guérin-Méneville, 1842)	1611
		Hippodamia sinuata (Mulsant, 1850)	54
		Hippodamia tredecimpunctata (Linnaeus, 1758)	173
Hymenoptera	Apidae	*Anthophora affabilis* (Cresson, 1878)	135
		Anthophora spp.	93
		Apis mellifera (Linnaeus, 1758)	1248
		Bombus centralis (Cresson, 1864)	119
		Bombus fervidus (Fabricius, 1798)	399
		Bombus griseocollis (DeGeer, 1773)	68
		Bombus huntii (Greene, 1860)	75
		Bombus rufocinctus (Cresson, 1863)	99
		Melissodes spp.	877
	Halictidae	*Agapostemon angelicus* (Cockerell, 1924) / *texanus* (Cresson, 1872)	1246

Order	Family	Species	Abundance
		Agapostemon femoratus (Crawford, 1901)	249
		Halictus ligatus (Say, 1837)	65
		Halictus rubicundus (Christ, 1791)	64
		Halictus tripartitus (Cockerell, 1895)	52
		Lasioglossum sisymbrii (Cockerell, 1895)	276
		Lasioglossum spp.	603
	Megachilidae	*Megachile rotundata* (Fabricius, 1787)	91
		Megachile spp.	232
Lepidoptera	Crambidae	*Chrysoteuchia topiarius* (Zeller, 1886)	1446
		Loxostege spp.	115
	Noctuidae	*Anarta decepta* (Grote, 1883)	1619
		Apamaea spp.	60
		Dargida spp.	53
		Euxoa spp.	56
		Helicoverpa zea (Boddie, 1850)	2138
		Heliothis spp.	838
		Plagiomimicus spumosum (Grote, 1874)	1670
		Resapamea spp.	58

[a] All lady beetles (Coleoptera) collected as bycatch are represented in the table above; only those bees (Hymenoptera) and non-target moths (Lepidoptera) represented by ≥ 50 individuals are shown.

Figure Captions

Fig. 1. Distribution of survey locations (dark circles) in Utah. Some survey locations overlap in the figure. Stars indicate major city locations, dotted polygons indicate major lakes, dark lines represent major highways, major cities are in bold faced font, and counties are in normal font and outlined by light borders. Insets show a zoomed-in view of some of the survey regions.

Fig. 2. Mean (± SE) number of insect bycatch caught in multicolored bucket traps baited with different pheromone lures (CON: control/no pheromone; CWW: *S. litura*; ECW: *S. littoralis*; OWB: *H. armigera*). Bars with different letters represent significant ($\alpha < 0.05$) Tukey-Kramer comparisons among lures.

Fig. 3. Mean (± SE) number of insect bycatch caught in all-green (black bars) and multicolored (gray bars) bucket traps across sampling events. Bars with different capital (and lowercase) letters represent significant ($\alpha < 0.05$) differences among groups with the same shade bar; an asterisk indicates a difference within a group (sampling event). Significant interactions were examined with stepdown Bonferroni adjustments.

Fig. 4. Mean (± SE) number of insect bycatch caught in all-green (black bar) and multicolored (gray bar) bucket traps baited with different pheromone lures (CON: control/no lure; CWW: *S. litura*; ECW: *S. littoralis*; OWB: *H. armigera*). Bars with different letters represent significant ($\alpha < 0.05$) differences among groups with the same shade bar; an asterisk indicates a difference within a group (pheromone lure). Significant interactions were examined with stepdown Bonferroni adjustments.