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ABSTRACTS

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Xylella fastidiosa epidemiology in California after introduction of the glassy-winged sharpshooter: insights from transmission studies

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Xylella fastidiosa is a gram-negative bacterium that inhabits two extreme environments: xylem tissue of plants and the foregut of sap-sucking insects (sharpshooter leafhoppers, Hemiptera, Cicadellidae; and spittlebugs, Hemiptera, Cercopidae) that serve as vectors of the bacterium. Among the major diseases caused by this bacterium in California are Pierce's disease of grapevine (PD), almond leaf scorch, alfalfa dwarf, oleander leaf scorch (OLS). The bacterium also colonizes many other plants, apparently without causing any disease.

The introduction of an exotic *X. fastidiosa* vector, the leafhopper *Homalodisca coagulata* (Say) (or 'glassy-winged sharpshooter'), into California has already caused economic losses to grape growers in Temecula Valley and Kern Co. It has also been blamed for the emergence of a new disease of oleander (OLS) in southern California. OLS has caused millions of dollars in losses to the California Department of Transportation (Caltrans), since this evergreen is planted along highways throughout the state, and other replacement plant species have higher maintenance costs. This insect now threatens the Central Valley, the major agricultural area of California, in which various crops susceptible to *X. fastidiosa* are coincident.

X. fastidiosa has been present in California for over 100 years, causing plant diseases in various crops under different environmental conditions, with different leafhopper vectors. Therefore the large impact of this introduction has generated many hypotheses for the reasons why *H. coagulata* has been such a devastating vector. Among those are: i) it has long dispersal capabilities, ii) it can feed on mature and dormant plants, iii) it can achieve high populations on citrus, a common crop plant in California, iv) it has a wide host plant range, and others.

Because of the current and potential threats of *X. fastidiosa* transmitted by *H. coagulata* to California's agriculture and ornamental industries, we studied aspects of the transmission of the pathogen by this invasive species. The epidemiology of vector-borne diseases is tightly linked with how transmission occurs; thus, better understanding of its characteristics is the first step for the development of sound and effective disease management strategies. Therefore, we have addressed basic questions about transmission that could help us understand why this insect is apparently such an effective vector in disseminating *X. fastidiosa* in California. The seminar will focus on the characterization of *H. coagulata* transmission of *X. fastidiosa* to grapes, and the implications of the results to PD epidemiology in California. Our results are briefly summarized below.

In laboratory experiments, the major characteristics of *H. coagulata*'s transmission of *X. fastidiosa* to grapevines were the same as reported for other vectors: short or absent latent period; nymphs transmitted but lost infectivity after molting and regained infectivity after feeding on infected plants; and infectivity persisted in adults. Adult *H. coagulata* acquired and inoculated *X. fastidiosa* in less than 1 h of access time on a plant. Inoculation rates increased with access time, but acquisition efficiency (20% per individual) did not increase significantly beyond 6 h access. Estimated inoculation efficiency per individual per day was 19.6, 17.9 and 10.3% for experiments where plant access was 1, 2 and 4 days respectively. *H. coagulata* transmitted *X. fastidiosa* to two-year-old woody tissues of grapevines as efficiently as to green shoots. *H. coagulata* transmitted *X. fastidiosa* 3.5 months after acquisition, demonstrating persistence of infectivity in adults. About half (14/29) of the *H. coagulata* from which we failed to culture *X. fastidiosa* from homogenized heads (with a detection threshold of 265 CFU/head) transmitted the pathogen to grape, and 17 of 24 from which we cultured *X. fastidiosa* transmitted.

H. coagulata has also been found feeding on dormant grapevines during the winter, raising the possibility of bacterial transmission during that season. We tested if *H. coagulata* could acquire *X. fastidiosa* from dormant vines under greenhouse conditions, and inoculate bacteria into dormant plants in the field and laboratory. *H. coagulata* survived well on dormant plants in the field and laboratory, and transmitted *X. fastidiosa* to healthy plants under both conditions. Our results also suggest that *X. fastidiosa* may be acquired from dormant plants by this sharpshooter. Transmission to dormant plants during the winter is likely to be a problem in vineyards adjacent to citrus groves, where large populations of *H. coagulata* over winter. Because dormant plants have positive root pressure, our findings provide indirect evidence suggesting that *X. fastidiosa* transmission requires an active probing behavior by vectors to be inoculated into plants.

INFLUENCES OF TEMPERATURE ON IMMATURE DEVELOPMENT OF THE COCONUT MITE, *ACERIA GUERRERONIS* KEIFER (ACARINA: ERIOPHYIDAE) ON QUEEN PALMS.

Tommaso Ansaloni and Thomas M. Perring

Aceria guerreronis Keifer (Acarina: Eriophydae) was first discovered as a major pest of coconut (*Cocos nucifera*) from plantations along the coast of Guerrero, Mexico, in 1965. In the following ten years the mite was reported to be on coconut plantations of many Central and Southern American countries and in West Africa, and in 1997 the mite was discovered in India and Sri Lanka, where coconut is a major agricultural product. In 1997 an eriophyoid mite was discovered to be associated with meristem necrosis and, eventually, death of young queen palm seedlings, *Syagrus romanzoffiana* (Cham.) Glassman, in a number of southern California nurseries. The mite was identified as *Aceria guerreronis* Keifer.

In this work, immature development of the coconut mite relative to temperature on queen palm has been investigated. For this study the mites were reared on plant tissue embedded into 3% agar solution, the substrate being changed every day. A generation took 30.7, 16.2, 11.8, 8.3 and 7.5 days at 15, 20, 25, 30 and 35 °C, respectively. Optimal developmental rates for the total immature development was estimated at 29.8 °C, and the maximal developmental threshold was estimated at 36.7 °C.

INSECT OOSORPTION: A BRIEF REVIEW AND NEW INSIGHTS FROM *ERETMOCERUS EREMICUS* (HYMENOPTERA: APHELINIDAE)

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Oosorption (egg resorption) is a common process in at least eight insect orders, including the five most speciose groups. It functions in breaking down nutrients from mature anhydropic (yolk-provisioned) oocytes and reallocating them to serve various somatic functions. Several biotic and abiotic factors can trigger or increase the frequency of the process, although dietary deficiencies are often the most common of these. Oosorption can also be maintained at low levels as a normal ovarian condition. In general, insects that are capable of egg maturation later in the adult stage only are reported as having the capacity to resorb oocytes.

Nearly all insects in which oosorption has been morphologically documented resorb eggs within the ovariole. These oocytes are typically terminal and have just completed vitellogenesis but lack the egg membranes (vitelline membrane and chorion). Follicle cells surrounding the oocyte appear to play a significant role in this process, switching their function from yolk deposition to facilitating oosorption. Their exact role is unclear, but nearly all taxa show a tight connection between the follicle cells and the oocyte just prior to and during oocyte degradation. This has led to the view that the ribosomes and enzymes responsible for oosorption are in part or wholly produced by the follicular epithelium. Some insects, however, demonstrate significant variations from this paradigm. These include extra-ovariolar resorption in dung beetles and the resorption of chorionated oocytes in some thysanurans and hymenopterans. While most of these cases involve the partial or complete breakdown of the egg membranes by follicle cells prior to oosorption, some parasitic wasps carry empty chorions. This suggests that an autolytic mechanism of oosorption must also be possible, although no ultrastructural evidence of this is currently available.

I will present the results of ultrastructural analyses of the oosorption process in the wasp *Eretmocerus eremicus*, a solitary parasitoid of whiteflies. Resorbed oocytes in this species are unusual in that the ribosomes responsible for yolk breakdown are unequivocally derived from within the oocyte itself. This is due to the complete barrier

to follicle cell penetration provided by portions of the egg membranes during their slow digestion by the follicular epithelium. Furthermore, the ultrastructure of yolk degradation in *E. eremicus* oocytes is identical to that of other species exhibiting follicle cell contact with the ooplasm. It seems more parsimonious for this exact process to have developed once rather than independently in groups with follicle cell contact and those with autolytic resorption. In addition to the potential it has for unifying oosorption under a largely autolytic mechanism, I will also discuss the possible adaptive significance of this novel mechanism to the strongly pro-ovigenic *E. eremicus*.

Collecting dust with a whitefly parasitoid:
Method and application for mass-mark-recapture studies with minute insects using florescent dust

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Gender differences in short-range (< 10 km) dispersal by the whitefly parasitoid *Eretmocerus eremicus* Rose and Zolnerowich (Hymenoptera: Aphelinidae) were examined in a mass-mark-recapture study using DayGlo® fluorescent dust. Before doing so, it was determined in the laboratory that this dust did not affect flight behavior, was retained over the length of the experiments, and allowed large samples to be processed quickly and inexpensively. In the field, traps were placed along annuli at 3, 5, 7, and 10 m from release points. Eighty-seven per cent of the 4153 parasitoids captured were males. Sex ratios were near parity on release. The difference in dispersal characteristics between males and females may be resource based, suggesting that certain requirements were met within the field plots for males that were not met for females. Locally, males dispersed in a manner consistent with a simple diffusion model while females engaged in wind-directed flight soon after leaving release sites. The fact that the genders exhibited dissimilar dispersal characteristics, supports the claim that insect flight, even by small species, can be self-directed.

FACTORS INFLUENCING *HOMALODISCA* SPP. DISPERSAL IN COMPLEX AND SIMPLE HOST-PLANT MATRICES

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The glassy-winged sharpshooter, *Homalodisca coagulata* (Say), was first detected in California in 1989. Since then, it has spread throughout southern California and into the southern San Joaquin Valley. *H. coagulata* feeds on a wide variety of ornamental and crop plants, and in the process transmits the bacterium, *Xylella fastidiosa*, which is the causal agent of Pierce's disease (PD), as well as several other diseases. There are currently no effective treatments for PD and its spread now threatens the viticulture, citrus, and ornamental industries of California. Area-wide management programs are being undertaken in an effort to limit the spread of the disease and vector. However, without a sound understanding of the factors that influence the dispersal of *H. coagulata*, as well as other native vectors, we can expect limited success in our control efforts. *H. coagulata* appears to be spreading faster than native vectors such as the smoke tree sharpshooter *Phera lacerta* Fowler, and this could be the result of a greater flight capacity; however, it might also be due to a higher reproductive potential and an expanded host range, which could result in larger populations that are more easily detected with the standard monitoring technique (yellow-sticky traps). The propensity of an insect to disperse is influenced by numerous factors such as population density, reproductive status, sex ratio, host breadth, host quality and changing environmental conditions, and it is likely that many of these factors play an important role in the spread of *H. coagulata*.

Here we used the mark-release-recapture (MRR) technique to examine the dispersal of *H. coagulata* relative to *P. lacerta*. Our objectives were to establish the validity of using an immunoglobulin G (IgG) protein marker for sharpshooter dispersal studies, to compare the dispersal propensity of glassy-winged and smoke tree sharpshooters, and to develop a better understanding of the biotic and abiotic factors that might influence sharpshooter dispersal. Furthermore, recapture data were fit to a diffusion model, which has been shown to accurately describe the movement of several species of insects. Based on parameters generated with the diffusion model, dispersal distances were estimated for each species and for two habitats (simple and complex). In 2001, field trials showed that the marker remained effective for at least 19 days and had no effect on cumulative mortality of sharpshooters. Additionally, in our mark-release-recapture studies, four concentrations (0.04, 0.2, 1 and 5 mg/ml) and two different IgG markers (chicken and rabbit) were found to be effective for marking sharpshooters. In the simple landscape of the abandoned alfalfa field, approximately 95% of the marked insects took off during the releases and the timing of takeoff was similar for *H. coagulata* and *P. lacerta*. Wind speed was the only environmental parameter that explained a significant amount of the variability in take-off activity in 2001. Sharpshooters rarely took off when the average wind speed exceeded 3 m s^{-1}. Both species of sharpshooters readily dispersed out to 90 m and up to 7 m in height; however, most sharpshooters were trapped at heights below 4.2 m and within 30 m of the release site. Linear regressions of recapture data with the diffusion model provided significant fits to the data with high coefficients of determination for all of the glassy-winged sharpshooter releases, and for three of the four smoke tree sharpshooter releases in 2001. Calculations of dispersal distances showed

that 95% of *H. coagulata* and *P. lacerta* were recaptured within 90 and 155 m of the release site, respectively. In 2002, MRR studies were conducted in an architecturally complex host-plant matrix (mature orange grove). Similar to 2001, linear regressions of recapture data with the diffusion model provided significant fits to the data in five out of six releases. In this setting, estimated dispersal distances for glassy-winged sharpshooter were almost identical to the simple landscape, despite the fact that the release-recapture interval was 12 times longer. This suggests that in the complex landscape, diffusion rates for sharpshooters are considerably slower. In a separate study that measured sharpshooter movement relative to time of day, and environmental parameters, we found that sharpshooters were most active, in terms of flight activity, between 1000 and 1400 h. In this more complex host-plant matrix, only temperature explained a significant amount of the variability in trap catch. Sharpshooters were rarely trapped when temperatures fell below 18° C. In conclusion, glassy-winged and smoke tree sharpshooter dispersal fits the diffusion model well. Calculations of dispersal distances indicate that, in the simple landscape, smoke tree sharpshooters disperse more quickly and further than glassy-winged sharpshooters, and that in the complex landscape, glassy-winged sharpshooters probably disperse more slowly. The most important environmental constraints for flight were wind speed in an open setting, and temperature in the orange grove.

INTEGRATING GLASSY-WINGED SHARPSHOOTER MANAGEMENT TACTICS

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Homalodisca coagulata (Say) (Homoptera: Cicadellidae), the glassy-winged sharpshooter (GWSS), is a vector of the plant pathogenic bacterium *Xylella fastidiosa* Wells et al. which induces diseases in important agricultural and ornamental plants, most notably Pierce's disease of grapevine. Since 1997, a few years after it's introduction into California from the southeastern United States, GWSS-spread Pierce's disease has devastated wine and table grapes locally in Southern California, and threatens grapevines throughout the state. Our investigation of GWSS biology and ecology has revealed ways of integrating biological, chemical, and physical management tactics to reduce GWSS vectors in the agro-ecosystem, and at the level of vineyards and individual grapevines to reduce the spread of Pierce's disease.

DOES PRESENCE OF CONSPECIFICS FACILITATE LEARNING OF COLOR CUES IN BUMBLEBEES (*BOMBUS IMPATIENS*)?

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Bees learn and remember the identity of rewarding floral resources based on specific signals, including color, scent, and morphology. The ability to learn such signals may reduce the costs associated with foraging. Social species such as bees could potentially further reduce the costs of foraging by utilizing conspecifics as cues to signal the location of food rewards. This study investigated how the presence of conspecifics affects color learning in *Bombus impatiens* (Hymenoptera: Apidae) using an artificial flower array. Specifically, we predicted that the presence of conspecifics on rewarding artificial flowers would decrease color learning latency, but that this effect would be frequency dependent. The results suggest that latency may decrease and that learning may increase with increases in conspecific density.

NOVEL SOURCES OF PLANT RESISTANCE TO INSECT PESTS OF GRAIN LEGUMES AND GRASSES

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Independent and collaborative research at the USDA-ARS Plant Germplasm Introduction and Testing Research Unit has identified novel (new and unusual) sources of insect resistance in the wild and/or unadapted relatives of grasses (cereal relatives, temperate grasses) and cultivated pea that are preserved as seed in repositories of the U.S. National Plant Germplasm System (NPGS). Searches for this resistance were performed because ample genetic variation was not located in domesticated germplasm, or to widen the arsenal of plant defensive traits for possible use in breeding for insect resistance. A new class of herbivore-specific elicitors was found to induce a novel type of defense response in pea accessions possessing the *Np* gene. These elicitors (called bruchins), long chain diols that are mono- and diesterified with 3-hydroxypropanioc acid, are excreted at oviposition by some weevils (Bruchidae) and elicit neoplastic growth at the site of egg attachment. These neoplasms impede entry of neonate larvae of pea seed weevil (*Bruchus pisorum*) into pea pods. Other research has identified pod (antixenosis, antibiosis) and seed (antibiosis) resistance to pea seed weevil in the secondary gene pool of pea. Research on the role of microbial germplasm (*Epichloe* fungi and their asexual *Neotyphodium* forms) in determining the outcome of grass - insect encounters revealed a vast diversity of *Neotyphodium* endophytic fungi in NPGS grass taxa, including wild

barley. A series of experiments involving cereal aphids (*Diuraphis noxia, Rhopalosiphum padi*, *Metopolophium dirhodum*), Hessian fly (*Mayetiola destructor*) and diverse grass taxa showed that the expression of insect resistance is affected by the host grass genotype or species (tall fescue, perennial ryegrass, wild barley) and the *Neotyphodium* species or strain involved in the interaction. The discovery of cereal aphid and Hessian fly resistance in endophyte-infected wild barley suggests a potential role for using *Neotyphodium* fungi to protect crop grasses from insect pests. In this symposium presentation, I provide details about these novel sources of plant resistance to insects and insights into their potential utility in world agriculture.

ECOLOGY OF WESTERN FLOWER THRIPS IN INTRA- AND NEAR-ORCHARD HABITATS

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Four apple orchards with adjacent uncultivated areas were located along the Columbia River in Washington. Apple shoots harbored adult and immature thrips throughout the season until frost. Adult thrips appeared on dandelion flowers, *taraxacum officinale*, before apple flowers developed and first appeared on apple buds at delayed dormant. On the orchard floor, dandelion flowers, as well as other flowers sampled, harbored thrips until frost, sustaining a resident population in the orchard. Thrips fed and reproduced throughout the year in near-orchard habitats by switching hosts that produce new leaves and flowers in different seasons. Some plants, such as arrowleaf balsamroot, *Balsamorhiza sagittata,* bloomed in spring and then were dormant until the next year. Others, such as gray rabbitbrush, *Chrysothamnus nauseosus,* provided growing shoots throughout the spring and summer, and flowers in the fall. The dominant climax woody species of the steppe, big sagebrush, *Artemisia tridentata,* attracted great numbers of thrips when in bloom in the fall. Native grass species attracted some thrips when in flower, but in general samples contained very few thrips. All native grass species sampled were dormant in the summer and fall, and could not serve as a continuous food source for immature thrips.

FIELD ECOLOGY AND POPULATION DYNAMICS OF THE GLASSY-WINGED SHARPSHOOTER IN CALIFORNIA

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Pierce's disease is vectored by the Glassy-winged sharpshooter (GWSS). It has severely damaged vineyards in Temecula and it threatens table and wine grapes in other regions of the State. To manage GWSS and the disease it vectors, information on GWSS' biology, ecology and population dynamics is needed. We recover all GWSS stadia except eggs from a plant by using military parachutes to cover citrus trees, which are then fogged.

Our results show that adult GWSS shift between different *Citrus* varieties in different seasons. In summer and fall, adult GWSS densities are similar on lemon and orange trees, whereas in winter, GWSS are found almost exclusively on lemon trees. A second aspect of our research seeks to explain these shifts in host plant choice by investigating correlations between insect densities and reproduction on a given host plant, and the physical and chemical properties of its xylem chemistry. We use a specially designed Schölander bomb to measure xylem hydrostatic pressure and to extract xylem for chemical analyses. We present density estimates for all stages of GWSS on different host-plants.

VOLATILES FROM VIRUS-INFECTED PLANTS INFLUENCE VECTOR BEHAVIOR: CLEVER LUTEOVIRUSES?

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Potatoes infected with *Potato leafroll virus* (PLRV) and wheat infected with *Barley yellow dwarf virus* (BYDV) attract or arrest the respectively most efficient aphid vectors of these viruses, *Myzus persicae* and *Rhopalosiphon padi.* Bioassays conducted in darkness and configured to prevent aphids contacting the plants show that the aphids are responding to volatile organic compounds (VOC) in the headspace of infected plants. VOC from PLRV-infected potato plants ('Russett Burbank') differ from VOC from uninfected plants and plants infected with *Potato virus X* or *Potato virus Y*, all of which are less attractive to *M. persicae*. VOC from BYDV-infected wheat seedlings ('Lambert') differ from VOC from uninfected Lambert seedlings, which are less attractive to *R. padi.* Several individual VOC elevated in virus-infected potato and wheat are candidate attractants or arrestants for the aphids. Both BYDV and PLRV, like most

other Luteoviridae, are entirely dependent upon aphid vectors for their transmission. Attraction of aphid vectors to virus-infected plants potentially benefits the viruses, enhancing their spread under certain conditions. This suggests that virus-infection-induced VOC are a component of a 'clever virus' strategy in which the virus manipulates its host plant's metabolic machinery to promote acquisition of the virus by its vector.

CUTWORM CONTROL ON PACIFIC NORTHWEST MINT

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A complex of lepidopteran pests infests mint fields in the Pacific Northwest. Identified pest species include: cabbage looper (*Trichoplusia ni*), alfalfa looper (*Autographa californica)*, and variegated cutworm (*Peridroma saucia)*. However, our research has determined that early-spring feeding by spotted cutworm (*Amathes c-nigrum)* has the greatest negative impact on mint oil yields. *A. c-nigrum* overwinter as 2nd through 5th instar larvae in plant debris and soil directly beneath dormant mint. Feeding commences as the mint plants break dormancy, typically in mid-March. Our research indicates that treatment is necessary when *A. c-nigrum* populations exceed a density greater than 1.5 larvae per ½ m^2. Since 1999 we have monitored mating flights of *A. c-nigrum* and have determined that there are two complete generations per year. It is only the overwintering generation that causes economic damage to peppermint, spearmint and native Scotch mint in the Pacific Northwest east of the Cascade range.

Insecticides have been field-evaluated over the past several years to determine their potential for controlling early-spring *A. c-nigrum* on peppermint. Traditional insecticides including acephate, chlorpyriphos, and lambda-cyhalothrin have proven effective at controlling *A. c-nigrum,* whereas newer insect growth regulators and stomach poisons are not effective. We speculate that the IGRs and stomach poisons are not effective under PNW cold spring conditions.

SUSPECTED CHEMOSENSORY STRUCTURES ON THE OVIPOSITOR OF A STEM-GALLING SAWFLY (HYMENOPTERA: TENTHREDINIDAE)

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Female *Euura lasiolepis* (Hymenoptera: Tenthredinidae) were examined under SEM to detect, by morphological characterization, the presence of chemoreceptors. *E. lasiolepis* have a saw-like ovipositor that comprises gonopophyses VIII and IX. Gonopophyses IX acts as a guide for gonopophyses VIII which saws back and forth into plant tissue to form a gall and lay an egg. There was no resemblance of chemoreceptors found on gonopophyses IX. Two types of probable chemoreceptors were found on gonopophyses VIII: sensilla basiconica and sensilla campaniformia. Both sensilla types are present on the inside and the outside of the saw, gonopophyses VIII. Sensilla basiconica are present on each annulus (segment) of the saw in numbers from 2 to 20. Sensilla campaniformia are only present on the apex of the saw. Along the exterior, single campaniformia sensilla are present on the last 3 annuli and on the interior 4 distinct sensilla are present on the last annuli of the apex. These findings concur with the plethora of circumstantial evidence that supports the presence of chemoreceptive qualities on the ovipositors of galling sawflies.

RESPIRATORY MORPHOLOGY OF ABEDUS HERBERTI EGGS (HEMIPTERA: BELOSTOMATIDAE)

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The brooding behaviors of the Belostomatidae likely evolved in response to the oxygen demands of the embryos. The respiratory morphology of the eggs is thus important. The respiratory morphology of the eggs of *Abedus herberti* (Hemiptera: Belostomatidae) was examined using scanning electron microscopy. Like other Belostomatidae, this species has a plastron network, though confined to the apical cap. The aeroplyles also have limited distribution across the upper 150μm of the egg and take one of three forms depending on their location on the egg. The inner portion of the chorion is comprised of a series of seemingly continuous layers that vary in size, number,

and composition from the upper to the lower portions of the egg. The respiratory structures are located such that they may be exposed to the atmosphere during surfacings and transfer gasses to the rest of the chorion. *Abedus herberti* eggs are similar to those of other Belostomatidae. The structure of the eggs in the family may have facilitated the evolution of brooding by providing the eggs an efficient respiratory system when they are neither entirely submersed in water nor exposed to air.

School IPM

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Issue

Most of our schools routinely spray their facilities to control an assortment of fire ants, cockroaches, mosquitoes and bark scorpions. Each month the pesticide treatments are repeated as part of an out-dated pest prevention program. But unacceptable pest populations remain a problem in our schools. More significantly, while the poisons were being applied and reapplied, children were being pulled out of school for a day or two each month by their parents to avoid pesticide exposure.

In April 2000, the Kyrene school district tried another approach and brought in a team of specialists that included entomologists from the University of Arizona.

What has been done?

Three schools in the Kyrene district were chosen for a pilot Integrated Pest Management (IPM) project, to control pests while avoiding reliance on chemical pesticides. The schools concentrated their efforts (and capital resources) on identifying what the pests were, finding where they came from and preventing their entry into buildings. The custodial and kitchen staffs also were mobilized to learn how to spot trouble. All of the openings around pipes and conduits were sealed, crawl spaces were closed off, and drains and building slabs were repaired to inhibit cockroaches. Trees were trimmed back and birds were encouraged to roost where their droppings wouldn't contaminate walkways and other high traffic areas.

The new program initially came from Indiana University (IU). IU entomologist Marc Lame had done a pilot study in the Midwest and wanted to try a similar program in the desert Southwest.

Impact

The IPM final evaluation showed that the schools reduced their pesticide applications by 90 percent and kept pest populations below 85 percent of their original levels. The program was expanded to 27 sites in the Kyrene School District.

In 2001 new pilot program was undertaken on The Navajo Nation in three BIA (Bureau of Indian Affairs) schools. The main pest issues at the three school sites included,

rodents, bed bugs and house flies. The final evaluation astonished everyone. The pilot schools have reduced chemical pesticide use by more than 90% and also reduced pest incidences by greater than 60%. The program has now been expanded to include all the BIA school on the Navajo, Hopi and South Pueblo reservations (68 sites).

A new pilot program has also been initiated on the Gila River reservation.

PARASITOIDS OF THE CITRUS LEAFMINER, *PHYLLOCNISTIS CITRELLA* (LEPIDOPTERA: GRACILLARIIDAE), IN SOUTHERN CALIFORNIA

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The citrus leafminer, *Phyllocnistis citrella* Stainton (Lepidoptera: Garcillariidae) was first detected in California in Calexico in January of 2000. By fall of 2000 its presence was limited to backyard citrus in the Southeast corner of the Imperial Valley. In winter of 2002, it was confirmed throughout the Imperial Valley including backyard, nurseries and commercial citrus. The citrus leafminer reached the Coachella Valley during 2002. Citrus leafminer and parasitoid activity have been recorded in backyard citrus sites in the Imperial Valley during fall 2000-2001 and early winter 2001-2002; no activity has been recorded later in 2002-2003. Citrus leafminer presence was recorded in commercial citrus sites only during fall 2001 and early winter 2002. Citrus leafminer populations have been monitored in a commercial citrus grove in the Coachella Valley since fall of 2002, and activity has been recorded during fall and winter. Only one parasitoid, *Closterocerus utahensis* (Hym.: Eulophidae) was detected parasitizing the citrus leafminer in backyard citrus in the Imperial Valley. In the Coachella Valley, several species of parasitoids have been recorded. The parasitoid complex includes *Closterocerus utahensis*, *Cirrospilus* spp., and *Pnigalio* sp. (not all the species have been identified).

EFFECTS OF SANITATION PRACTICES ON ALMOND MUMMIES INFESTED WITH NAVEL ORANGEWORM

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Abstract: Lab and field evaluations were conducted in order to assess the effect of mowing and disking treatments on the survival of immature stages of the navel orangeworm (NOW) infesting almond mummies. Flail mower treatments, which included mowing single layers of mummies once or twice and mowing mummies in windrows, resulted in 95 to 99 percent mortality relative to controls. For the field disking treatments,

one or two passes of a disk resulted in 41 and 89.5 percent mortality, respectively. In addition, flight peaks in disking treatments were delayed up to 2 weeks relative to controls. Field disking treatments were imitated in lab studies by covering infested nuts with 1 or 3 inches of soil, resulting in 9.5 and 43 percent mortality. These studies indicate that mowing is vastly superior to disking for destroying overwintering NOW populations and disking may alter flight dynamics in surviving populations.

GLASSY-WINGED SHARPSHOOTER IMPACT ON NAVEL ORANGE, SIZE, YIELD, AND QUALITY

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Two *Homalodisca coagulata,* glassy-winged sharpshooter (GWSS), population extremes were established in a 'Washington' navel orange grove. These extremes are defined as low (near 0 GWSS/tree) and high (1100-4900 GWSS/tree). The low extreme was maintained by using systemic and foliar insecticides as needed. Oranges were harvested at the beginning of this study and graded for yield, size distribution, and fruit quality to provide background data. The low population trees were allowed to 'recover' from heavy *H. coagulata* feeding for 15 months Oranges were then harvested on 28 January 2003 and graded for total yield, size distribution, and fruit quality. Orange size and total yield were significantly greater on the low trees in comparison to the high population trees.

EFFECTS OF ALASKA SPRUCE BEETLE (COLEOPTERA: SCOLYTIDAE) OUTBREAKS ON REGENERATION AND FUEL LOADING

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The spruce beetle, *Dendroctonus rufipennis* (Kirby), has had a major effect on the spruce forests of south-central Alaska. From 1989-1999, approximately 4 million acres of spruce forests were infested, twice the amount that were infested from 1919-1989. Infestations were intensive on the southern part of the Kenai Peninsula where many spruce stands had more than 80 percent mortality. Forest structure has changed and species richness of ground vegetation has declined significantly. This reduction in plant diversity was a result of the significant increase, and competitive advantage, of blue-joint grass and fireweed. On many sites in south-central Alaska, competing vegetation quickly invade sites where spruce beetles have "opened up" the canopy. This, plus the lack of

seed trees, has delayed re-establishment of tree species. Thus, many south-central Alaska forests have reverted back to early seral stages comprised of birch and shrubs.

Fire spreads rapidly through these beetle impacted forests. Large woody debris begins to accumulate on the ground as beetle-killed spruce breaks or is up-rooted. This combination of fine, flashy fuels and abundant large woody debris has resulted in dangerous fire behavior situations, especially crown fires.

THE FUNCTIONAL REPRODUCTIVE MORPHOLOGY OF FEMALE *HOMALODISCA COAGULATA* (AUCHENORHYNCHA: CICADELLIDAE)

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The functional reproductive morphology of female *Homalodisca coagulata* (Taylor) is described. The insect has nine abdominal segments, the tenth being the pygofer. The seventh through ninth abdominal segments are modified for reproduction. The ovipositor is almost completely enclosed by the pygofer and consists of three valvulae and two valvifers. There are seven main muscles associated with the ovipositor and pygofer. The reproductive system consists of a pair of ovaries with approximately ten ovarioles per ovary, a pair of lateral oviducts, a common oviduct, a spermatheca and two types of accessory glands. The female morphology follows the general pattern of Cicadellids as a group. Current research on the oögenesis cycle of the female is being facilitated by this research. This knowledge of morphology is also useful to those conducting pest management research on this insect, specifically those attempting to determine reproductive maturity based on ovary development and fertilization.

HERBIVORE-INDUCED PLANT VOLATILES: NEW TOOLS FOR PEST MANAGEMENT?

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Plants respond to herbivore damage by producing volatiles that attract natural enemies of the herbivores responsible for the damage. A number of these herbivore-induced plant volatiles (HIPV's) have been identified and shown to attract predators (primarily

predatory mites) in laboratory studies. Very few field experiments have examined the bioactivity of HIPV's and none have tested synthetic HIPV's as predator attractants. Three HIPV's (methyl salicylate (MeSA), hexenyl acetate (HA), Dimethyl-nonatriene (DN)) were evaluated for their attractiveness to winged predators of spider mites and aphids in an unsprayed hop yard in Washington State during April-October 2002. Yellow sticky cards, baited with HIPV's, were attached to poles and examined/renewed weekly. MeSA was demonstrated to be a significant attractant for the green lacewing, *Chrysopa nigricornis* (Neuroptera: Chrysopidae), *Geocoris pallens* (Hemiptera: Miridae) and some species of hover flies (Syrphidae). HA-baited cards attracted significantly greater numbers of the predatory mirid, *Deraeocoris brevis* (Hemiptera: Miridae) and the minute pirate bug, *Orius tristicolor* (Hemiptera: Anthocoridae), than unbaited cards. No attraction to DN-baited cards by any predatory insect was observed. The potential of using HIPV's as an aid to conservation biological control will be discussed.

PHYLOGENY OF THE LEAFHOPPER SUBGENUS *ERRHOMUS (ERRONUS)* (HOMOPTERA: CICADELLIDAE) BASED ON MTDNA SEQUENCES

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The leafhopper genus *Errhomus* was recently revised by Oman (1987) and Hamilton and Zack (1999). Both studies employed a variety of tools including morphological and biogeographic analyses. The taxon lends itself well to molecular study as the females are brachypterous and dispersal is extremely limited. Additionally, the biogeographic history of the genus is relatively well understood. We believe that some populations have been isolated due to geological changes for various time periods ranging from ten thousand to millions of years. Although these studies generally agreed in their results, there were some variations in species-level designations. In this study, we employed mitochondrial DNA sequencing to better elucidate the phylogenetic relationships among members of this subgenus.

Developing Immunomarkers For studying landscape-level movement patterns

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Immunomarkers are being developed for studying the landscape-level movement patterns of insects. Our approach is to utilize ELISA tests that detect novel compounds that are applied in the field using conventional airblast sprayers or handgun applications. We currently have antibodies that can be used to detect soy protein (as soy milk), egg albumin (as egg beaters), the pesticide imidacloprid, and codling moth granulosis virus. The assays for all compounds are sensitive, the different markers do not cross-react, and each insect can be screened for presence of all possible markers, so that multiple marks can be used to study inter-area movement patterns. Studies on the importance of the different mechanisms by which the insects may acquire the mark in field situations are underway.

APPLE MAGGOT, RHAGOLETIS POMONELLA (WALSH), (DIPTERA: TEPHRITIDAE) SURVEY IN WASHINGTON STATE

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The Washington State Department of Agriculture (WSDA) has conducted surveys for various fruit flies since 1980. Based on survey results from 1980 – 2000, all of western Washington except for San Juan County is now considered infested with apple maggot (AM). A monitoring and detection program for AM remains necessary for Washington growers to be able to ship fresh apples to various domestic and foreign markets. Recent changes in IPM practices with emphasis on mating disruption and other tactics may increase the risk of AM infestation of commercial fruit in areas where AM occurs.

The objectives of the 2002 AM Survey were:

1. To determine which areas of Washington meet the official pest free areas designation, as defined by the North American Plant Protection Organization (NAPPO, 1994).
2. To conduct certification monitoring in or around commercial orchards, as required to determine which growers could meet regulations for shipping fresh apples out of the AM quarantined areas of Washington.
3. Implementation of the Apple Maggot Detection Response Plan – a cooperative plan intended to prevent the establishment of AM.

WSDA monitored for AM from June 19 through September 30 using standard AM Yellow panel sticky traps baited with ammonium carbonate “supercharger” lures. Traps were checked every two to four weeks and were changed at least every four weeks. Trap

deployment focused on noncommercial residential host trees in populated areas, abandoned apple orchards and wild, roadside host trees. Major host trees included apple, crabapple, ornamental and native hawthorn.

The 2002 AM survey included 5,384 trap sites. There were several significant detections of AM in 2002, including Ellensburg and Yakima. These catches prompted the implementation of the Apple Maggot Detection Response Plan. This plan includes high-density trap placement around recent detection sites in cooperation with local Horticultural Pest and Disease Board AM control efforts.

MAKING SPACE FOR A HITCHHIKER: DYNAMICS OF LEAF-RIDING IN TROPICAL LEAF-CUTTER ANTS

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The purpose of hitchhiking, in which minima leaf-cutter ant workers ride plant loads carried by their larger colony mates, has been presumed to involve protection against parasitoids, either animal or fungal. It has been reported that in order to reduce the parasitism of major workers by phorid flies, hitchhiker ants are recruited as bodyguards. Additionally, it has been suggested that hitchhikers clean the surface of plant loads before they are incorporated into the colony's fungal gardens. I challenge both hypotheses, using measures of *Atta cephalotes* (La Selva, Costa Rica) and *A. colombica* (Barro Colorado Island, Panama) behavior and natural history. Temporal and spatial hitchhiker frequencies did not correlate with reported phorid fly presence. Also, replication of an observational study did not support the presumed preparation of plant material by hitchhiking ants.

I hypothesized that hitchhiking densities positively correlate with plant fragment surface area on which they travel, and not with size class of the laden worker. I also hypothesized that some discernible rhythm of hitchhiker frequency may exist, explaining the variation in hitchhiker density per load. I found that hitchhiker number did positively relate to surface area of respective plant fragments, but not to size class of the laden worker. Only random patterns of hitchhiker appearance over time were discovered, and interspecific differences were found.

PARASITOIDS OF *EUSCHISTUS CONSPERSUS* , (HEMIPTERA: PENTATOMIDAE) IN NORTH CENTRAL WASHINGTON

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The parasitoid complex of the consperse stink bug, Euschistus conspersus Uhler, was investigated in a series of field experiments conducted in native vegetation surrounding commercial apple orchards in the state of Washington. Rearing of parasitoids from adult E. conspersus confirmed the presence of two tachinid species , Gymnosoma filiola Loew and Gymnoclytia occidentalis Townsend. Three species of scelionid wasp were reared from fresh egg masses placed on mullein plants (Verbascum thapsus L.) with Trissolcus utahensis (Ashmead) being the most common species. Though some parasitism was recorded in all study sites by both tachinids and scelionids, overall levels of parasitism were low (<10%). Predation comprised the major source of egg mortality in the field. Bucket traps baited with the male-produced aggregation pheromone component, methyl (2*E*,4*Z*)-decadienoate, captured significantly more G. occidentalis than unbaited controls, suggesting that this parasitoid may use this compound as a host-finding kairomone. A test comparing E. conspersus egg masses placed on baited vs. unbaited V. thapsus revealed no differences in the rate of parasitism by scelionid parasitoids.

DEGREE-DAY MODEL FOR PREDICTING FLIGHT ACTIVITY OF WESTERN BEAN CUTWORM IN IDAHO

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Division of Entomology, University of Idaho, Moscow ID 83844-2339

We developed a degree-day model that predicts seasonal flight activity of western bean cutworm, *Richia albicosta* (Smith) (Lepidoptera: Noctuidae), an occasional pest of dry beans and sweet corn in southcentral Idaho. Moth flight was monitored with blacklight traps at 57 commercial bean fields in Twin Falls County during 1979 – 2000; we used the 1979 – 1991 data (31 fields) to derive the model and 1992 – 2000 data (26 fields) for model validation. Degree-days were computed by single-sine from daily max:min air temperatures at the Twin Falls WSO weather station (# 15-km from field sites). Ten base temperatures (0 to 22.5 at 2.5EC intervals) and four starting dates (1 Jan , 1 Feb, 1 Mar and 1 Apr) were evaluated by using the least-variability method. The parameters that most precisely predicted seasonal flight were 0EC base, 1 January initiation. Given observed mean calendar date of peak capture (23 July) observed during 1979 – 1991 as the validation standard, degree-day forecasts of 1992-2000 peak moth flight were more accurate than calendar-time forecasts: 4-day vs 7-day mean absolute prediction errors, respectively. Future work will incorporate the model into a time-sequential sampling plan that forecasts the economic status of larval infestations from moth captures in traps.

ECONOMIC INJURY LEVEL AND WITHIN-PLANT VERTICAL DISTRIBUTION OF SPIDER MITES (ACARI: TETRANYCHIDAE) IN CALIFORNIA FIELD CORN

Richard R. Lewis[1], Larry D. Godfrey[1], Kevin Keillor[2], Jorge J. Cisneros[3], Carol Frate[4] and Kent Brittan[5]

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Studies were conducted over a three year period to investigate the population dynamics and economic injury levels of spider mites on field corn grown in California. A total of seven fields located in three counties were sampled. At each location, various acaricide rates and active ingredients were used to develop a gradient in mite densities. Mite populations were monitored vertically within the plants as well as across the different treatments. Weekly sampling was conducted throughout the growing season. Silage and grain yields were taken at harvest from all treatments and locations. Silage nutrient values were obtained for crude protein, ADF and NDF. We were successful in creating a gradient of mite densities at all the locations using acaricides. Within plant distribution showed the highest mite densities were found on the middle leaves while the lowest densities were on the newest leaves. Generally, no significant differences were found among treatments for grain or silage yields with mite counts as high as 800 per leaf and mite-day values up to 24,000. Likewise, we found no significant differences between treatments in nutrient values for the first two years. It is apparent field corn has a very high tolerance for spider mites before treatment would be considered economical.

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LIFE HISTORY AND DAMAGE OF *ELATOBIUM ABIETINUM* (HOMOPTERA: APHIDIDAE) ON SPRUCE IN THE SOUTHWESTERN U.S.A.

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Elatobium abietinum (Walker) (Homoptera: Aphididae) is an exotic pest on *Picea* in the interior Southwestern United States. This insect is causing extensive and severe damage on dormant *Picea engelmannii* Parry and *P. pungens* Engelm., in high elevation forests in late fall and winter. In other regions, where the insect develops high density populations in the spring, it's mostly parthenogenic population dynamics and damage are limited to maritime areas where temperatures seldom fall below freezing. In the interior Southwestern U.S., populations increase in the fall, and a sexual life cycle and greater cold-hardiness are possible factors contributing to the insects success under more severe

conditions. Outbreaks appear to be associated with dry winter and spring weather prior to the fall and winter in which feeding occurs, and relatively warm winter temperatures during the epizootic. Average mortality on heavily defoliated plots is 28-42%, with 100% mortality on some plots. *P. engelmannii* is more susceptible than is *P. pungens*. Mortality is greatest in heavily defoliated *P. engelmannii* that are also heavily infected with *Arceuthobium microcarpum*.

ROLE OF HOST WALNUT FRUIT QUALITY IN PATTERNS OF OVARIAN DEVELOPMENT IN THE TEPHRITID FLY, RHAGOLTETIS JUGLANDIS

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Ovarian development in the tephritid fly, *Rhagoletis juglandis*, was previously found to be cued by the presence of host walnut fruit. In this study, we manipulated fruit characteristics known to influence oviposition, in order to determine if they also influenced ovarian development. Using fruit and fruit mimics, we manipulated fruit size, level of infestation, and presence of host-marking pheromone for cohorts of newly-emerged females. Effects of fruit characteristics on oogenesis generally paralleled previously-determined effects on oviposition. Fruit size strongly affected egg maturation, with females held with large fruit or large fruit mimics producing more eggs than females held with small fruit or mimics. Level of infestation likewise affected egg maturation, with females held with infested fruit or visual fruit mimics producing fewer eggs than females held with uninfested fruit or mimics. Results with host-marking pheromone were mixed. In light of previously-established effects of fruit size and infestation on larval growth and survival, we conclude that oogenesis is generally retarded when females are presented with fruit that are suboptimal for larval performance. The sensitivity of ovarian development to fruit quality probably reflects uncertainty in the quality of fruit in host trees under which female flies emerge as adults.

UNDERSTANDING THE MODE OF ACTION OF ELEVATED CARBON DIOXIDE FOR POSTHARVEST INSECT CONTROL

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Controlled atmospheres (CAs) are a promising alternative to methyl bromide for postharvest and quarantine insect control. With CAs, the levels of carbon dioxide (CO_2) and oxygen (O_2) are regulated in an enclosed area. Elevated CO_2 and low O_2 atmospheres have both been used, separately and in combination, with varying degrees of control success. The overall goal of our research is to understand the process of CA mortality so that this control tactic can be rapidly implemented for different insect pests and commodities. Specifically, we are studying the effects of elevated CO_2 on the physiological changes of the lepidopteran pest, *Platynota stultana*, the omnivorous leafroller. We are testing the hypothesis that ATP and pH levels decrease as the concentration of CO_2 in the atmosphere increases. We used nuclear magnetic resonance (NMR) spectroscopy to measure these physiological changes *in vivo*, while the insects were being treated with 5 different atmospheres (0, 5, 20, 40 and 80% CO_2). As we hypothesized, ATP and pH levels decreased. Lower energy levels and/or acidic conditions could indicate the mechanism behind CO_2 mortality.

Implementation of Active Adaptive Management Strategies for Glassy-winged Sharpshooter Biological Control in California

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The California Department of Food and Agriculture has developed a biological control component as an integral part of the program to control the primary vector of Pierce's Disease in California, the glassy winged sharpshooter (GWSS). Over the past two years we have made considerable progress in setting up a framework for evaluating parameters involved in the process of biological control. Through the use of procedures developed in conservation ecology, we aim to incorporate statistically rigorous research into our primary responsibility of managing the glassy-winged sharpshooter. This presentation aims to describe the concept of active adaptive management and how it can be used in biological control. We will also describe the framework we have in place for optimizing parameters such as agent selection, inoculation size, inoculation frequency, and spatial distribution. We will end by summarizing the progress we have made in GWSS biological control to date.

Molecular Detection of Bt Resistance in the Field

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Transgenic crops expressing insecticidal toxins from *Bacillus thuringiensis* (Bt) are widely used for pest control. Although laboratory selection results show that many pests have the genetic potential to evolve resistance to Bt toxins, the molecular basis of resistance had remained elusive for many years. It was shown previously that resistance to Cry1Ac in the cotton pest *Heliothis virescen*s is associated with disruption of a cadherin-superfamily gene. Here we report that field populations of pink bollworm (*Pectinophora gossypiella*), a major cotton pest, harbor three mutant alleles of a cadherin-encoding gene linked with resistance to Bt toxin Cry1Ac and survival on transgenic Bt cotton. Each of the three resistance alleles has a deletion expected to eliminate at least eight amino acids upstream of the putative toxin-binding region of the cadherin protein. We will discuss the benefits and drawbacks of using the cadherin gene as a leading target for DNA-based screening of resistance to Bt crops in lepidopteran pests.

Molecular Response of Plants to Herbivore Salivary

Musser, R.O., Hum-Musser, S., Vanier, C., Elumalai, R., Galbraith, D., Felton, G.W., Brown, J.K., and Chandler, V.

The main objective of our project is to use functional genomic approaches to identify global gene expression patterns that occur in maize as a result of herbivory. Herbivory triggers plant responses that are different from mechanical wounding. Oral secretions from herbivorous insects can stimulate anti-herbivore defenses, plant growth, and phytopathogen resistance. In the past we have established that a salivary component, glucose oxidase from the caterpillar *Helicoverpa zea*, can suppress induced anti-herbivore defenses in plants analogous to mosquito saliva suppressing the human immune response. Also we have determined that RNase from regurgitant of the beetle *Epilachna varivestis* functions as an elicitor of plant pathogen defenses. Based on our findings that herbivore saliva can affect plant defenses we have performed maize cDNA microarray experiments and have found drastic changes in expression of hundreds of genes. For example maize drought resistance genes and chitinase gene are significantly suppressed by *H. zea* that can secrete labial saliva, than caterpillars that cannot secrete saliva due to surgery. However, protease inhibitor gene expression was equally stimulated in herbivory regardless of saliva. We envision in the near future the ability to quickly identify the induction of genes and pathways stimulated by a wide variety insect salivary factors never before realized as chemical elicitors of plant defenses.

AVOCADO THRIPS, *SCIRTOTHRIPS PERSEAE* NAKAHARA, IN ITS NATIVE HOME: MEXICO AND GUATEMALA

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The avocado thrips is just one of several recent invasive species that have challenged California's existing IPM programs. The *S. perseae* was new to science, only receiving its scientific name in 1997, shortly after its arrival in southern California. Its origin was suspected to be Mexico or Central America. Subsequent foreign exploration by this author and Dr. Mark Hoddle at UCR confirmed it native range to be Mexico and Guatemala.

A severe pest of southern California avocados, *S. perseae* was never recorded as a significant pest of avocado in its native home. Research conducted in these countries confirmed the presence of breeding populations of avocado thrips within commercial Hass orchards. However, these populations never reached the astronomical levels experienced over the last 5 years in southern California and the Mexican and Guatemala populations were confined to the new growth, never moving to the tender new fruit to cause feeding scars.

In Mexico, both differences in Hass avocado phenology and rapidly rising temperatures coupled with a concurrent decrease in thrips levels during the bloom period explained the lack of fruit damage from avocado thrips. However temperatures remained relatively mild through the fruiting period in Guatemala with thrips populations on the rise but confined to the flush growth, their preferred feeding substrate, which continued through the fruit set and early development periods. In the temperate climate of southern California avocado phenology is delayed by 2 months, resulting in the major growth flush period ending just as young avocado fruitlets are developing. Under the conditions in southern California the thrips move from the hardening and maturing foliage to the succulent fruitlets where they continue to feed and breed, causing significant fruit rind scarring.

GREEN PEACH APHID OVERWINTERING STRATEGIES IN THE PACIFIC NORTHWEST

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Multi-year field research on green peach aphid, *Myzus persicae*, in the Northwest was undertaken in winter to elucidate the extent of its survival on perennials and winter annuals. It has long been recognized that the aphid overwinters successfully in the egg stage on peach trees. It is clear now that some anholocyclic populations of the aphid (adults and nymphs) also overwinter successfully on herbaceous plants despite cold, sometimes freezing conditions. This means that there are numerous sources from which the aphid can originate to infest potatoes in the spring. The findings also explain why programs attempted years ago to control the aphid on peach as a means to reduce its pest presence in potatoes were futile. The details on the winter findings of this and other aphid species will be discussed in the poster.

COPULATION AND SPERM RELEASE IN *Anelosimus analyticus*: DIFFERENTIAL MALE BEHAVIOR BASED ON FEMALE MATING HISTORY

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Cohabitation of adult males and immature females is often seen when sperm competition favors the first male to inseminate a female. We observed adult males and immature females often occupying the same web in *Anelosimus analyticus* (Araneae: Theridiidae), a subsocial spider that resides in riparian habitats in southern Arizona. Based on this observation, we predicted that there should be a disproportional fitness benefit for a male in inseminating a virgin female tract. To evaluate this hypothesis, we staged copulations with wild-caught spiders in the lab. Female spiders have two separate reproductive tracts, and males were presented with females that were virgin on both sides, mixed, or

non-virgin on both sides. Across treatments, males did not show differences in latency to court, in latency to copulate, or in duration of courtship. However, female mating history did influence copulation attempts, copulation success, and sperm release. Males were more likely to copulate with virgin females than with non-virgin females, and copulations with non-virgins often involved more unsuccessful insertion attempts. Males presented with non-virgin tracts were also less likely to release sperm than males presented with virgin tracts. Patterns of sperm release may explain the fitness benefit for males of cohabiting with immature females.

MACROEVOLUTIONARY THEORY ON MACROECOLOGICAL PATTERNS: DISTRIBUTION, ABUNDANCE AND POPULATION DYNAMICS

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Synthesis in ecology can be most effectively achieved by employing evolutionary principles. The case is presented that macroecological patterns such as distribution, abundance and population dynamics will be found in the comparative ecology of phylogenetically related groups, with phylogenies providing the strongest patterns to be discovered in nature. Similarity in female structure, behavior, physiology and relationships to host plants observed across genera and larger taxa result in comparable ecological traits in distribution, abundance and population dynamics. This approach is illustrated using gall-inducing common sawflies (Hymenoptera: Tenthredinidae), other taxa with similar phylogenetic constraints such as in the tree hoppers (Homoptera: Membracidae) and bush katydids (Orthoptera: Tettogoniidae: Phaneropterinae), and extrapolated to taxa with divergent constraints and consequently different kinds of population behavior including outbreaking species in groups such as forest Lepidoptera, acridid grasshoppers (Orthoptera: Acrididae) and stick insects (Phasmatodea: Phasmatidae). A strongly comparative and Darwinian approach to the ecological subjects of distribution, abundance and population dynamics allows for the development of synthesis and theory well beyond that achieved by relying on ecological factors alone, as in the prevailing methods of the past.

IMPACT OF PESTICIDES ON SPIDER MITES (ACARI: TETRANYCHIDAE) AND THEIR NATURAL ENEMIES ON GRAPE IN SOUTH-CENTRAL WASHINGTON

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Arthropod densities were monitored on grapevines receiving high, low, and no chemical input in 2001-2. During 2001, 48 vineyard sites were sampled monthly from June-Sept., while in 2002, 30 vineyards were sampled. Sites were located in five grape growing regions of south-central Washington and northern Oregon. Leaf and canopy suction sampling revealed that *Tetranychus mcdanieli* McGregor (Acari: Tetranychidae) was the most abundant spider mite, although *T. urticae* Koch was also present in high numbers, while *Galendromus occidentalis* (Nesbitt) (Acari: Phytoseiidae), a specialized spider mite predator, dominated the phytoseiid mite fauna. Several other predaceous arthropods were collected, as well as organisms that could serve as alternative prey. In general, there seemed to be lower pest densities and higher predator densities in sites receiving no chemical input, although between the two main groups of greatest interest, low and high input sites, there were no significant differences among arthropod densities, with the exception of generalist phytoseiid mites. Given their extremely low densities, it does not seem likely that phytoseiids or other predators are controlling spider mite densities in managed vineyards, but that pesticides or other factors are regulating pest mite populations.

NUTRIENT ENRICHMENT EFFECTS ON OVIPOSITION PREFERENCE, LARVAL PERFORMANCE, AND CHEMICAL DEFENSE OF A SPECIALIST INSECT HERBIVORE

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Host-plant allelochemical composition is often governed by environmental conditions, such as nutrient availability, potentially affecting herbivorous insect chemical defense. We performed a controlled greenhouse experiment to investigate the effects of soil nutrient enrichment on female oviposition, larval performance, and chemical defense of a specialist phytophagous insect, *Junonia coenia* (Lepidoptera: Nymphalidae). We grew host-plants (*Plantago lanceolata*, Plantaginaceae) under one of two treatment groups: fertilized or unfertilized. Plants grown under fertilized conditions contained more foliar nitrogen and less allelochemicals than unfertilized plants. If host nutritive quality is the determining factor in female oviposition preference, females should preferentially oviposit on fertilized plants. Alternatively, if host allelochemical content dictates female oviposition preference, females should prefer unfertilized plants with higher allelochemical content. Furthermore, we predicted that larvae would perform better on fertilized plants, at the cost of decreased chemical defense. Female *Junonia coenia* preferred to oviposit on fertilized nutrient enriched host-plants, but also preferred host-plants with increased chemical defenses when the host-plant nutrient content was equal between plants. Larvae exhibited a significant decrease in their chemical defense when

raised on fertilized plants, but they did not perform better based on several growth measurements and survival. We discuss the evolutionary and ecological implications of these results.

INVOLVING GRADUATES AND UNDERGRADUATES IN SCIENCE EDUCATION IN RURAL OREGON SCHOOLS

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Graduate and undergraduates from Oregon State University (OSU) spend 1 to 2 days every week of the school year engaging students in rural schools in Oregon in inquiry-based science education through the Rural Science Education program run by the Entomology Department. The goal is to make science exciting for middle and high schools student, and to motivate them to consider a career in science after graduation. The program is funded by the NSF GK-12 program.

The Rural Science Education program has impacted over 500 middle and high school students in 12 classrooms in rural Oregon this past year. K-12 students benefit by hands-on experience in scientific research using live material and exposure to current scientific ideas and advanced technology. Experiments conducted include insect surveys on school grounds using pitfall traps and observations and classification of insects. The program better equips science teachers in rural schools for providing advanced scientific inquiry-based science instruction in their classrooms. Besides obtaining a lucrative stipend for their programs, NSF Fellows at OSU benefit by the hands-on teaching experience in the classroom. The program enables OSU professionals to recruit high quality graduate students, provide teaching experience to complement research experience gained on campus, and form partnerships with Oregon schools for extending science education.

MOLECULAR MARKER FOR EARLY IDENTIFICATION OF LARVAE OF EXOTIC CRANE FLY SPECIES IN THE PACIFIC NORTHWEST

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Two exotic crane fly species, *Tipula paludosa* Meigen (Diptera: Tipulidae), and *Tipula oleracea* L., have been inadvertently introduced into the Pacific Northwest. Larvae of both species damage lawns, turf, grass seed, and crops such as peppermint. The two exotic species differ in larval development, and hence there is variation in treatment strategies. However, larvae of both species are undistinguishable, often resulting in unwarranted insecticide sprays. Additionally, insecticides are applied to native crane flies in the same habitats due to their resemblances to the exotics. A rapid, accurate identification tool is required for reducing pesticides used for crane fly control.

We initiated a study of mitochondrial DNA (mtDNA) sequence determination for species identification at the larval stage. We identified a diagnostic marker, 410 bp long (excluding primer sequences) with 7.3% sequence divergence between *T. paludosa* and *T. oleracea*. An unknown sample that was tested was identical to *T. oleracea*. The molecular marker will be used for identification of crane fly larvae collected from cropping systems in WA and OR, to determine geographical distribution, species abundances, host ranges of *T. paludosa* and *T. oleracea* and their economic impacts on cropping systems in the Pacific Northwest.

EFFICACY OF SELECTED TOXICANTS FOR LOCALIZED CONTROL OF THE WESTERN DRYWOOD TERMITE, *INCISITERMES MINOR* (HAGEN)

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More efficacious than presently available local treatments, thousands of costly whole-house fumigations are done annually in areas where drywood termites are problematic. Ranging in price from hundreds to several thousands of dollars per residence, >55,000 fumigations were done in 2002 in Los Angeles county alone. Per capita, similar numbers of fumigations were done in adjacent counties. Local treatment consists of toxicant directly injected into identified termite galleries. This study was made to determine if some new-generation toxicants may be effective for less costly local control.

Worker termites were exposed to treated wood to determine acute and chronic effective rates (LT_{90}) of new-generation toxicants such as imidacloprid, fipronil, thiamethoxam, and spinosad compared to disodium octaborate tetrahydrate (Tim-Bor), a widely-used commercial preventative and remedial termiticide. Transfer of toxicant among termites and inhibition of feeding was determined. In addition, choice tests to mimic incomplete treatment of galleries and tests in which termites had an opportunity to avoid treatment indicated that some toxicants were exceedingly active against termites without being highly repellent. Pyrethrins and most pyrethroids are ineffective because they are highly repellent, allowing survival of termites which avoid lethal deposits. These trials suggest

that some new-generation toxicants may effectively eliminate termites in identified isolated situations.

TWOSPOTTED SPIDER MITE CONTROL IN ALFALFA: EFFECTS OF MITICIDES AND WESTERN FLOWER

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Miticides were applied in both in spring and summer of 2002 to alfalfa. Application periods differed in regards to presence of western flower thrips, *Frankliniella occidentalis* (Pergande), a predator of twospotted spider mites (*Tetranychus urticae* Koch). Western flower thrips populations were high in spring but essentially absent during the summer period, providing contrasting data for western flower thrips interactions with miticides for spider mite management. In spring testing, many of the 22 treatments utilized had more spider mites than the untreated check at three days post treatment, including two fertilizer treatments that contained high amounts of sulfur. Increases were thought due to repellency/activity against adult western flower thrips as active ingredients have thrips activity (avermectin, chlorpyrifos, dimethoate, etc.). Fewer motile spider mites than in the untreated control in the spring section of the experiment at three days post treatment were noted from only from treatments containing bifenthrin, and the combination treatment of hexythiazox and milbemectin. All treatments providing some control during the summer experiment. Active ingredients that provided excellent (90%+) control for 21 days included hexythiazox, milbemectin, etoxazole, a combination of bifenthrin and dimethoate, fenpropathrin, and a combination of avermectin and clarified neem oil. The disparity in data sets indicate that western flower thrips presence/absence should be considered in spider mite control decisions in alfalfa.

CONTROLLING ARGENTINE ANTS (HYMENOPTERA: FORMICIDAE) WITH AQUEOUS BAITS

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Argentine ants, *Linepithema humile* (Mayr) (Hymenoptera: Formicidae), are important pests in urban, natural and agricultural settings. Perimeter sprays and granular treatments primarily kill workers and have limited residual activity whereas baits are consumed and transmitted to the colony via trophallaxis. Argentine ants prefer sucrose solutions and baits incorporating low concentrations of imidacloprid, fipronil, and thiamethoxam are readily accepted. Baits containing 0.0001 % active ingredient provided delayed mortality of workers or about 50% kill in 1 to 3 days. Delayed toxicity permits the toxicants to be passed via trophallaxis to workers in the colony. In urban settings, baits containing 0.0001% imidacloprid and 0.0001% fipronil provided greater than 80% reductions. In grapes, baits containing 0.0001% thiamethoxam provided significant reductions in ant populations. The number of ants foraging in vines declined from 30-50% and the amount of sugar water consumed at monitors declined 50-75% from July to August. The number of mealybugs per vine decreased by 40-70% as did the damage to grape clusters.

Phylogenetic analysis of the genus *Kiefferiella* Ashmead (Hymenoptera: Cynipoidea: Liopteridae)

Katherine N. Schick & Fredrik Ronquist

We examine the genus *Kiefferiella* Ashmead, an archaic parasitic cynipoid wasp confined to the western Nearctic. The genus includes two described species and three undescribed extant species. An Eocene fossil from Florissant, Colorado, shales has been described as the one extinct *Kiefferiella* species. We examine morphological characters of the fossil and extant species and our phylogenetic analysis yields a parsimonious cladogram with a node at which the fossil specimen is attached.

EFFECT OF PHAGOSTIMULANTS IN *A. mellifera* L. DIETS

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The role of phagostimulants and diet formulation in dietary choices made by honey bees *(Apis mellifera*) was studied in laboratory. Diets in which sucrose or pure glucose comprised the added carbohydrate sweetener rapidly lost water, hardened, and became difficult for the bees to eat. Reduction of the glucose level to 75% or less and replacement of sucrose with fructose yielded a soft, acceptable diet texture that lost little water and could be readily consumed by bees. A sugar combination of 50% fructose and

50% glucose appeared ideal for incorporation in bee diets. Feeding choice preference tests in young 1-3 days old honey bees revealed that addition of phagostimulant equal to 1-5% pollen extract significantly enhanced dietary feeding behavior. Phagostimulant enhancement of seven commercial honey bee substitute diets or dietary ingredients was analyzed for nutritional potential in longevity tests. The diets differed in the time lengths of bee survival, suggesting potential differences among the nutritional values of the diets. Complicating factors were the presence of heavy parasite loads of varroa mites on the bees. Phagostimulants derived from pollen appear to play an important role in feeding behavior of honey bees and potential for developing better artificial diets for bees.

Population dynamics and resistance to Bt crops

Mark S. Sisterson, Yves Carrière, and Bruce. E. Tabashnik

Models of the evolution of insect resistance to transgenic crops have often assumed that population size was infinite and that dynamics were deterministic. However, the interaction of population size with stochastic factors is likely to have a strong influence on the rate and the manner in which resistance evolves. Therefore, we examined the role of population size on the evolution of insect resistance to a transgenic crop in a stochastic, spatially-explicit simulation model of the pink bollworm/Bt cotton system. We focused on the interaction of population size (small, medium, or large) with region size (number of fields). We found that stochastic events such as genetic drift played an increasingly important role as population size declined and region size increased. With small region sizes, small populations took the longest time to evolve resistance, but with large region sizes, small populations evolved resistance the fastest. The complex interactions observed among parameters demonstrates that care must be taken when interpreting results from models that assume populations of infinite or arbitrarily large size.

DOES HARASSMENT BY UNPAIRED MALES INFLUENCE EGG-LAYING BEHAVIOR IN THE DAMSELFLY *ENALLAGMA BOREALE*?

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In some Odonata, unpaired males harass copulating pairs and ovipositing females. Harassment by unpaired males can be costly to ovipositing females, therefore females may behave to minimize harassment. Within a single oviposition bout, females of the damselfly *Enallagma boreale* lay eggs both in vegetation floating on the surface of a pond and underwater. Large interindividual variation in the relative amount of time spent ovipositing at the surface and underwater suggests that extrinsic factors, like harassment,

might influence the behavior. I examined the influence of harassment on the relative amount of time females spent laying eggs at the surface and underwater. If harassment is a factor, females should spend relatively more time underwater when rates of harassment are high. Tandem pairs were captured while copulating and moved to an enclosure surrounding a small pool containing water and vegetation. I varied the amount of harassment by changing the number of unpaired males in the enclosure. I found that the relative amount of time spent laying eggs underwater was only weakly related to the rate of disturbance; even at low rates of disturbance, several females spent almost all their time laying eggs underwater. This result suggests that harassment has little influence on oviposition behavior in this species. However, an artifact of the experimental set-up, pool size, may have affected female response.

RESISTANCE TO Bt CROPS: LESSONS FROM THE FIRST SEVEN YEARS

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Transgenic crops producing insecticidal proteins from *Bacillus thuringiensis* (Bt) have been grown commercially on millions of hectares since 1996. The primary threat to the continued success of such Bt crops is evolution of resistance by pests. Although many diamondback moth populations have evolved resistance to Bt sprays, as far as we know, no pest has evolved resistance in the field to a Bt crop. However, strains of many pests have been selected for resistance to Bt toxins in the laboratory. The most common pattern of Bt resistance in field- and lab-selected Lepidoptera, called "mode 1," entails >500-fold resistance to at least one Cry1A toxin, recessive inheritance, little or no cross-resistance to Cry1C, and reduced binding of at least one Cry1A toxin. Whereas some resistant strains of diamondback moth and pink bollworm can complete larval development on Bt plants, recent results show that a Dipel-resistant strain of European corn borer did not survive on Bt corn. With the notable exception of pink bollworm, estimates from field populations of the frequency of alleles conferring resistance to Bt plants have been less than 0.01. In summary, the success of Bt crops exceeds the expectations of many, but does not preclude resistance problems in the future.

MANAGEMENT OF CUTWORMS IN WASHINGTON VINEYARDS

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There are several species of cutworms verified as pests of grapes grown in the PNW. The spotted cutworm *Amanthes c-nigrum* (L.) appears to be the dominant cutworm pest in Washington vineyards. It overwinters as a 2nd to 5th instar larva in the soil litter. Feeding ceases in spring and the subsequent 2nd generation is associated with other weed or crop hosts.

Many varieties of grapes can tolerate a significant amount of damage without economic loss. Feeding on grapevines occurs from bud swell to when shoots are several inches long. Injured buds may fail to develop. Yield reduction may occur primarily on varieties with non-fruitful secondary buds. Bud injury to grapes in April to early May is typically associated with spotted cutworm feeding.

In early-spring 2002, concentrated barrier delayed-dormant applications of the pyrethroid insecticide fenpropathrin applied to the soil/vine/trellis interface repelled cutworms. This repelled cutworms from subsequently climbing up into the vines and feeding on the swelling buds. This treatment shows promise and is being investigated further in Washington State.

Ode to a Cricket

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On this biased Earth, backbones, skin, fur, teeth, and feathers receive top billing for prose. Arthropods as a rule are overlooked. There are exceptions. Crickets are revered for the soothing sounds they create with stridulating organs on their wings. Graduate students at Cornell and Oxford received grants of $8,000 and $12,000 to paint words on dairy cows and sheep respectively, to produce poetry. We contend that crickets are far superior and far more efficient then domesticated livestock in creating prose. We purchased 200 crickets for $9 and attached word labels to them We then took pictures at random over several days and have documented proof of cricket talent for poetry.
Some excerpts:

Imagine through poem what cricket hear
Would any ever imagine
A Crickets world
If you would chirp
And a song perfect too
What can crickets feel
Sprays could kill

The windshield executes
Never talk down crickets
Imagine the poem through all
Imagine your inside wing down
Got a birds poem
Insect world better
With the swats of her world
Or squish many

National Public Radio has applauded cows and sheep as poets. We conclude that crickets have greater talent and are far less expensive poets. Unfortunately, cricket talent is short-lived. They lose their words at their next molt.

LYGUS FEEDING DAMAGE STUDIES ON WASHINGTON STATE APPLES

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Lygus bug, *Lygus hesperus* Knight (Miridae: Heteroptera), feeding has been likened to chemical injury. *Lygus* feeding damage in apple orchards can result in fruit disfigurement. Branch cage studies have helped quantify proportional *Lygus* abundance to fruit damage. Sleeve cages have been placed on branches of Fuji trees. Fruit was hand thinned within each cage and specific numbers of adult *Lygus* were added to each cage to produce specific ratios of fruit to *Lygus*. Cages were left on for 2 weeks at each cycle in April and July 2001 and May 2002. On 30 August 2001, and 10 September 2002, ten fruit were removed from each cage site and peeled with a paring knife. *Lygus* damage was noted if necrotic feeding spots were present below the fruit skin surface. April feeding injury was greater than feeding damage in May or July. In 2002 we conducted a sequential experiment. Cages were established weekly from 17 June through 19 August 2002 on tree branches on which fruit had been thinned to a total of 10. Ten adult *Lygus* were placed into 3 replicate cages each week. *Lygus* feeding damage was greatest at 70% on the 17 June cages. Damage for every other week was consistent at approximately 40%.

VITAL DYES FOR MARKING INSECTS

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Crop protection practices, such as habitat management, insecticide application, and crop rotation, can influence the movement of pests and beneficial insects. A better understanding of how these practices influence arthropod dispersal within and between crop fields would facilitate the development of strategies to improve pest suppression. Investigations of arthropod dispersal rely on the availability of marking methods that are accurate, reliable, and logistically feasible to use. We used vital dyes to mark the tarnished plant bug, *Lygus lineolaris* Palisot de Beauvois (Heteroptera: Miridae), and its egg parasitoid, *Anaphes iole* Girault (Hymenoptera: Mymaridae). Laboratory studies evaluated internal and external retention, methods of application, and mortality effects of several vital dyes. Rhodamine B and Acridine Orange were chosen for mark-release-recapture studies in the field. These dyes fluoresce, making their detection possible at low concentrations. External application of Rhodamine B effectively marked *L. lineolaris* in our short-term (<1 day) trials. Detection of these dyes in *A. iole* was more difficult, owing partly to the minute size of this wasp. Our results suggest that vital dyes are suitable markers for arthropods, but that additional research may be needed to assess and improve their usefulness.

The dark-color-inducing neurohormone (DCIN) of locusts and corazonin; NMR study of their 3-D structures in solution

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[His[7]]-corazonin was discovered in *Schistocerca americana* a decade ago with no known physiological role. Recently, it was independently rediscovered as a dark-color-inducing neurohormone (DCIN) in *Locusta migratoria* and *Schistocerca gregaria*. DCIN and corazonin, the latter being a potent cardio-stimulator in the cockroach *Periplaneta americana*, are 11 residue-long peptides that differ only at the 7th position (His in DCIN and Arg in corazonin) and are blocked at both termini. The peptides are equally efficient in inducing dark coloration when injected into albino nymphs of a mutant strain of the migratory locust, *L. migratoria*, and are significantly more effective when dissolved in oil

in comparison to aqueous medium. The peptides three-dimensional structures in solution were determined by nuclear magnetic resonance (NMR) studies. These studies show that both DCIN and corazonin aggregate in water and, since oil is unfavorable for NMR analysis, we chose dimethylsulfoxide-d_6 (DMSO) as a solvent. To confirm the biological relevance of the analysis, DCIN and corazonin were dissolved in DMSO and injected into the albino nymphs. The activity level was higher than in water but still lower as compared to the oil. The NMR studies of both peptides revealed a negative electrostatic potential surface from which only the 7^{th} residue sidechain of each peptide protrudes.

Culex quinquefasciatus mosquitoes feed on a range of hosts in urban Tucson Arizona

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We are analyzing the blood-meal source of *Culex quinquefasciatus* mosquitoes captured in urban Tucson Arizona. We wish to better understand mosquito biology in an urban, desert environment. We anticipate that the sources of blood-meals for *C. quinquefasciatus* may differ in the residential environment compared to wetlands. This may be important in determining how well *C. quinquefasciatus* may serve as a vector for West Nile.

We have been using a double-antibody ELISA (enzyme-linked immunosorbant assay) to distinguish between bird, human, cat, and dog blood sources. The mosquitoes were collected in the summer of 2002 using carbon dioxide and gravid traps set in a wide range of microhabitats located in urban Tucson.

For residential sites, preliminary results indicate that of 60 mosquitoes giving positive results, 6 fed on bird, 7 on dog, 42 on humans, 1 on cat, 3 fed on both dog and cat, and 1 fed on bird and human.