

**Final Project Report  
Conservation Innovation Grant  
The Xerces Society**

Grant agreement between the United States Department of Agriculture Natural Resources Conservation Service and the Xerces Society, Inc.

**PROJECT:** Promoting agricultural sustainability through conserving beneficial insects: Restoring pollination and pest control services on farms in California's central valley, Phase II

**PRINCIPLE INVESTIGATORS:** Scott Black, Executive Director; Mace Vaughan, Pollinator Program Director; Eric Mader, Assistant Pollinator Program Director

**TIMEFRAME:** September 17, 2009 – September 16, 2012

**CONTRACT AMOUNT:** \$202,631

**GRANT NUMBER:** NRCS 69-3A75-9-142

**DATE OF SUBMISSION:** December 7, 2012

**DELIVERABLES IDENTIFIED IN THE GRANT AGREEMENT:**

Evaluation of effectiveness, utility and cost-benefit of buffer plantings.

- Use established protocols to continue scientific monitoring of pollinator diversity and pollination function to demonstrate efficacy of restoration practices.
- Evaluate restoration sites for insect pests, natural enemies, and pest control functions.
- Monitor mature hedgerows of pollinators, insect pests, natural enemies and pest control and pollinator functions.
- Determine whether hedgerow habitat provides not only floral resources but also provides nesting habitat for bees.
- Assess the economic benefits from pollination and pest management provided by buffer plantings.

Disseminating results to NRCS staff and other agricultural professionals.

- Finalize and field test in two regions, a citizen science monitoring protocol and train NRCS conservation personnel and growers to conduct their own evaluation of native pollinator diversity on their farms.
- Produce restoration guidelines for how to manage conservation buffers for beneficial insects (e.g., pollinators, and predators and parasites of pests).
- Organize, at minimum, six workshops per year for NRCS and RCD staff across California highlighting approach to pollinator conservation

Attend at least one NRCS CIG Showcase or comparable NRCS event during the period of the grant.

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## **EXECUTIVE SUMMARY**

In order to evaluate the effects of habitat restoration for crop pollinating native bees, natural enemies of crops pests, and crop productivity and to disseminate the results of this work broadly to NRCS staff, the Xerces Society launched a Conservation Innovation Grant project in 2009 titled: “*Promoting Agricultural Sustainability through Conserving Beneficial Insects: Restoring Pollination and Pest Control Services on Farms in California’s Central Valley, Phase II*”. (Pollinator conservation is a specific priority for the NRCS, through mandated Farm Bill provisions, and through the agency’s broader natural resource conservation objectives which explicitly include Soil, Water, Air, Plants, Animals, and Humans).

This project was an outgrowth of studies by UC Berkeley Professor Claire Kremen and other researchers who demonstrated that wild bees contribute substantially to crop pollination on farms where their habitat needs are met. The Xerces Society developed the ground-breaking publication, *Farming for Bees: Guidelines for Providing Native Bee Habitat on Farms*, as a result of this earlier research.

To develop even more detail conservation guidance for the NRCS and NRCS clients, the Xerces Society and UC Berkeley launched Phase I of this project in 2006 in California’s Central Valley with funding from a CA CIG grant and an NRCS Fish and Wildlife grant. In Phase I, we restored buffer plantings on six sites, and we monitored bee communities before and after restoration at these sites and also at twelve control sites. We presented dozens of workshops across California and developed a variety of NRCS publications that provide the technical information and specifications needed to implement pollinator habitat using NRCS EQIP and WHIP Conservation Practices. We also completed an initial citizen science bee monitoring protocol for NRCS staff to assess whether habitat restoration is supporting pollinator communities.

Capitalizing on these successes, we continued this project to provide a full evaluation of restoration effectiveness and determine the agricultural benefits of including small-scale wildlife habitat elements on farms. Restoration could not proceed far enough during Phase I’s duration to permit this evaluation. Therefore, in Phase II, we went on to: (1) continue to monitoring at all previously restored sites, (2) monitored mature hedgerows to look at pollinator and pest control function, (3) determined whether hedgerow sites provide bee nesting habitat, (4) finalized a citizen monitoring protocol for NRCS staff, (5) assessed the economic benefits of habitat restoration, (6) used this information to refine specifications and job sheets for pollinator and other beneficial insect habitat, and (7) engaged producers and NRCS staff through workshops across the state.

These components resulted in a total project cost of \$406,340, of which \$202,631 of Federal Conservation Innovation Grant funds were requested. All Federal funds were matched with non-Federal sources. All funds were spent as anticipated, however in August 2011, we request a 12-month no-cost extension to (1) conduct the final synthesis of 2011 field monitoring results, (2) produce the final print guidelines informed by those field results, and (3) to disseminate full project results to a national audience as part of an in depth conference session and nationwide CIG poster showcase. Aside from the single extension request, all key goals and objectives were met or exceeded.

Currently, the direct beneficiaries of this project are the more than 500 farmers and farm agency staff directly reached with project results at workshops, field days, and through other events. Those audiences are being further supported through the development of a new 40+ page NRCS technical note (*Conservation Biological Control: Providing Habitat for Predators and Parasitoids of Crop Pests*), which is currently undergoing final approval by the West National Technology Support Center for official publication. That technical note, along with outreach supported by ongoing (non-CIG) leveraged funds, will continue to ensure meaningful technology transfer to farmers of bee-pollinated crops, producers who benefit from beneficial insects, and to NRCS field staff. That transferable technology has been specifically designed to meet the criteria of NRCS Programs, and Practice Standards, ensuring long-term viability as a conservation innovation.

Based upon the results of this work, we recommend continuing agency support for the restoration of pollinator habitat on working lands. This recommendation is supported by the findings included later in this document and by several pending scientific articles that are an outgrowth of our work (including economic findings that demonstrate clearly how the creation of pollinator/beneficial insect hedgerows through NRCS cost-share programs pay for themselves within several years of establishment).

## **INTRODUCTION**

This final report describes a multipart project to develop detailed guidelines for creating and managing farm habitat for beneficial insects (pollinators and predators of crop pests). This project included both extensive field research to test habitat creation and management practices (as well as training) for NRCS staff and farmers on implementing conservation practices that support these beneficial insects. This subject area falls within the “Natural Resources” emphasis of the Conservation Innovation Grant program, and within the “Wildlife Habitat: Pollinator Protection” application review category.

An earlier phase of this project was conducted with support from an NRCS Conservation Innovation Grant and an NRCS National Fish and Wildlife Grant. During that phase, we monitored five sites newly restored with native plants and fifteen control sites on farms in California’s Central Valley for their suitability in supporting pollinating insects. This work took place from 2006 through 2009. We also studied four mature hedgerow sites and four control sites (2008-2010) using other funding sources.

The project described here, a partnership between the Xerces Society for Invertebrate Conservation and the University of California, Berkeley (UCB), continued and extended that earlier work, examining the benefits of restored habitat for pollinators as well as other types of beneficial insects (predators and parasitoids of crop pests). The results of this expanded monitoring have been integrated with previous data, resulting in new NRCS management guidelines for beneficial insect conservation.

Key project participants and investigators included:

Scott Hoffman Black, M.S.; Executive Director, The Xerces Society. Scott Black has been Executive Director of the Xerces Society since 2000. He has degrees in ecology, plant science, and entomology from Colorado State University, and extensive experience in the conservation and ecology of insects and natural areas. Scott was the lead project partner who supervised all Xerces staff, and managed collaboration between project partners.

Jessa Guisse, M.S., California Pollinator Outreach Coordinator, The Xerces Society: Jessa Guisse managed the day-to-day operations of the project, including providing technical assistance for hedgerow and habitat restoration. Her previous experience includes work as an educator in the fields of plant sciences and entomology, an IPM consultant, a plant propagator, an organic farm inspector, and a farmer. She received a master's degree in Environmental Entomology from California State University, Chico, and a bachelor's degree in Sustainable Agriculture from Hampshire College.

Claire Kremen, Ph.D.; Assistant Professor, University of California, Berkeley. Claire Kremen is an Assistant Professor at the University of California, Berkeley, and an Associate Conservationist with the Wildlife Conservation Society. She received her Ph.D. in Zoology from Duke University in 1987. Her current research examines the links between the spatial distribution of wildlands, the composition of wild bee communities, farm management practices, and the delivery of pollination services to agriculture in California and New Jersey. She was a member of a National Academy of Sciences panel examining the status of pollinators in North America, and recently received a MacArthur Fellowship award for her work in ecology, agriculture, and biodiversity conservation. Claire supervised the field research portion of the project.

Lora Morandin, Ph.D.; Post Doctoral Fellow, University of California, Berkeley. Lora Morandin received her M.Sc. in applied pollination biology in 2000 from the University of Western Ontario and her Ph.D. in pollination and agroecology in 2005 from Simon Fraser University. Her past and current research examines the relationships between agroecosystems, pest control, and pollination. Lora was the principle field researcher involved with this project.

Eric Mader, M.S., Xerces Assistant Pollinator Program Director, has extensive experience in farming, native bee management, and native seed production. He supervised major national outreach around this project, including the development of final fact sheets and workshop content.

In addition to direct project participants and research investigators, outreach, including field days and workshops for NRCS staff, clients, and partner agencies was conducted throughout both Phase I and Phase II of this project with the California Association of Resource Conservation Districts, the California State Board of Agriculture, the Lockeford, California NRCS Plant Materials Center, University of California Cooperative Extension, the California Audubon Land Stewardship Program, and the Soil and Water Conservation Society through their 2012 annual conference where the project was highlighted in poster and oral presentation sessions.

## **BACKGROUND**

Pollination by bees is a critical step in the production of many crops, including alfalfa, almonds, apples, blueberries, cherries, pears, raspberries, squash, sunflowers, and watermelons. Over 30% (by weight) of the American diet relies on insect pollination, and insect-pollinated crops provide critical sources of vitamins, fiber and micro-nutrients. Nevertheless, the current reliance on the domesticated honey bee (*Apis mellifera*) exposes U.S. crop production to potentially serious risks. The spread of parasitic mites and diseases has resulted in a decline in honey bee colonies from a peak of 5.9 million in 1947 to less than half that now. In addition, the beekeeping industry is currently facing the new threat of Colony Collapse Disorder, which resulted in significant honey bee losses in 2006 and 2007.

Some of the 4,000 species of wild bees native to the U.S. can provide, at minimum, a complementary source of pollination services and an insurance policy against fluctuations in honey bee supply. In addition, native pollinators are keystone species ensuring the reproduction of native plants in many terrestrial ecosystems, and thus permitting plant communities to provide food and shelter for wildlife, prevent soil erosion, and help maintain healthy streams and rivers.

Given the critical role of pollination in both agriculture and natural ecosystems—and the potential for services provided by wild native bees to serve as an incentive for growers to conserve natural habitat—it is important to understand the contributions that wild pollinators are making to agriculture, and to protect and restore this important ecological resource.

Initial studies by Professor Claire Kremen of University of California, Berkeley and other researchers have shown that wild bees can contribute substantially to crop pollination on farms where their habitat needs are met. This research resulted in a new question of whether functional habitat could be restored on farms where it was lacking to enhance native bee populations in economically and ecologically significant ways.

To test this question, from 2006 to 2008, with funding from a California CIG and an NRCS Fish and Wildlife Grant, we restored buffer plantings on six farms. We monitored these farms before and after restoration, along with twelve control farm sites. While the initial findings were encouraging, this phase of the project was not long enough to determine the full effect of the restoration on the bee communities.

In addition, some growers were reluctant to include restoration plantings on their land because of perceptions that they may be a source of insect pests. In our initial investigations of mature hedgerows however, we found that hedgerows not only harbor fewer pest insects, but also increased the abundance and diversity of beneficial insects that control crop pests in adjacent fields. With these findings in mind, we added pest and beneficial insect monitoring to our protocol in all hedgerow and control sites, and evaluated pest control benefits to adjacent crops.

Prior to initiating this project, limited attempts had been made to encourage native pollinator and beneficial populations with habitat conservation adjacent to farm fields. More typically however, limitations to resident pollinator and beneficial insect populations were addressed from a crop input model, where producers supplemented pollinator numbers with managed bees (including additional but increasingly expensive honey bee hives, managed bumble bees, mason bees, and

others), and supplemented predator or parasitoid insect numbers with the release of commercially-produced (often non-native) beneficial insects. The conservation-based model developed through this project represents a new paradigm that can positively impact both producers of bee-pollinated crops, as well as producers of non bee-pollinated crops alike (by enhancing pest control from native beneficial insects).

## **REVIEW OF METHODS**

### Hedgerow Installation

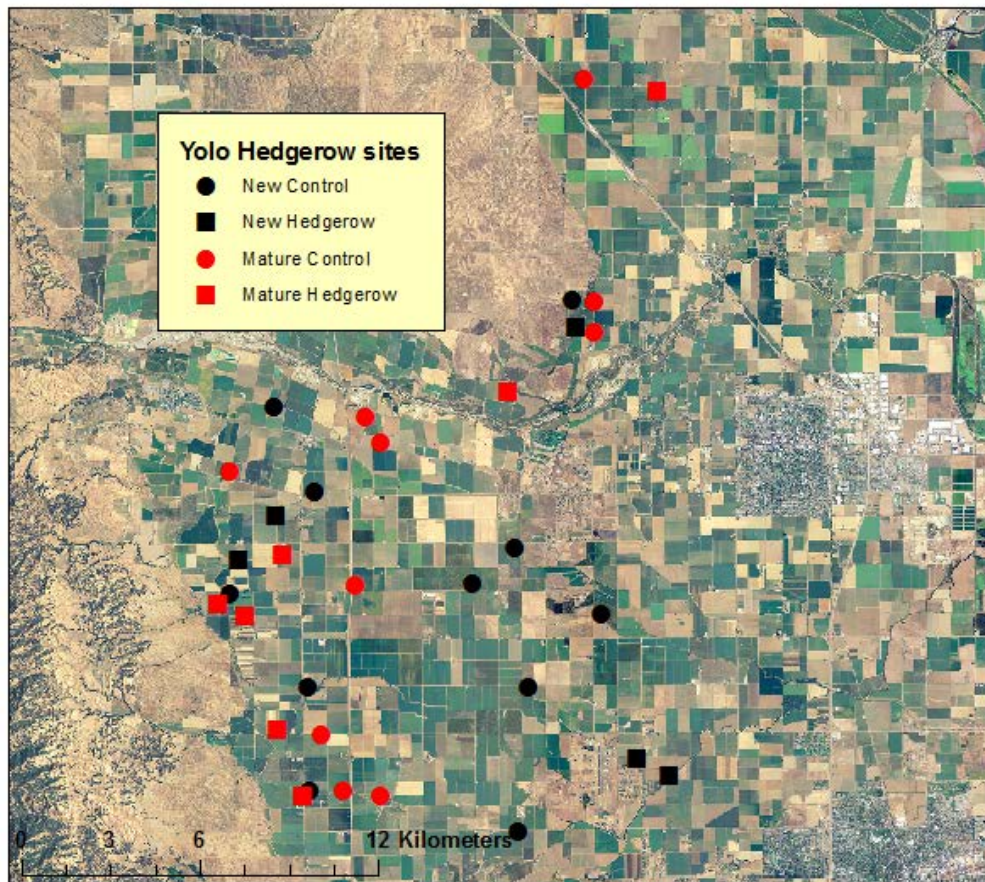
This project specifically examined native shrub hedgerows as a multi-benefit conservation practice, focusing specifically on the value of flowering hedgerows as pollinator/beneficial insect habitat. Hedgerows (dense woody vegetation established in a linear design) are a formal NRCS conservation practice standard (422), typically requiring a minimum and maximum width of 5 to 30 feet, and a minimum height of 3 feet. Hedgerows are usually established on property boundaries, roadsides, adjacent to small watercourses such as irrigation ditches, and in locations where they can block prevailing winds.

Hedgerow establishment has been an increasingly popular conservation in California's Central Valley (where this project was launched), with nearly 70 miles of hedgerows contracted through NRCS programs in recent years to achieve multiple conservation benefits. For individual producers, hedgerow establishment in the region usually involves: (1) initial weed abatement (such as spraying existing weedy vegetation with broad-spectrum herbicides), (2) transplanting shrubs (from contain stock), (3) irrigating the transplants (usually with drip irrigation) during the establishment phase, and (4) managing the hedgerows (primarily for weed removal).

In California's Central Valley, the areas where hedgerows are not established typically are maintained with routine herbicide and/or mowing treatments to suppress weed growth. The establishment of hedgerows, while initially labor and monetary-intensive, provides multiple conservation benefits, and in the long term reduces the use of herbicides and fossil fuels.

### Study Location and Timeframe

The study was conducted in Yolo County, CA, an intensive agricultural landscape with rotational and orchard crops. Data were collected at four mature hedgerow sites and corresponding control sites in 2009, and 2010 (Figure 1). Additional work (with phytometer plants) was conducted at mature sites and controls in 2010, 2011, and 2012. Mature hedgerow sites that were selected were at least 10 years old (most were planted in 1996), had a diversity of perennial native shrubs that had successive and overlapping bloom during the growing season, were at least 300 m in length, and were adjacent to a processing tomato field. A control site was chosen for each hedgerow site. Corresponding control sites were weedy, relatively unmanaged field edges that were >1k and <3km from the hedgerow site, and adjacent to a processing tomato field. We chose this design so that both hedgerow and control sites would have independent insect communities but span the same environmental gradient across the study area.



**Figure 1. Mature and new hedgerow sites and controls. There were four mature hedgerow sites and four associated controls each year in 2009 and 2010. Because sites were chosen to be adjacent to tomato fields, only two of the hedgerow and two of the control sites were the same between years. All new restoration sites and controls were the same in all years sampled.**

Five new hedgerow sites and 10 corresponding control sites were monitored during this grant in 2009, 2011, and 2012. New hedgerow sites were restored starting in the fall 2006 with the last one in spring 2008, and monitoring began at each hedgerow in the year prior to restoration. All new restoration sites were on slough banks. The locations chosen had landowners who were restoring a slough bank with native perennial plants and forbs from a native plant palette that was made up of species that had continuous bloom over the growing season, were not considered to be weedy, and were known to be used by crop pollinating native bees.

## **DISCUSSION OF QUALITY ASSURANCE**

### Sampling Design and Procedure

*Pollinator monitoring:* Mature sites and associated control sites were monitored four times per growing season and new sites and associated control sites were monitored three times per growing season. Monitoring was set up in rounds so that the four and three rounds at mature and



new sites respectively were spread over the growing season in order to capture temporal changes in pollinators throughout the season. Each site was monitored once, for approximately five hours during each sample round. At the beginning of the day, 21 pan traps were evenly placed along edges in an alternating yellow, blue, white color pattern. Pans contained water and a small amount of detergent to lower surface tension. All insects in pans were collected after five hours and transferred to centrifuge tubes with 70% ethanol for later identification. At mature hedgerow sites and controls, pans were also placed at 10, 100, and 200 m into fields. Pollinators were collected off of flowers using timed aerial netting for 1 hour at each site (30 min in 2009 at mature sites and associated control sites). Any insects touching the reproductive parts of flowers were collected and transferred to labeled vials, documenting the plant species it was collected from, for later identification. At mature hedgerow sites, pollinators were also observed for 4 min at six locations along the edge and at six locations in adjacent tomato fields during each sample round.

*Floral cover:* At each sample round, floral cover was assessed by placing 50, 1 m<sup>2</sup> quadrats along the hedgerow or control edge, approximately 8 m apart. At newly restored and associated control sites, quadrats were evenly spread along edges and were distributed among the slough bank, the center of the restored or control strip, the edge of the restored area, and a few feet away from the restored area in order to get a measure of all vegetation within and adjacent to the restored or control edge. At mature restoration and associated control sites, the 50 quadrats were placed evenly along the edge, with 25 at the center of the restored or weedy edge and 25 at the edge of the restoration or weedy edge. Within quadrats all plants with bloom were identified to species and floral cover estimates were made for each species in the quadrat using percent cover categories. Samples of plants that could not be identified in the field were brought back to the laboratory and identified using additional identification manuals or by staff at the Jepson Herbarium at UC Berkeley.

*Native bee nesting assessment:* During the final sample round each year, bee-nesting habitat was assessed in each of the 50 quadrats. We quantified potential nesting resources as percent of quadrats with dead wood, hollow stems, bare ground, cracked ground, land slope, and soil hardness (using three measurements with a penetrometer per quadrat, at the two closest corners and the quadrat center). In addition, we counted small (< 2 cm) and large (> 2 cm) cavities in the ground, which could indicate ground nesting bee tunnels.

*Sweep samples for pests and beneficial insects:* Sweep samples were taken during each sample round at all mature sites and associated control sites and at the five new restoration sites and five associated control sites. A sweep sample consisted of ten 180° sweeps with a standard 40 cm diameter net. Two samples were taken in the vegetation, 50 to 100 m from each end of the hedgerow or control edge (depending on edge length), and at the center. At hedgerow sites, sweeps were taken into the native plant vegetation. Sweep samples were taken only when temperatures were  $\geq 18^{\circ}\text{C}$ , winds  $\leq 2.5$  m/s and skies were clear. Sweep samples were always conducted at a hedgerow and its paired control site on the same day.

In hedgerows, we also conducted one sweep sample at each location in the edge in weeds if they were present. Because there were far fewer samples in this category (weeds in hedgerows) and samples were absent in some sites and sample rounds, we did not include these data in the

overall comparison. However, we report the mean (SE) numbers of pest and natural enemy insects in weeds in hedgerows. Sweep samples were only conducted at edges of fields (hedgerows and weedy controls) and not in fields due to the potential to damage crop plants with this sampling method. We employed other methods to sample insects on tomato plants (see below).

After each sweep sample, insects and any vegetation in the net were carefully transferred from the net to a sealed, labeled bag, and put into a cooler. At the end of the field day, bags were put into a freezer for later processing at which time all insects  $\geq 0.5$  mm (plus mites and spiders) were removed from the bags and transferred to centrifuge tubes with 70% ethanol. Insects were identified that were of economic importance to crops in our region. Identification was to species or higher taxonomic levels (Table 1).

**Table 1. Main pest and beneficial insects collected in hedgerow and control sites and adjacent tomato fields in 2009. Type is general role in agricultural environment, group is taxonomic grouping in which arthropods were grouped to compare abundance within types. Identification level is the lowest level of identification that we identified specimens, used for richness and diversity calculations (for predators only), species or higher order are the species or taxonomic groups represented within identification level.**

Type	Group	Identification level	Species or higher order within ID level	
<b>Parasitoid</b>	Aphidiidae	Aphidius	<i>Aphidius</i> spp	
	Chalcidoidea	Encyrtidae	Encyrtidae	
		Mymaridae	Mymaridae	
		Pteromalidae	Pteromalidae	
		Trichogrammatidae	<i>Trichogramma</i> spp	
		other parasitoid wasp	Brachonidae	Brachonidae
			Ceraphronoidea	Ceraphronoidea
			Chrysoidea	Chrysoidea
			Cynipoidea	Cynipoidea
			Ichneumonidae	Ichneumonidae
<b>Pest</b>	Scelionidae	Scelionidae	Scelionidae	
	Tachinidae	tachinid fly	Tachinidae	
	aphid	aphid	Aphidoidea	
	flea beetle	flea beetle	<i>Phyllotreta</i> spp., <i>Epitrix</i> spp.	
	leafminer	leafminer	<i>Liriomyza</i> spp.	
	<i>Lygus</i> bug	<i>Lygus</i> bug	<i>Lygus</i> spp <i>Diabrotica undecimpunctata undecimpunctata</i>	
	cucumber beetle	spotted cucumber beetle	<i>undecimpunctata</i>	
	stink bug	conspere stink bug	<i>Euschistus conspersus</i>	
		red-shouldered stink bug	<i>Thyanta pallidovirens</i>	
	<b>Predator</b>	weevil	weevil	Curculionidae superfamily
lady beetle		convergent lady beetle	<i>Hippodamia convergens</i>	
		mealybug destroyer	<i>Cryptolaemus montrouzieri</i>	
		parenthesis lady beetle	<i>Hippodamia parenthesis</i>	
		Seven-spotted lady beetle	<i>Coccinella septempunctata</i>	

	spider mite destroyer	<i>Stethorus picipes</i>
	twicestabbed lady beetle	<i>Chilocorus orbus</i>
mantid	praying mantid	<i>Mantidae</i> family
		<i>Chrysopa</i> spp., <i>Chrysoperla</i> spp.
neuropteran	green lacewings	spp.
	snake flies	Raphidioptera order
predatory beetle	collops beetle	<i>Collops</i> spp.
	rove beetle	Staphylinidae family
	soldier beetle	Cantharidae family
predatory bug	Big-eyed bug	<i>Geocoris</i> spp.
	damsel bug	<i>Nabis</i> spp.
	leafhopper assassin bug	<i>Zelus renardii</i>
	minute pirate bug	<i>Orius</i> spp.
predatory thrips	banded thrips	<i>Aeolothrips</i> spp.
spider	spider	Araneae order

*Sticky card sampling of pests and beneficial insects:* Yellow “Sticky Strip” 7.6 x 12.7 cm sticky cards (Bioquip Inc.) were set out at sites four times each season at mature sites and controls and 3 times each season at new restoration sites and five associated control sites. At each sample round, two sticky cards were placed at three field edge locations and along each of two transects into fields (into fields only at mature and associated control sites), at 10, 100, and 200m distant from field edges, 100 to 200m apart depending on field size, for a total of six sticky cards along field edges and six in fields. Sticky card wire holders (Bioquip Inc.) were used to hold cards above or adjacent to vegetation at all sites except where they hung from hedgerow shrubs with metal shower hangers. After seven days, sticky cards were individually collected, wrapped in plastic wrap, labeled, and put into freezers for later processing.

Sticky cards were examined by dividing the cards into 5, 1.9 cm strips (corresponding with the width of view under our dissecting microscopes at the lowest magnification) and identifying and quantifying the total number of insects on both sides of two end and middle strips. Insect identification level was similar to identification for sweep specimens except parasitic microwasps were not identified further due to difficulty of manipulating and identifying specimens on sticky cards.

*Visual assessment of field pests, natural enemies, and crop damage:* At mature hedgerow sites and associated control sites we assessed pest and natural enemy insects in fields and crop damage using tomato crop assessment protocols outlined in the University of California integrated pest management guidelines (<http://www.ipm.ucdavis.edu>). In late May each year, when the tomato plants were at flowering and early fruit set stage, we assessed leaves for pests, primarily potato aphids (*Macrosiphum euphorbiae*). We also recorded the presence of any other pests or pest egg masses and natural enemy insects as described on the UC IPM site (<http://www.ipm.ucdavis.edu/PMG/r783301711.html>). This was done three times over each season. During the second and third crop assessments we also quantified damage to fruit, pests on fruit, and pests and natural enemies on plants using standard plant shaking protocols. Fruit was examined for stink bug and caterpillar pest damage. In all cases, we assessed more leaves,

plants, or fruit than recommended in the UC IPM guidelines. Assessments were conducted at three distances into the crops: 10, 100, and 200m from field edges, along the two transects described above. For all data in fields, if fields were treated with an insecticide prior to our collections or crop assessments, we exclude the data and report the incidence of insecticide use in the results. We also report number of fields within field type (hedgerow or control) that reached threshold levels for insecticide treatment based on based on UC IPM guidelines.

*Stink bug control experiment:* Stink bugs, primarily consperse stink bugs (*Euschistus conspersus*) in our study region, are a pest of processing tomato and other fruit crops. In spring and summer, stink bug adults lay eggs on the undersides of crop leaves. Emerging nymphs and adults feed on the fruit causing external spots and internal damage, lowering the market value of the crop. For tomato crops, stink bug damage lowers the value of both fresh market and processing tomato. Natural enemies of stink bugs include generalist predators and parasitoid wasps (Ehler 2000, Pease and Zalom 2010). To assess if the presence of a hedgerow affected stink bug parasitism and predation rates we used sentinel stink bug egg masses placed in edges and into fields beside mature hedgerows and associated controls. In April each year we collected consperse stink bug adults from weedy areas in our study region. Adults were put into sealed, ventilated plastic containers lined with brown paper towel and fed organic green beans and sunflower seeds *ad libitum*. Every two to three days, we removed the paper towel lining and cut out any egg masses that had been laid, leaving an approximately 1 x 3 cm paper towel strip with the egg mass offset to one side. Egg masses were immediately transferred to a -20°C freezer.

In early July, when stink bug egg control by natural enemy insects would be most essential for tomato crops in our region, we placed the sentinel egg masses in field edges and crops. In 2009 we placed 20 egg masses along the edge of fields and 10 egg masses at each of 10, 100, and 200m into fields. In 2010 we placed 15 egg masses in the edge and 15 at each of the three distances into fields. In control edges we clipped egg masses to the underside of broad-leaved weeds if present, or around wire flag stakes if no broad-leaved vegetation was present. In both cases, egg masses were covered by vegetation and oriented with the egg mass towards the ground, mimicking where stink bugs lay their eggs. In hedgerow edges, egg masses were clipped with metal hairpins to the underside of native shrub leaves. In fields, egg masses were clipped to the underside of tomato leaves, at approximately 1/3 from the bottom of the plant. At each distance, egg masses were placed approximately 10 m from each other, along transects parallel to the reference field edge.

After five days, egg masses were collected and placed into individually labeled and ventilated plastic bags and kept at room temperature. After one month, egg masses were assessed for parasitism or predation. Predation was counted when egg masses were either completely consumed or had caps and contents removed. Parasitism was counted if egg masses were dark black and/or emergence or partial emergence of parasitoids. If any eggs within the egg mass were positive for parasitism, the egg mass was scored as parasitized. Generally, predated egg masses had no intact eggs left.

*Sample custody procedures:* Samples were brought back to the laboratory, pinned, labeled and databased. Native bees were sent to Dr. Robbin Thorp (UC Davis) for identification and syrphid flies to Dr. Martin Hauser (CA Department of Food and Agriculture). All native bee and syrphid

fly specimens have a unique barcode and number identifier and have been recorded in a database. Samples are stored at Dr. Claire Kremen's laboratory (UC Berkeley) and the UC Berkeley Essig Entomology Museum. All pest and beneficial insects were identified to the level described in Table 1. Specimens are stored in 70% ethanol in the Kremen laboratory.

*Equipment calibration procedures:* All collecting material including thermometers, windmeters, nets, pans, were checked at the beginning of each field season and new supplies were ordered when needed.

*Data Analysis:* Data was analyzed using raw data and then nesting a random design in a statistical analysis system. For example, numbers of each type of insect, on each sticky card were put into the analyses that had sticky card location, number, and site, nested within a given year as random variables. Therefore, 'site' was the replicate for all response variables and all values, from each sample, were included in the analyses. Analyses for some of the data (the citizen-science monitoring study, preference data, and all bee and syrphid fly community analyses) are currently in peer-reviewed manuscripts that are either published or in press.

## FINDINGS

### *1. Insect Preference for Native vs. Exotic Plants*

*Bee abundance, richness, and diversity:* Of the 23 species of native bees netted on flowers at the new hedgerow sites, seven species were observed *only on* exotic plants and seven species were observed *only on* native plants. Of the 30 species of native bees netted on flowers at mature hedgerow sites, 23 bee species were observed *only on* native plant species and only one bee species was found only on exotic plant species.

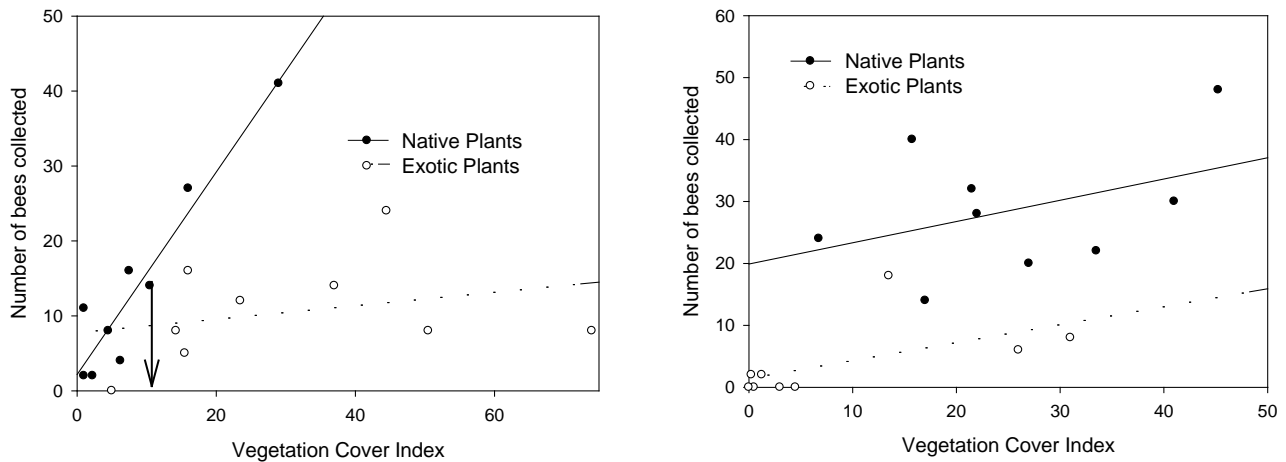
We found significantly more native bees on native plants than exotic plants ( $t_{17} = -3.32$ ,  $P = 0.004$ ; Fig 2) and  $p < 0.05$  for all floral cover values greater than 15. At new hedgerow sites, there was no difference in native bee species richness and diversity between native and exotic plants (richness:  $F_{1,18} = 0.83$ ,  $P = 0.37$ , diversity:  $F_{1,18} = 0.17$ ,  $P = 0.68$ ).

At mature hedgerow sites, there was greater abundance, richness, and diversity of native bees on native plants than exotic plants (abundance:  $F_{1,25} = 19.22$ ,  $P = 0.0002$ , richness:  $F_{1,25} = 13.07$ ,  $P = 0.001$ , diversity:  $F_{1,25} = 10.00$ ,  $P = 0.004$ ). Honey bee abundance was the same on native and exotic plants at new hedgerow sites ( $F_{1,17} = 0.38$ ,  $P = 0.55$ ). At mature sites there was an interaction between floral cover and plant type on honey bee abundance ( $F_{1,24} = 105.2$ ,  $P < 0.0001$ ). Closer inspection of the region of significance revealed that honey bee abundance was greater on native plants at all cover levels and that the magnitude of difference between honey bee abundance on native versus exotic plants increased with increasing cover score.

*Floral preferences:* At new hedgerow sites, regression slopes were significantly different for native bee abundance on native vs. exotic plants (floral cover by plant type interaction:  $F_{1,11} = 10.64$ ,  $P = 0.008$ ). Mean bee abundance on native plants was greater than abundance on exotic plants ( $t_{11} = -5.44$ ,  $P = 0.0002$ ). At floral cover scores greater than 10, native bees showed a preference for native plants. As floral cover score increased, the difference between bee abundance on native and exotic plants increased (Figure 2). Native bees preferred native plants

over exotic plants at mature hedgerow sites at all cover amounts ( $F_{1,13} = 39.08$ ,  $P < 0.0001$ ) (Figure 2).

Honey bees exhibited no preference for exotic or native plants in new hedgerow sites ( $F_{1,16} = 0.01$ ,  $P = 0.93$ ). In mature hedgerow sites, however, honey bees preferentially selected native plant species ( $F_{1,12} = 102.81$ ,  $P < 0.0001$ ).



**Figure 2. Analysis of Covariance of native bee abundance on exotic and native plants at new hedgerow sites (left) and mature hedgerow sites (right). Cover of exotic and native plants at each site, sample round combination was included as a covariate in the model in order to assess bee preference. There is a significant preference for native plants ( $p < 0.05$ ) for all values to the right of the arrow (in the left graph).**

*Ranking native plant species:* Semi-quantitative ranking of preference among native plant species showed that when present, *Eriogonum fasciculatum* and *Salvia* spp. were the most preferred native plant species. Other species within the top preferred native plants for bee forage were *Eschscholzia californica*, *Rhamnus californica*, and *Grindelia camporum*. *Heteromeles arbutifolia*, *Achillea millefolium*, and *Atriplex lentiformis* had mixed results in terms of preference. *Sambucus mexicana* and *Rosa californica* were consistently less preferred by native bees when other native species were available. However, large numbers of syrphid flies (Family Syrphidae), which also can be important native pollinators of agricultural crops (Jauker and Wolters 2008), were caught on elderberry (L. Morandin and C. Kremen, unpublished data). Of the native bee species that were represented by greater than two individuals (17 species), four bee species were found on only one species of native plant in this subset of samples.

## **2. Evaluation of a Citizen-Scientist Bee Monitoring Protocol**

Across the 25 site-date combinations used to assess a citizen-scientist monitoring protocol, scientist-participants collected 2119 insects in nets and 4548 insects in nets plus pan traps, whereas citizen scientists observed 3763 insects. There was no significant correlation between the netting versus the pan-trapping data sets by site date for *Apis* abundance, non-*Apis* abundance, proportion of non-*Apis* individuals, species richness, or bee group richness. The two data sets differed in species composition, with mean dissimilarity (Bray-Curtis Index) of 0.69

(SD 0.15; n= 25 site dates; 0, complete similarity; 1, complete dissimilarity). Mean dissimilarity based on bee group composition was similarly high (0.67 [0.16]). Of the 43 species detected across all sites, 23 (56%) were detected by both methods. Thirty-six species (84%) were caught in nets and 31 (72%) in pan traps.

*Comparisons between Observational and Specimen-Based Data:* Higher-level taxonomic groups were recorded in similar proportions in observational and specimen-based data sets (sites and dates combined, Fig. 3, netting:  $p= 0.68$ ,  $p < 0.05$ ; netting and pan trapping:  $p= 0.79$ ,  $p= 0.01$ ). *Apis* and non-*Apis* bees were the most abundant insects, but collections also included wasps, flies, and other insects. Forty-eight species of non-*Apis* bees in four families (Apidae, Colletidae, Halictidae, Megachilidae) were identified from the collected specimens.

Comparisons of observations with netting data for *Apis* abundance, non-*Apis* abundance, taxonomic richness (at the species and bee group level for specimen-based data), and proportion of non-*Apis* individuals were all significantly and positively correlated (Table 2). Similar significant results were obtained for comparisons of observations with netting plus pan-trapping data (with smaller correlation coefficients, Table 2), except for taxonomic richness when compared at the species level for specimen-based data.

**Table 2. Results of sampling-method analyses of native bees, syrphid flies, and honey bees in four hedgerow and four control sites over two years. The table shows F values (\*\*\*P < 0.001, \*\*P < 0.01, \*P < 0.05; df = 1,14 for all analyses except adjusted abundance which was an ANCOVA controlling for total species abundance and denominator df reflect the number of species). In all cases where there is significance, values at hedgerows are greater than values at control sites.**

Location	Collection method	Species group	Abundance	Adjusted abundance	Uncommon species	Richness	Diversity
Edge	Net	Native bees	0.23	26.64***	16.53***	7.07*	9.03**
		Syrphid flies	6.81*	4.45*	2.2	7.75*	5.57*
		Honey bees	16.91***				
	Pan	Native bees	1.36	0.78	2.33	1.03	0.51
		Syrphid flies	1.24	0.83	5.73*	0.01	0.35
		Honey bees	0.11				
	Visual	Native bees	10.14**			5.39*	10.2**
		Honey bees	3.87				
		Syrphid flies					
Field	Pan	Native bees	0.57	1.43		1.2	2.74
		Syrphid flies	0.11	0.12		0.39	0.59
		Honey bees	1.8				
	Visual	Native bees	13.31**			10.23**	
		Honey bees	8.83**				
		Syrphid flies					

Community dissimilarity among sites was correlated significantly between observational and specimen-based data sets for both the bee group (observational) to bee group (specimen-based) comparison (netting:  $r = 0.489$ ,  $p = 0.001$ ; netting and pan trapping:  $r = 0.310$ ,  $p = 0.001$ ) and the bee group (observational) to species-level (specimen-based) comparison (netting:  $r = 0.475$ ,  $p = 0.001$ ; netting and pan trapping:  $r = 0.324$ ,  $p = 0.001$ ).

For specimen-based data, we detected no trend in non-*Apis* bee abundance among hedgerow classes (netting:  $z = 0.79$ ,  $p = 0.43$ ; netting plus pan trapping:  $z = -0.09$ ,  $p = 0.93$ ). Species richness was also significantly higher in sites with mature hedgerows than in sites with new hedgerows or no hedgerows. Similarly, the observational data showed no differences among hedgerow classes for non-*Apis* bee abundance, but showed a significantly higher richness in sites with mature hedgerows than in sites with new hedgerows or no hedgerows.

On average the citizen-scientists detected 48% (SE 4) of the fully resolved bee groups collected by netting at the same sites and an additional 8% (1.6) of bee groups with partial taxonomic resolution (e.g., tiny dark bee instead of tiny dark bee/dull round tip). There was no significant difference between the first and second sample rounds in the proportion of groups recorded in both observational and specimen-based data sets at a site date (GLM ANOVA:  $F_{1,24} = 0.47$ ,  $p = 0.50$ ). On average, 1.8 bee groups (SE 0.2) were undetected in observations, but observations included 1.2 bee groups per site (0.2) not sampled by netting. Similar results were obtained when comparing citizen-science detection rates with netting and pan-trapping specimens, but the fully resolved detection rates dropped to 41% (SE 3), with 3.2 bee groups per site (0.2) undetected and reporting of 0.96 bee groups per site (0.14) not sampled by netting or pan trapping. Across all bee groups we found a higher proportion of discrepancies between the observational and specimen-based data for bee groups that had lower relative abundance (netting:  $p = -0.69$ ,  $p < 0.005$ ; netting and pan trapping:  $p = -0.59$ ,  $p = 0.01$ ) or frequency of occurrence (netting:  $p = 0.58$ ,  $p = 0.01$ ; netting and pan trapping:  $p = 0.46$ ,  $p = 0.06$ ).

### ***3. Pollinator Communities***

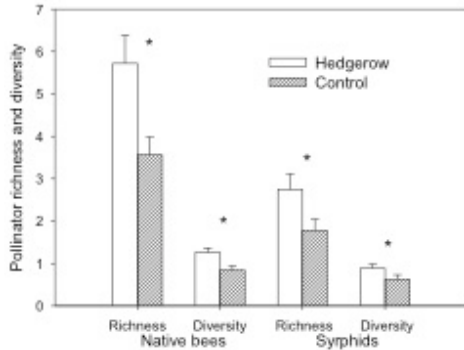
*Site characteristics:* As expected, there was significantly greater floral cover in hedgerow than weedy control edges ( $F_{1,14} = 9.46$ ,  $P = 0.008$ ). Examining differences by sample round however revealed some unexpected findings, mainly, that while hedgerows had significantly greater floral cover in the first sample round, cover declined sharply by the second sample round to levels that were similar to control sites. In mid- and late-summer, floral cover at control sites declined but cover at hedgerow sites remained constant. Floral richness was marginally greater at hedgerow than control sites throughout the summer ( $F_{1,14} = 3.88$ ,  $P = 0.069$ ) with mean richness (SE) of 3.97 (0.36) and 5.84 (0.63) at control and hedgerow sites respectively. There was significantly more dead wood, a potential nesting resource for tunnel and cavity nesters, at hedgerow sites than at control sites ( $F_{1,14} = 10.40$ ,  $P = 0.006$ ). There was a trend towards more bare ground, which is a potential nesting resource for ground nesting bees, at control sites, and more small cavities at hedgerow sites ( $P < 0.10$ ).

*Collection method:* We hypothesized that pollinators may be more attracted to floral resources than they were to pan traps. If so, abundance in pan traps should be negatively correlated with floral cover (Baum and Wallen 2011). We found a significant, negative relationship between



native bee abundance in pan traps and floral cover ( $F_{1,46} = 5.07$ ,  $P = 0.029$ ) and negative (but not significant) relationships between syrphid fly and honey bee abundance in pans and floral cover.

Further, we found that abundance of uncommon species (making up less than 1% of the total sample) was greater at hedgerow than at control sites (mean (SE) of 5.7 (1.1) and 0.8 (0.2) at hedgerow and control sites respectively;  $F_{1,14} = 16.53$ ,  $P = 0.001$ ). There was greater richness ( $F_{1,14} = 7.07$ ,  $P = 0.019$ ) and alpha-diversity ( $F_{1,14} = 9.03$ ,  $P = 0.009$ ) of bees net-collected at hedgerow than control edges (Figure 3).



**Figure 3. Mean native bee and syrphid richness and diversity (Shannon's Index) (+SE) on flowers in hedgerow and control edges in 2009 and 2010.**

*Native bees collected on field edges:* Community analyses (Multi-Response Permutation Procedure) indicated significantly different native bee communities at hedgerow and control edges ( $T = -3.4$ ,  $P = 0.005$ ). Bee communities were also more dissimilar from one another among hedgerow than among control sites (mean Sorensen (Bray-Curtis) distance measure = 0.76 and 0.41 at hedgerow and control sites respectively indicating higher beta-diversity among hedgerows;  $F_{1,54} = 158.8$ ,  $P < 0.0001$ ). We compared the set of species known to be using floral resources at one site type (net-collected) versus the species collected by both sample methods at the opposite site type, since net collected specimens are known to be utilizing resources present at the site, whereas pan-collected individuals may simply be traversing through the area. This gives an indication of number and proportion of species that are unique to the floral resources at hedgerow and control sites compared to species that are present at both site types. Twenty of the 50 native bee species using floral resources at hedgerow sites were absent from control sites (net or pan collections), whereas all of the 20 species net collected at control sites were found in net and/or pan collections at hedgerow sites.

There were two marginally significant indicator species of hedgerows: *Megachile coquilletti* ( $p = 0.07$ ) and *Bombus vosnesenskii* ( $p = 0.07$ ). Indicator analyses by genera showed the genus *Megachile* ( $P = 0.03$ ) as a significant indicator and the genera *Bombus* ( $P = 0.075$ ), *Hylaeus* ( $P = 0.076$ ), and *Osmia* ( $P = 0.087$ ) as marginally significant indicator species of hedgerow restoration.

*Pan collected honey bees and syrphid flies (on field edges):* There was no difference in honey bee or syrphid fly abundance between hedgerow and control field margins. Syrphid richness and diversity was not different between the two site types however there were more uncommon

syrphid species in pans at hedgerow than control sites ( $F_{1,14} = 5.73$ ,  $P = 0.03$ ). There were no significant differences in syrphid community composition between the two site types.

*Net collected honey bees and syrphid flies (on field edges):* There were significantly more honey bees ( $F_{1,14} = 16.91$ ,  $P = 0.001$ ) and syrphid flies ( $F_{1,14} = 6.81$ ,  $P = 0.02$ ) net-collected off of flowers in hedgerows than in control margins. Analysis of covariance, controlling for overall abundance of each species, showed that there were significantly more of each syrphid species in hedgerow than control sites ( $F_{1,39} = 4.45$ ,  $P = 0.04$ ; Figure x). There was no difference between control and hedgerows in abundance of uncommon syrphid species. Syrphid fly richness ( $F_{1,14} = 7.75$ ,  $P = 0.015$ ) and diversity ( $F_{1,14} = 5.57$ ,  $P = 0.033$ ) were greater at hedgerow than control field margins. Syrphid fly communities were not different among treatments (MRPP) and showed a high dissimilarity among sites within treatment types (0.82 and 0.81 for control and hedgerow sites respectively).

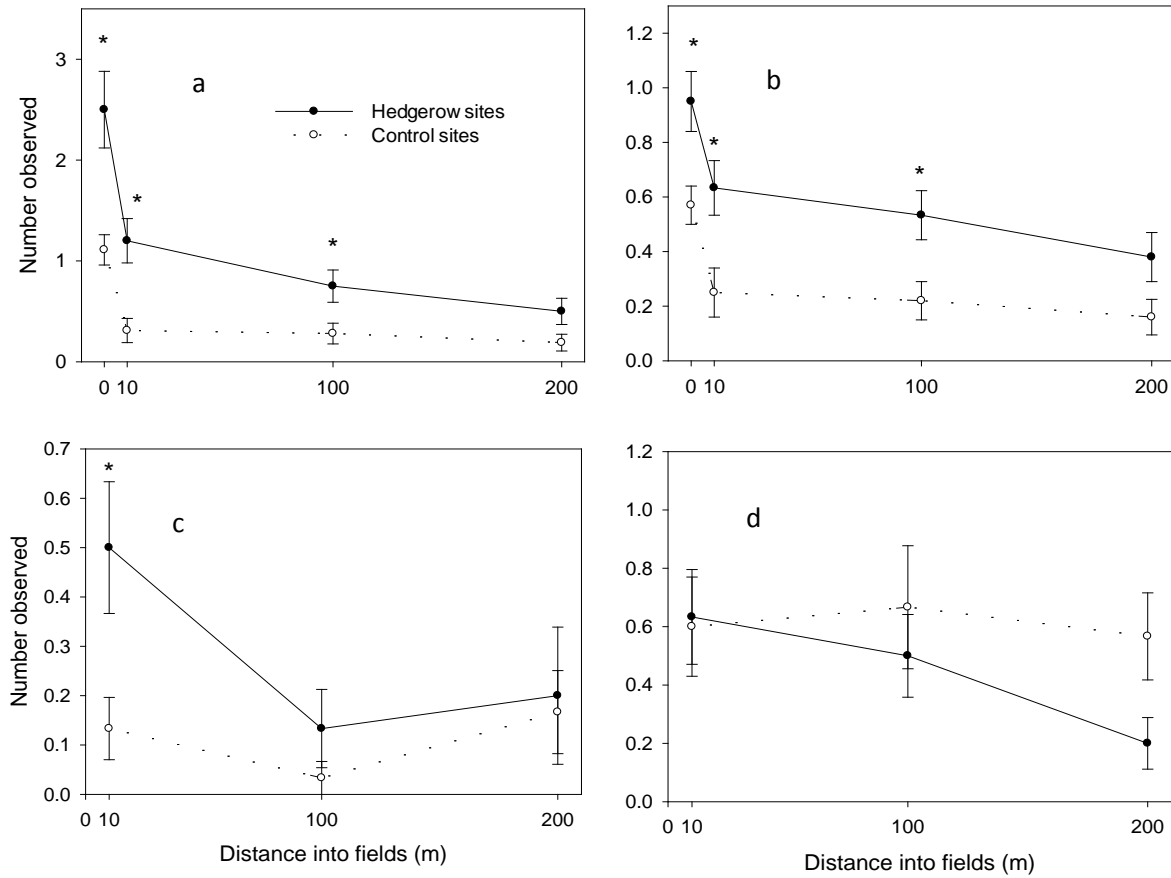
*Visual observations (on field edges):* More native bees ( $F_{1,14} = 10.14$ ,  $P = 0.007$ ) and marginally more honey bees ( $F_{1,14} = 3.87$ ,  $P = 0.069$ ) were observed at hedgerow than control sites. Visual observations of native bees showed greater categorical richness ( $F_{1,14} = 5.39$ ,  $P = 0.036$ ) and diversity ( $F = 10.2$ ,  $P = 0.006$ ) at hedgerow sites. Syrphid fly abundance did not differ between the two site types.

*Pan collected native bees (on field edges):* There was no interaction between distance and treatment, no difference in abundance of native bees in pan traps at hedgerow and control sites, but there was a significant decrease with distance into fields at both site types ( $F_{1,125} = 12.42$ ,  $P = 0.001$ ). Further examination of differences among distances revealed that there were significantly more bees at 10 m than at 100 and 200 m ( $p < 0.05$ ), and no difference in abundance between 100 and 200 m.

Pan collected bees did not differ in richness or diversity between site types but there was a significant difference between bee communities in fields adjacent to hedgerows and those adjacent to control edges (MRPP;  $t = -1.9$ ,  $P = 0.048$ ).

*Visual observations (on field edges):* There were significantly more native bees observed in fields adjacent to hedgerows than in fields adjacent to control edges ( $F_{1,14} = 13.31$ ,  $P = 0.002$ ), and a significant decrease with distance into fields ( $F_{1,175} = 10.45$ ,  $P = 0.002$ ; Figure xa). We observed significantly more native bees in fields at hedgerow than control sites at 10 and 100 m ( $P < 0.05$ ), and marginally more native bees at hedgerow than control sites at 200 m ( $P = 0.08$ ). Native bee categorical richness was greater in hedgerow than control sites ( $F_{1,14} = 10.23$ ,  $P = 0.006$ ) and there was a significant decrease in categorical richness with distance into fields ( $F_{1,175} = 5.17$ ,  $P = 0.024$ ; Figure 4).

**Figure 4. Visual observations of a. native bees, b. native bee richness, c. honey bees, and d. syrphid flies at three distances into fields that were adjacent to hedgerow or control edges, in 2009 and 2010.**



*Pan* collected honey bees and syrphid flies (in crop fields): There was no difference in honey bee abundance, or syrphid abundance and richness between site types, or effect of distance.

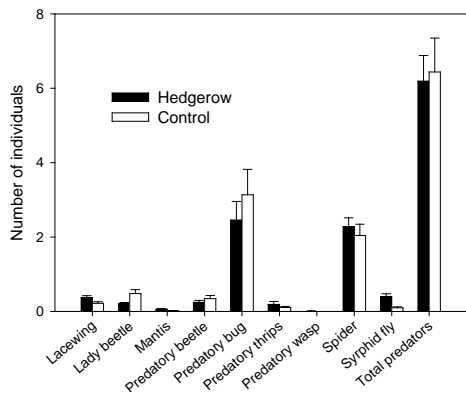
*Visual observations (in crop fields):* There was a marginally significant interaction between field treatment and distance into the field on honey bee abundance ( $F_{1,174} = 3.72$ ,  $P = 0.056$ ; Figure 4) and we therefore left the interaction in the model. We observed significantly more honey bees in fields adjacent to hedgerows than in fields at control sites ( $F_{1,14} = 8.83$ ,  $P = 0.01$ ). Pairwise examination showed that there was a greater abundance of honey bees at hedgerow than control sites only at the 10 m distance. There were no significant differences observed in syrphid abundance in fields, or decrease with distance into fields (Figure 4).

#### 4. Pests and Beneficial Insects

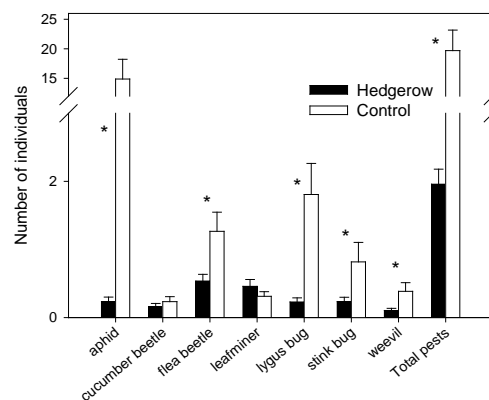
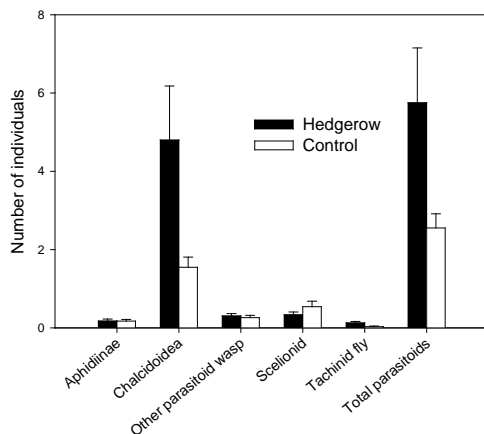
*Edge sweep samples:* The most common predators were (total individuals collected) minute pirate bugs (933), spiders (829), green lacewings (108), convergent lady beetles (99), syrphid flies (94), big-eyed bugs (93), and collops beetles (86). There were no differences in total parasitoid or predator abundance from sweep samples between hedgerow and control field edges. We found no differences in abundance of any predator groups between edge types except syrphid flies which were more abundant in hedgerow vegetation than in control edges ( $F_{1,11} = 4.86$ ,  $P = 0.049$ ) (Figure 5).

However, richness of predators was greater in hedgerows than control edges (First order Jackknife estimator) ( $F_{1,14} = 12.16$ ,  $P = 0.004$ ) with means (SE) of 15.12 (.81) and 19.14 (.82) respectively. The superfamily Chalcidoidea were the most abundant parasitoids (1375) and were marginally more abundant at hedgerow than control sites ( $F_{1,14} = 4.45$ ,  $P = 0.053$ ) in sweep samples (Figure 5).

There were significantly more pest insects in control than in hedgerow edges in sweep samples ( $F_{1,14} = 14.71$ ,  $P = 0.002$ ). The five most abundant pest groups (total abundance collected at all sites and vegetation types) were aphids (3018), lygus bugs (401), flea beetles (397), stink bugs (208), and leafminers (160). All except leafminers were significantly more abundant in control than in hedgerow planted vegetation ( $p < 0.05$ ). Sweep sample data showed a larger beneficial:total ratio at hedgerow than control sites ( $0.81 \pm 0.02$  and  $0.52 \pm 0.03$  at hedgerow and control sites respectively;  $F_{1,13} = 26.03$ ,  $P = 0.0002$ ) (Figure 5).



**Figure 5. Beneficial and pest insects collected by sweep net samples at native plant hedgerows and weedy control edges.**



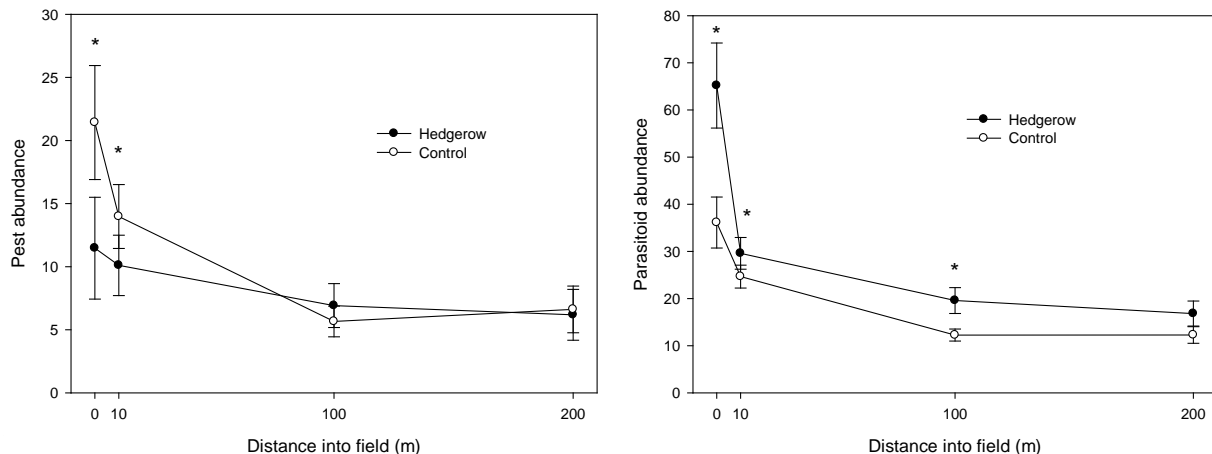
There were fewer samples in hedgerow weedy vegetation than in the other two sample types (control weeds and hedgerow native vegetation) due to the absence of weeds at many hedgerow sample locations. Therefore, we present the means and SE of variables in hedgerow weeds but do not include these values in the statistical analyses. There was a relatively low abundance of pests in weeds at hedgerow sites compared to abundance of pests in control weedy vegetation [4.5(1.1), 1.9(0.2), 19.7(3.5) in hedgerow weeds, hedgerow native plants, and control site vegetation respectively]. The abundance of parasitoids and predators was lower in hedgerow weeds than in hedgerow native plants [parasitoids: 4.0(1.0), 5.6(1.3), 2.4(0.3), predators 4.7(0.8), 6.4(0.7), 6.6(0.9) in hedgerow weeds, hedgerow native plants, and control site vegetation respectively].

*Sticky card samples:* There were significantly more parasitoids in the hedgerow than control sites ( $F_{1,13} = 10.53$   $P = 0.006$ ) and a decrease with distance into fields at both site types ( $F_{1,630} = 10.7$ ,  $P < 0.001$ ) (Figure 6).

There was no effect of site treatment on predator number, but there was a significant decrease in predator abundance with greater distance into fields ( $F_{1,630} = 5.05$ ,  $P = 0.02$ ), however, sticky cards do not sample most predatory insects very well and we did not examine abundance of predator groups due to low numbers captured by this method. Similarly there was no effect of treatment on predator richness or diversity, but a significant decrease of both with distance into the field ( $p < 0.05$ ).

Overall, there was a significant decrease in pests into fields ( $F_{1,630} = 29.6$ ,  $P < 0.0001$ ) and less pests in hedgerow than control fields ( $F_{1,13} = 4.9$ ,  $P = 0.04$ ). Pairwise comparisons of means showed that there were fewer pests on sticky cards at 0 m ( $P = 0.041$ ) and 10 m ( $P = 0.045$ ) at hedgerow sites than control sites, and no differences at 100 and 200 m into fields (Figure 3b). The most abundant pest group on sticky cards were leafminers (total = 4778) followed by aphids (total = 3401). There was no difference in leafminer abundance between the two field types. Aphids were more abundant at control than hedgerow sites ( $F_{1,13} = 16.87$ ,  $P = 0.001$ ), however, the difference was only significant at 0 and 10 m and there was no difference in aphid abundance on sticky cards at 100 or 200 m into fields (Figure 6).

**Figure 6. Abundance of field pests and parasitoids with increasing distance from field edge.**

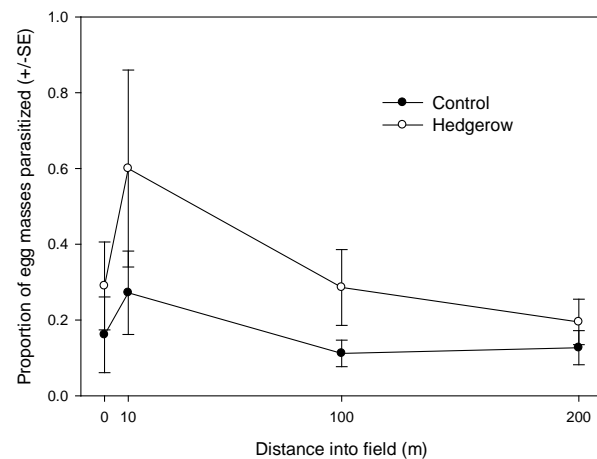


*enemies, and crop damage:* More leaves had aphids on them in control sites than hedgerow sites ( $F_{1,13} = 6.14$ ,  $P = 0.028$ ) with the number of tomato leaves with aphids declining with distance into fields at both site types ( $F_{1,84} = 29.91$ ,  $P < 0.0001$ ).

Because fields were operated for commercial tomato production, we were not in control of treatment schedules. Fields may have been treated for pests because they pest numbers reached levels that necessitate treatment based on the UC IPM guidelines or may have been treated based on the judgment of a grower or pest advisor. Therefore, to compare number of fields that warranted pest control based on UC IPM guidelines, we again exclude fields that were treated prior to our assessments. This likely is a conservative estimate of the number of fields that required treatment, since some fields may have reached threshold levels after our early season assessments but before fields were treated. In 2009, no fields reached the threshold recommended level for treatment of aphids (50% or greater of leaves having aphids). In 2010, three control fields and one hedgerow field reached the threshold for aphid treatment. The hedgerow field subsequently was treated and one of the control fields was treated for aphids after our assessments. The only hedgerow field in our study that reached the threshold level for aphid treatment in the adjacent tomato field also had greater abundance of edge weeds and aphids than the other hedgerow sites.

There were more natural enemy insects, mostly made up of the native lady beetle, *Hippodamia convergens*, at hedgerow than control sites ( $F_{1,12} = 5.77$ ,  $P = 0.033$ ) with no decline in other beneficial insects up to 200 m into fields. All other pests, indicators of pests, and fruit damage were rarely found, far below recommended treatment levels, and showed no differences among sites types.

*Stink bug parasitism experiment:* Of the 871 egg masses recovered (394 of 400 in 2009 and 477 of 480 in 2010), 74 were predated and 127 were parasitized. For predated egg masses, we could not determine if they were, or would have been parasitized if not predated, and therefore predated egg masses were not used in the analyses of proportion of egg masses parasitized. Proportion of egg masses predated was 8% at both site types. There was no distance by treatment interaction or difference among treatments, but there was a highly significant effect of distance ( $F_{3,45} = 18.0$ ,  $P < 0.0001$ ) with a predation rate of 20% in edges and between 1 and 4% in fields. Most predation seemed to be from small mammals, possibly mice or other small rodents, evidenced by complete removal of egg masses and chew marks on the paper towel.



**Figure 7. Parasitism rates of stink bug egg masses by distance from field edge.**

Overall, parasitism was 11% at control sites and 20% at hedgerow sites. There was no distance by treatment interaction, but a marginally significant effect of distance ( $F_{3,45} = 2.58$ ,  $P = 0.066$ )

and significantly greater parasitism at hedgerow than control sites ( $F_{1,14} = 7.13$ ,  $P = 0.018$ ; Figure 7). There was greater parasitism, at both site types, at 10 m than at all other distances ( $p < 0.05$ ). However of note, in a preliminary experiment in 2008, using the same protocol but with both red-shouldered and consperse stink bug egg masses, there was no difference between parasitism rates at hedgerow and control sites.

### 5. Economic Assessment

*Cost of hedgerow establishment and upkeep:* The cost of installing a native perennial shrub and grass hedgerow was estimated by Long and Anderson (2010) from data on many of the same hedgerows examined in this study. Their cost estimate was based on a 305 m long hedgerow with a single row of shrubs and trees bordered by perennial grass. Their estimate included initial site design and preparation, materials, labor, weed control, irrigation for the first three years, and vertebrate pest control. The total cost estimate for establishment of the hedgerow was USD \$3,847. They noted that there would be minimal additional upkeep costs beyond the first three years, consisting of yearly mowing, spot treatment with herbicides, or occasional watering in drought years. We add a \$100 value per year for upkeep acknowledging that in many years, there would be no upkeep costs and in other years the cost may exceed \$100. The majority of hedgerows in our study received no maintenance during the years we conducted our work.

Because most of the hedgerows in our study were 350 m in length (or if greater we only used 350 m of the length), we increased the cost estimate in proportion to the greater length, which resulted in a total cost of USD \$4,415. Increasing the length of a hedgerow by 15% likely wouldn't increase costs linearly, as we have calculated, but we feel a conservative, overestimate is more prudent than underestimating costs. All of the hedgerows in our study were part of an EQIP cost share contract which generally covers 50% of habitat establishment costs. We therefore include models that account for a 50% cost reduction to the grower.

We estimated the economic benefit of hedgerows for pest control as the difference between sites with and without hedgerows in the proportion of fields that reached threshold pest or damage levels requiring control by insecticides (using threshold levels outlined by UC IPM monitoring guidelines):

$$P_{PC} = \sum_{S=1}^n W_S C_S - H_S C_S$$

Where  $P_{PC}$  is the average profit increase attributed to having a hedgerow adjacent to the field,  $W_S$  is the proportion of control fields (weedy edges) and  $H_S$  is the proportion of hedgerow fields that had pest populations or damage for species  $S$  at or above the recommended management threshold.  $C_S$  is the average cost of control for a typical field in our study area, for pest species  $S$  ([http://coststudies.ucdavis.edu/files/tomatoessv1\\_2008.pdf](http://coststudies.ucdavis.edu/files/tomatoessv1_2008.pdf)).

*Valuation of pollination service enhancement from native bees:* Measurements of pollination limitation can be used to estimate profit differences resulting from differences in ambient pollinator populations among sites (Morandin and Winston 2006). This approach isolates the effect of pollinators on crop yield, which otherwise varies among fields due to factors including

planting density, soil conditions, pest loads and treatment, weather conditions, and insect-mediated pollination.

We calculated proportional seed set deficit due to pollen limitation (herein referred to as seed deficit) at four hedgerow and four control sites each year, in 2010 and 2011, using sentinel canola (*Brassica rapa* v. Eclipse). We selected *B. rapa* because it increases fruit set in response to animal visits, shows minimal self-pollination, and is easy to work with for pollination studies (Morandin and Winston 2005, National Research Council of the National Academies 2006). We used 32 potted *Brassica* plants per site, in clusters of four placed along the two transects described in the pest control section, at 0, 10, 100, and 200 m into the field. We manually cross-pollinated 2-3 flowers on each plant to achieve maximum pollination and left 3-4 flowers open for pollination from ambient pollinator populations (Morandin and Winston 2005). In 2010 plants were in fields for 5 hours and we conducted one, 4-min observation on each cluster of plants. In 2011, plants were in fields for 2.5 days and we increased our number of visual observations to 4, 4-minute observations on each cluster (2 on each of 2 days). During visual observations we recorded any flower visitors that touched the reproductive parts (anther and/or stigma) of any mature flower in the cluster. Flower visitors were recorded in Citizen Scientist Monitoring (CSM) categories described in Kremen et al. (2011).

Because native bees are the most important unmanaged crop pollinators that could be enhanced by the presence of farm habitat restoration (Morandin and Kremen, in review), we first calculated pollination differentials with all floral visitors, but then modeled pollination deficit differences due only to native bee differences. Excluding managed pollinators, which were plentiful and ubiquitous in our landscape, allows insight into differences that hedgerows could make to pollination and yield in the absence of managed bees. This is vital to know because of recent, drastic losses in numbers of managed honey bee colonies resulting in uncertainty around their future. Additionally we excluded syrphid fly pollinators from the second model. Syrphid flies were abundant in our landscape and were efficient pollinators of our sentinel plants, however they are not considered important pollinators of most crop species, and were not affected in fields by the presence of hedgerows (Morandin and Kremen, in press).

Proportional seed deficit was calculated at each location (location was defined as two sets of 4 plants at a distance into each field) as the mean number of seeds per fruit from manually-cross-pollinated fruit minus mean seeds per fruit from open-pollinated flowers, divided by full potential seed set at each location. Full potential seed set at each location was the mean of either seeds from manually cross-pollinated or open pollinated flowers, whichever was greater. A greater difference in seed number between open and supplementally-pollinated flowers indicates a greater degree of pollen limitation. While this measure may overestimate pollen limitation because it does not account for resource allocation to supplemented flowers (Knight et al. 2006), it provides a relative estimate that is suitable for comparing among hedgerow and control sites to test whether hedgerows affect pollination function.

In 2010, plants were in the field for only 5 hours, which allowed us to determine the relationship between floral visitor abundance and seed deficit using non-linear regression, since in many locations flowers were not fully pollinated as they were in 2011 when plants were left out for 2.5 days. In contrast, the 2011 data allowed us to calculate the relationship between floral visitors



from one observation to expected visitors, of each CSM category, at each site type, when plants were left for the full duration of focal flower receptivity. We therefore calculated 12 regression analyses (one for each of the six CSM categories, at each site type) and used the regression equations to calculate expected floral visitors from each CSM category over the life of a flower.

Contribution to seed set from one visit of each CSM floral visitor group was experimentally determined in 2012 using methods outlined in previous publications by Dr. Kremen. We then factored out estimated contribution of honey bees and syrphid flies to seed set at each location by subtracting their observed (2011 data) or estimated (2010 data) visits, scaled to their relative seed set contribution at that location.

We compared calculated proportional seed deficit means using a mixed model ANOVA (SAS 1999; Proc MIXED) using arcsine squareroot transformed proportional seed set values, and site nested within treatment and year and distance nested within treatment, year, and site as random effects. If mean proportional seed deficit (calculated using (1) all floral visitors and (2) only native bees) was significantly different between site types, we then calculated the difference between the mean and the proportional increase in seed set ( $PI$ ) due to the presence of a hedgerow. Proportional differences in seed number were used rather than absolute differences between open and supplemental pollinated flowers because maximal seed set may have varied among fields due to factors other than pollination, such as differences in pest pressure. We expected hedgerow sites to have lower proportional seed deficit values than control sites, leading to  $PI > 0$ . (However we acknowledge that  $PI$  could be  $\leq 0$ ). We translated  $PI$  into profit change per hectare by:

$$P_p = MV * Y * PI$$

Where  $P_p$  is the estimated change in profit (\$) per unit area with a hedgerow, resulting from altered pollination,  $Y$  is the average yield per unit area (tons), and  $MV$  is the current market value per ton of the crop.

*Economic cost benefit model synthesis:* Using the pest reduction and pollination enhancement data we created a cost-benefit model for a typical agricultural field. While the data was derived from our study area in Yolo County, CA, the cost-benefit model can apply to any agroecosystem where pest, beneficial insect, and wild bee abundances are impacted by a farm management technique or other farm management techniques. Estimated economic benefit to growers of establishing hedgerows, for each year ( $Y$ ) after establishment (starting at  $Y > 3$ , see below) was calculated as:

$$B_Y = [(Y - 3)(P_p + P_{PC})] - C - (Y - 3)U$$

Where  $B_Y$  is the estimated net economic benefit in dollars per field at  $Y$  years from the time of initial restoration,  $P_p$  is the mean profit difference resulting from differential pollination deficit (scaled to a per field basis), between control and hedgerow sites,  $P_{PC}$  is the average profit change attributed to having a restored hedgerow adjacent to the field for pest control, and  $C$  is the average cost of establishing and maintaining a 350 m insectary hedgerow for the first three years.

We have observed that it takes approximately 3 years before plants are mature and therefore net benefits are calculated starting at  $Y > 3$ .

*Pest control:* In 2009, no fields reached the threshold recommended level for treatment of aphids (50% or greater of leaves having aphids) or other insects during our assessments, prior to fields being treated. One field in 2009 in the control group was treated for aphids, possibly reaching treatment thresholds after our assessments. In 2010, three control fields and one hedgerow field reached the threshold for aphid treatment from our assessments. In total therefore, 4 of 8 control and 1 of 8 hedgerow fields reached thresholds for aphid treatment or were treated for aphids. Using an average cost of treatment for aphids of \$43.24/ha ([http://coststudies.ucdavis.edu/files/tomatoessv1\\_2008.pdf](http://coststudies.ucdavis.edu/files/tomatoessv1_2008.pdf)), the estimated cost difference of pest control between control (4/8 of 16 ha fields treated) and hedgerow sites (1/8 of 16 ha fields treated) is \$259.44/field.

Few pests, other than aphids, were observed in fields. Some fields were treated for Tomato russet mites (*Aculops lycopersici*) however we don't include this in our model because these mites are not controlled by beneficial insects and therefore their populations would not be impacted by the presence of hedgerows (<http://www.ipm.ucdavis.edu/PMG/r783400111.html>). The lower number of aphids and fields reaching treatment thresholds with hedgerows may have been due to lower aphid populations in hedgerow than weedy edges and/or greater beneficial insect abundance in hedgerows and adjacent fields than in weedy edges and adjacent fields.

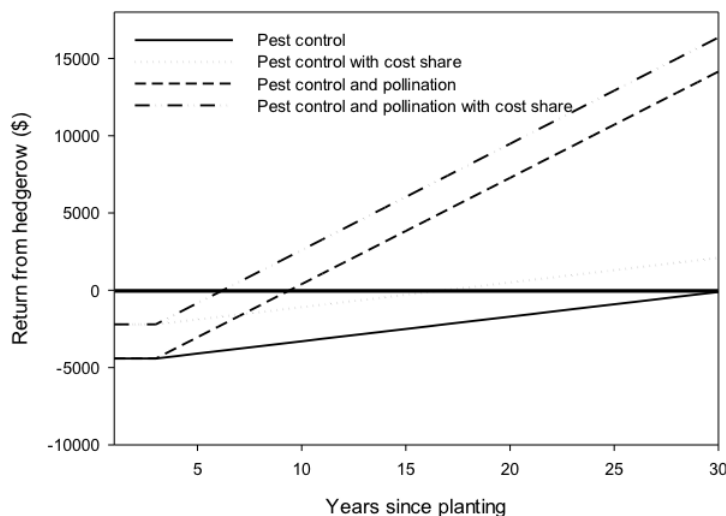
*Pollination:* The best fit relationship between observed floral visitors and seed deficit was an exponential decay equation;  $y = 1.078\exp(-0.172x)$  ( $R^2 = 0.51$ ,  $F_{1,62} = 64.9$ ,  $P < 0.0001$ ) for hedgerow sites and  $y = 0.783\exp(-0.282x)$  ( $R^2 = 0.62$ ,  $F_{1,62} =$ ,  $P < 0.0001$ ) for control sites. We calculated regression formulas separately for hedgerow and control sites because of different floral visitor communities.

Using the observed total floral visitor abundance of each CSM group (2011 data) or the estimated floral visitor abundance of each CSM group (2010 data) we estimated expected seed deficit for all locations using the exponential decay equations above. Estimated proportional seed deficit, with all experimental flowers exposed to ambient pollinators for the life of the flower, was 0.00 for both hedgerow and control sites. When we removed the proportion of pollination resulting from honey bees and syrphid flies, calculated mean proportional seed deficit was 0.025 (0.007) and 0.187 (0.032) at hedgerow and control sites respectively, significantly greater at control sites ( $F_{1,14} = 18.24$ ,  $P = 0.0008$ ). We did not calculate *PI* for the scenario that include all pollinators since there was no difference between site types in seed deficit, due to the high numbers of honey bees and syrphid flies at both site types. Using the mean values for seed deficit considering only native bees,  $PI = 0.162$ , a 16.2% seed increase at hedgerow sites due to enhanced native bee populations (in the absence of honey bees and syrphid flies). Yield varies widely based on agronomic conditions, however we used an average yield of 1100 kg/ha (site link), and 2011 average market value of canola seed of \$558/ton (\$0.56/kg)(site link) to calculate that an average value of \$616 per hectare. Input costs for non-GM canola are approximately \$300/ha resulting in a net profit of approximately \$316/ha. Therefore if a hedgerow were present, greater pollination from enhanced native bee populations would increase yields to 1278 kg/ha resulting in a net profit increase over no hedgerows of \$99/ha. As in Morandin and Winston

(2006) we acknowledge that harvest and transport costs would increase slightly with greater yield, however this likely would be a small amount and we do not factor it in. Applied to a standard size field in our study of 16 ha, using the above values, profit from an average canola field would be \$5056. With the pollination increase from native bee enhancement by hedgerows (in an area with no managed or efficient pollinators other than native bees), profit is \$415/ha and \$6640/field (an increase of \$1584/field), a 31% profit increase. However, this enhanced profit would only be realized if pollination was deficient prior to native hedgerow installation, unlikely if managed honey bees or other pollinators such as syrphid flies were abundant in the area and efficient pollinators of the crop. In this case of abundant managed pollinators or efficient pollinators other than native bees, native flowering plant hedgerows likely would have no economic value from enhanced crop pollination, unless fewer honey bees colonies were rented. We do not include analyses factoring in honey bee rental costs at this time. However, as has often shown to be the case in intensive agricultural landscapes, pollination is a limiting factor to seed set, and seed set is increased in the presence of enhanced native bee populations (Klein et al. 2003, Kremen et al. 2004, Morandin and Winston 2005).

*Cost benefit synthesis:* Due to crop rotations, we modeled a situation in which the adjacent crop would benefit from the pest control services every year (at the rate calculated for a processing tomato field) and pollination services (for the pollinator-dependent *Brassica rapa*) every third year.

In an environment with abundant pollinators whose numbers would not be impacted in fields by the presence of hedgerows (such as in our case where there were abundant managed honey bees and syrphid flies, both efficient pollinators of *Brassica rapa*), we measured no pollination enhancement benefit from hedgerows. Cost return estimates then factor in only the reduced cost of pest control that we observed on tomato crops adjacent to hedgerows than weedy edges. Cost return to the grower in this case would take just over 30 years if the grower paid for the full amount of the hedgerow (Figure 8). With a 50% cost-share provided by EQIP, a producer would break-even in costs and return at approximately 17 years post-installation. The hedgerows at the time of this study were about 15 years old, and we therefore estimate that growers (all of which had 50% cost-share for installation), as of 2012, may have recuperated the cost of installation and upkeep as a result of fewer required insecticide applications.



**Figure 8. Profit from hedgerows based on pest control and pollination service enhancements to adjacent crops, with and without the presence of honey bees in the landscape and with and without growers receiving a 50% cost-share.**

However, when we model a situation in which we discount pollinators other than native bees, simulating an environment with no managed pollinators or efficient pollinators other than native bees, cost return times decrease substantially. With no cost share and cost-share, and pollination benefits every third year, the break-even time is approximately 8 years and 6 years respectively. By 15 years old, the age of most of our hedgerows during this study, if managed honey bees and syrphid flies were not present and/or were not efficient pollinators of the crops, growers could have profited by \$7000 and \$9000 (without and with cost share respectively). Upkeep costs likely would increase at some time as hedgerow age increased past 15 or 20 years possibly due to cost of replacing old plants, therefore, the continued, linear rise of profit shown in figure 8 would not be expected to continue beyond some age greater than 20 years.

This cost-benefit model is a starting point for valuing the economic benefit of multiple ecosystem services resulting from farm-scale land rehabilitation in intensive agricultural landscapes. The value could be an over or under estimate for multiple reasons. These values could be underestimates of benefits of hedgerows to growers because costs can be comprehensively estimated while total benefits are multifaceted and comprehensive estimation is beyond the scope of any one study (Olson and Wackers 2007). Specifically, we have not valued other services potentially provided by hedgerows, such as water quality enhancement. These values could be overestimates in agroecosystems with crops that do not benefit from biological pest control, agroecosystems with few crops that require or benefit from pollination services or have their pollination needs met with managed honey bees, or pest control protocols that are preemptive rather than dictated by pest levels in individual fields. The necessity for renting managed honey bee colonies and costs of rental could be reduced by enhancement of native bees with hedgerows. With data on pollination and pest control service enhancement from hedgerow or other habitat enhancement on multiple crops, calculations can be made for specific crop rotations. In addition, other ecosystem service benefits could be added to these cost return calculations. This model acts as a starting point for evaluating multiple ecosystem service benefits and economic return of farm-scale habitat enhancement.

## ***6. Outreach and Technology Transfer***

### *Workshops and training events:*

Over the course of this project, we reached more than 800 people at farm conferences, field days, and agency workshops, including:

On November 10<sup>th</sup>, 2011, we held a talk on pollinators at the CA Association of Resource Conservation Districts Annual Conference in Stockton, CA for 40 people, including 10 NRCS staff and 22 RCD staff.

On January 4<sup>th</sup>, 2012, we conducted a webinar for leadership of Whole Foods Market on pollinator conservation strategies that focused in part on the research findings of this project. Based upon that presentation, Whole Foods is in the process of launching an educational campaign for their farmer-vendors and will be promoting attendance by their farmer-vendors at pollinator-conservation training workshops in the year ahead.

On January 23<sup>rd</sup>, 2012, we conducted a presentation for fifteen people at the UC Davis Information Center for the Environment, partnering with UC Davis.

On February 7<sup>th</sup>, 2012, we presented to the Association of Applied (IPM) Insect Ecologists Annual Conference in Oxnard, CA to twelve attendees, who were either independent pest-management consultants or suppliers of IPM related products. The presentation included a module on mitigating pesticide impacts on pollinators.

On February 15<sup>th</sup>, 2012, we held a workshop titled *Promoting Agricultural Sustainability: Creating Habitat for Native Bees* in partnership with the Yolo County RCD at the Farm on Putah Creek in Winters, CA. 80 people attended the event, including farmers, land and resource management agency workers, and native nurseries and seed producers/native plant landscapers. The speakers included Jessa Guisse (Xerces), Rachael Long (UCCE), John Anderson (Hedgerow Farms), Taylor Lewis (Cornflower Farms), Jeanette Wrysinski (Yolo County RCD), Miles DePrato (CA Audubon Land Stewardship Program), Jo Ann Baumgarten (Wild Farm Alliance), and Winters Field Office NRCS Staff. The talk included information about native bee diversity and biology, shared research on native bee contributions to crop pollination, and discussed the multiple benefits of on-farm habitat. Other topics included mitigating the potentially harmful effects of pesticides on pollinators and highlighted the work that Xerces has done in partnership with the NRCS and local RCDs in creating on-farm pollinator habitat.

On February 16<sup>th</sup>, 2012, we conducted a webinar that highlighted research results from this project for a U.S. Army Agriculture Development Team being deployed to Afghanistan. The Ag Development Team included more than 20 participants and the training was organized by Clemson University and the NRCS East Regional Technology Support Center in Greensboro, NC.

On February 17<sup>th</sup>, 2012, we held a workshop for 32 people in Ukiah, CA at the Bonterra Vineyards for the Mendocino County RCD. RCD staff made up the largest proportion of attendees, but beekeepers, farmers, and Master Gardeners also attended. Speakers included Peter Braudrick (North Coast RC&D), Ann Thrupp (Fetzer / Bonterra Vineyards), Kathy Kellison (Partners for Sustainable Pollination), Linda MacElwee (MCRCD), Carol Mandel (NRCS), and Jessa Guisse (Xerces). The talk covered the same topics as the one two days earlier in Winters, CA.

On February 21, 2012, Xerces staff held a pollinator workshop for University of California Cooperative Extension (UCCE) in Woodland, CA for 38 people. In attendance were several seed producers, some RCD staff, and farmers. The talk was titled *Pollinator Conservation: Creating Habitat For Native Bees*, and highlighted the work that Xerces has done in partnership with the NRCS and local RCDs in creating on-farm pollinator habitat. Speakers included Dr. Eric Mussen (Apiculturalist, UCCE Yolo County), Dr. Neal Williams (Professor, UC Davis), Katharina Ullman (Graduate Student, UC Davis), and Dr. Sandra Gillespie (Post-doc, UC Davis).

On February 24<sup>th</sup> and 25<sup>th</sup>, 2012, we conducted two workshops at the Midwest Organic and Sustainable Education Service Conference in La Crosse, Wisconsin that were collectively attended by 400 people. The first workshop, *Farming for Bees and Other Beneficial Insects*, highlighted basic pollinator and beneficial insect ecology within farm systems and general conservation strategies to increase their numbers. The second workshop, *Functional Native Plant Restoration for Farms*, highlighted opportunities for integrating native plant hedgerows, filter

strips, field borders, and other plant-based conservation practices into farm systems to achieve multiple benefits. Specific farms used in the monitoring component of this project and project research results were highlighted. The majority of the participants at both workshops were farmers, and both workshops highlighted conservation opportunities available through the NRCS.

On April 20<sup>th</sup>, 2012, we conducted a field day presenting research findings and general information on hedgerow establishment to more than 125 people at the California Native Grasslands Association's Annual Field Day in Winters, California. Co-presenters included UC Cooperative Extension staff and local restoration ecologists.

The next week, on April 24<sup>th</sup> we worked with UC Davis staff, the state NRCS office, and staff of the Lockeford, CA Plant Materials Center staff to conduct a workshop for 30+ people at the Lockeford Plant Materials Center. The event was attended by State Conservationist Ed Burton, and included a tour of hedgerow demonstration sites.

Finally, on July 22-23, 2012, we presented project findings in poster and oral presentations as part of the CIG showcase at the annual meeting of the Soil and Water Conservation Society in Ft. Worth, Texas.

*Publications:*

In addition to workshops and field day events we developed the manuscript of a forthcoming book titled *Farming for Beneficial Insects: Providing Habitat for Predators and Parasitoids of Crop Pests*. The publication is scheduled for release in July 2014 by Storey Publishing, a leading farm management handbook publisher. This publication will serve as a companion to our highly successful book *Attracting Native Pollinators*, which has been distributed to thousands of NRCS offices, partner agency staff, and farmers nationwide since 2006. This new guide includes a comprehensive but easy-to-understand overview of beneficial insect biology, habitat restoration guidelines, adaptive farm management recommendations, and information on NRCS programs.

A companion NRCS technical note (Figure 9) has already been developed titled *Conservation Biological Control: Providing habitat for Predators and*

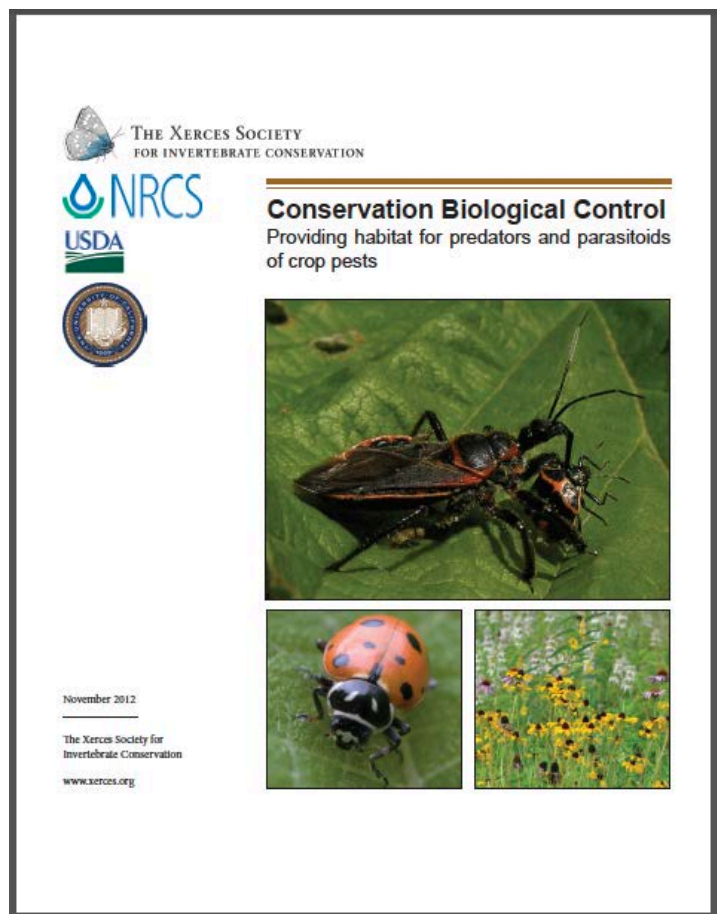


Figure 9.

*Parasitoids of Crop Pests*. The technical note has undergone peer review to ensure scientific accuracy, feasibility, and transferability of relevant technical recommendations. A key highlight of the technical note is a series of real world case studies of beneficial insect conservation on working farms. These individual case studies were authored by leading university researchers, Extension staff, and other agricultural professionals from across the country, giving the document national relevance. *Conservation Biological Control* is currently undergoing final approval by NRCS staff at the West National Technology Support Center for nationwide release.

In addition, a manuscript is currently being prepared for publication in the journal *Restoration Ecology* titled *Bee preference for native versus exotic plants in restored agricultural hedgerows*. A second manuscript on pollinator communities in hedgerows and in adjacent fields is in the final stages of revision and will soon be submitted to a peer-reviewed journal. A third paper, on pest and natural enemy communities and pest control services, is in an early draft stage and is in the process of being submitted to a peer-reviewed journal.

## **CONCLUSIONS AND RECOMMENDATIONS**

Our results show that field edge plantings of native California shrubs and perennial grasses can enhance both pollinator and beneficial insect abundance. The enhancement of pollinators and beneficial insects may occur in several ways. First, most species require or benefit from nectar or pollen sources from flowering plants that hedgerows provide, helping them survive and reproduce, especially during times of prey scarcity. This was apparent in our study; beneficial insect abundance was greatest on shrubs during bloom, suggesting that insects were using floral resources. Second, hedgerows provide some non-pollinator beneficial insects (predators and parasitoids) with alternative prey or hosts, which may be important when pests are not present in crop fields. Third, hedgerows provide pollinators and beneficial insects with overwintering habitat, which is important when neighboring fields are cultivated and fallow for the winter, and there are few other refuges (Dennis et al. 1994).

Our study provides evidence that hedgerow plantings can enhance ratios of beneficial to pest insects compared with weedy areas, where pests were found in significantly greater abundance than beneficial insects. The extent to which this enhanced abundance of beneficial insects in hedgerows will improve biological pest control in adjacent crops is largely unknown. Previous research showed that beneficial insects used floral resources provided by hedgerows and moved into adjacent crops (Long et al. 1998). In a review of natural pest control, 74% of cases studied showed that landscapes with high proportions of non-crop habitat had enhanced natural enemy populations in crop fields (Bianchi et al. 2006). Further, eliminating edge weeds (by mowing or spraying) or replacing them with managed vegetation such as native perennial grasses has led to reduced pest pressure in adjacent crops (Ehler 2000; Mueller et al. 2005; Pease and Zalom 2010).

For improved biological control through hedgerow plantings on farms, it is important that plants enhance beneficial insects without increasing pest populations (Fiedler and Landis 2007). In our study, the native shrubs and perennial grasses, though used by pests, were not as preferred as the weeds were, as noted by the significantly greater proportion of beneficial insects compared with pests in the hedgerow plantings. Although California buckwheat attracted *Lygus* bugs during summer and coyote brush attracted spotted cucumber beetles during fall, beneficial insect

abundance was far greater than pests on those plants.

One of the impediments to growers adopting hedgerows is the concern that they will harbor and enhance pest insect populations in adjacent crops. Our data show that hedgerow plantings can sustain or enhance pollinators and other beneficial insects and serve as replacement vegetation for weedy field edges, which harbor pests.

Based upon the study reported here and our current evaluations of the economic benefits of hedgerows on pollination and pest control, we recommend the NRCS continue and increase the wider adoption of hedgerow plantings on farms, helping to enhance the many ecosystem service benefits they provide in agricultural landscapes.

## **APPENDICIES**

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## 2. Photos



In this study, hedgerows enhanced the ratio of beneficial to pest insects compared with weedy areas. Plantings at Sierra Orchards in Solano County include deer grass, California lilac and elderberry. Inset left to right, the beneficial insects identified included lady beetles, syrphid flies and their larvae (feeding on aphids).



**Hedgerows of California native shrubs and perennial grasses, including at Fong Farms in Yolo County, were compared to weedy field margins for the abundance of beneficial and pest insects.**

### **TECHNOLOGY REVIEW CRITERIA**

See NRCS Conservation Practice Standard 422 (Hedgerows), and encourage the specific establishment of locally native shrub species where this practice is implemented.