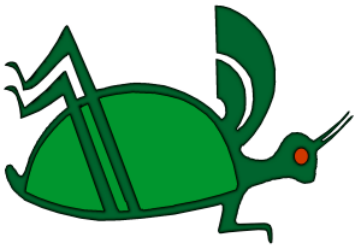
# Abstracts

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## IS THERE ANY REASON FOR BUSINESSES NOT TO ADOPT INTEGRATED PEST MANAGEMENT PRACTICES? THE ECONOMICS OF IPM IN STORED GRAIN

Brian D. Adam[1], Poh Mun Mah[1], Thomas W. Phillips[2], and Paul Flinn[3]

[1]Oklahoma State University, Dept. of Agricultural Economics, Stillwater, OK
[2]Oklahoma State University, Dept. of Entomology & Plant Pathology, Stillwater, OK
[3]Agricultural Research Service, Grain Marketing Research Laboratory, Manhattan, KS

Many grain storage elevator operators have been reluctant to adopt IPM practices. Previous work has found that although IPM reduces pesticide use and associated costs, it requires more management skill and labor, both expensive inputs, so that some IPM practices are more expensive than conventional chemical-based practices, while some are less expensive. However, no studies have measured the costs of grain damage caused from incompletely controlling insects. Applying treatments when they are not needed adds unnecessary, though typically small, costs. However, not applying treatments when they are needed results in large costs due to grain damage discounts. Typically, IPM practices use monitoring to decide when treatments are needed. However, monitoring itself is costly. If grain elevator operators believe that they lack the expertise to choose an appropriate insect control strategy based on monitoring, or believe that monitoring is too expensive, they may choose predictable fumigation costs rather than risk an abnormally large cost from failing to control insects effectively.

## ASSOCIATION OF SYMBIOTIC FUNGI WITH DEVELOPMENT OF THE MOUNTAIN PINE BEETLE (*DENDROCTONUS PONDEROSAE*)

Aaron S. Adams, Diana L. Six
University of Montana, Department of Ecosystem and Conservation Sciences,
Missoula, MT

Fungi associated with *Dendroctonus ponderosae* Hopkins (Coleoptera: Scolytidae alt. Scolytinae) were sampled throughout *D. ponderosae* brood development in naturally attacked *Pinus contorta* Douglas. Overall, the incidence of fungi (both yeasts and filamentous fungi) with individual brood increased as brood development progressed. *Ophiostoma clavigerum* (Robinson-Jeffrey & Davidson) Harrington and *O. montium* (Rumbold) von Arx exhibited generally opposing trends in prevalence over the developmental period of *D. ponderosae*. *Ophiostoma clavigerum* was isolated less often than expected in phloem adjacent to eggs and 1st instar larvae, more often than expected adjacent to pre-wintering 3rd and post-wintering 4th instar larvae, and less often than expected adjacent to pupae and teneral adults. The opposite trend was observed for *O. montium*. Our results suggest that not only are *D. ponderosae* brood in contact with fungi throughout development, but also that during development contact of brood with a particular fungus is likely to change.

## SPATIAL DYNAMICS OF INSECTS IN CROP SYSTEMS AT THE LANDSCAPE SCALE: HOW CAN WE MAKE USE OF SPATIAL INFORMATION IN IPM?

Jon C. Allen[1] and Carlyle C Brewster[2]

[1]University of California, Ecology, Evolution and Marine Biology, Santa Barbara, CA
[2]Virginia Polytechnic University, Department of Entomology, Blacksburg, VA

The movement of insects in large scale crop systems is difficult to study, understand and predict and consequently IPM on this scale is difficult to implement. We present a case study of whiteflies in the Imperial Valley crop system in which we have constructed crop maps and made spatially explicit population models (SEPMs) of the whitefly's movement and reproduction. From the models we can simulate the dynamics of the whitefly in response to crop changes, weather patterns and other variables, and investigate IPM methodologies for controlling this insect at the landscape scale. One such possibility is timing and spacing of various crops to discourage or prevent successful whitefly movement between fields. Another is to implement a more connected system to facilitate natural enemy movement since we suspect that natural enemies of this insect are not as good at dispersing over the long distances between fields that are typical of the Imperial Valley system. In Florida, for example, where the summer crop system is much more connected than Imperial Valley, we have observed high levels of parasitism by three parasitoids that are virtually absent in Imperial Valley.

An alternative approach to the problem of IPM at the landscape scale is to calculate the Bayesian probability that a field is infested using various infestation criteria that increase the probability of infestation such as distance to melon fields and crop type. From this information one can construct a probability of infestation above some threshold level that can be used to guide scouting efforts and implement IPM tactics on a landscape scale.

We conclude that for IPM decision making the Bayesian approach may be best, whereas for population studies, the SEPM approach may be best.

## *TRIONYMUS HAANCHENI* MCKENZIE – A NEW PEST OF BARLEY IN IDAHO

Juan M. Alvarez

Aberdeen Research & Extension Center, University of Idaho,
1693 S 2700 W, Aberdeen, ID 83210

A new insect pest of barley, *Trionymus haancheni* McKenzie, referred to as the Haanchen barley mealybug, was discovered for the first time in Idaho near Soda Springs during June 2003 from a commercial barley field. Surveys since then have detected this pest in nine eastern Idaho counties. Infestations occur at the soil surface, but adults and nymphs can also be seen along the stems under the leaf sheaths of the plant. Both nymphs and adults feed on plants causing extensive yellowing and browning of the foliage and severe infestations in commercial fields

eventually kill the plants. In addition to direct feeding injury to plants, *T. haancheni* can damage the crop indirectly by producing honeydew, which has the potential to reduce grain quality. The circumstances that explain how this pest established itself in Idaho and what environmental or biological factors account for population increase are not known. Barley growers at different meetings unanimously agreed that mealybugs have been the worst insect pests in many years. There are no insecticides registered for this insect pest in the U.S. Information on the biology and potential management of this insect is presented.

## REMOTE MONITORING OF SALTCEDAR BIOLOGICAL CONTROL DYNAMICS IN LOVELOCK, NEVADA

G. L. Anderson

USDA, ARS, Northern Plains Agricultural Research Laboratory, 1500 N Central Ave., Sidney, Montana

Saltcedar (*Tamarix ramosissima* and *T. parviflora*) are major invasive weeds throughout the United States and Mexico. Introduced to the United States in the 1800s, the weeds infest riparian areas, displace much of the native vegetation, increase fire hazards and cause an estimated $300 million (annually) in damage to agricultural and natural ecosystems. A similar cost is estimated for water loss, flood disaster relief and control efforts. Until recently chemical and mechanical control methods were the primary techniques for treating saltcedar infestations in North America. However, in 1999 researchers from the United States Department of Agriculture released a Chinese leaf beetle (*Diorhabda elongata*) in six states as the first step in developing a biological control program for saltcedar. This presentation focuses on monitoring efforts at one of the first sites demonstrating substantial impacts by the beetles – Lovelock, Nevada. Efforts focused on the use of ground sampling and hyperspectral remote sensing to quantify *Diorhabda* impact, defoliation dynamics, population growth and movement within the monotypic saltcedar stands found at the site.

## THE DIVERSITY OF THE DANCE FLIES (DIPTERA: EMPIDIDAE) OF UTAH, USA

Todd Anderson and C. Riley Nelson

Department of Integrative Biology, Brigham Young University, Provo, Utah, 84602
tja33@email.byu.edu and rileynelson@byu.edu

Dance flies are common in wet environments. They are notable in having males of some species transfer nuptial gifts of prey insects to females as an enticement for mating. No focused inventory has ever been done for Empididae in Utah, although records of numerous species are scattered in the literature. Approximately 150 species from 39 genera are thought to occur in Utah. This study was designed as a preliminary survey of empidid flies for Utah with special

emphasis on the Mount Timpanogos area of the state. Mount Timpanogos rises to 11,750 feet, and was chosen for its steep altitudinal gradient and associated diversity of microhabitats suitable for empidids. Dance fly distributions in other parts of Utah are being gathered as opportunities arise during associated surveys in our laboratory. As part of this preliminary survey we will be preparing a photo guide to the empidids of Utah for the continued study of these flies. Maps of Utah detailing the distributions of empidids will also be made available. As data is compiled and analyzed we will compare it with the distributions of empidids elsewhere in the United States.

## ENVIRONMENTAL SAFETY OF A WEED BIOLOGICAL CONTROL AGENT OF HOUNDSTONGUE IN REGARD TO ENDANGERED BORAGINACEAE SPECIES

Jennifer E. Andreas and Mark Schwarzlaender

Department of Plant, Soil, and Entomological Sciences, University of Idaho, Moscow, ID 83844-2339

Non-target effects of biocontrol agents at the individual plant and population level has put the practice of weed biocontrol under scrutiny. Divergence in environmental safety assessment policies between Canada and the U.S. exist, due in part to the generally greater diversity of non-target species in the U.S. In 1997, Canadian scientists released the root-mining weevil *Mogulones cruciger* to control houndstongue (*Cynoglossum officinale*). Permission for field release in the U.S. has not yet been granted due to concerns of the U.S. Fish and Wildlife Service regarding potential non-target effects on rare and endangered Boraginaceae species. To assess the risk associated with the release of the weevil in the U.S., we tested whether eight rare and federally-listed endangered species could support weevil development. All species tested were accepted in choice oviposition tests and five species supported full development of *M. cruciger*. Monitoring over two years of co-occurring confamilial Boraginaceae species at six *M. cruciger* release sites in Alberta and British Columbia showed that all four co-occurring species were attacked by the weevil; although, to a lesser degree than houndstongue. Our data suggests that the release of *M. cruciger* in the U.S. may pose risks to native Boraginaceae including rare and endangered species.

# SIMPLIFICATION OF INHERITANCE OF RESISTANCE TO WHEAT STEM SAWFLY IN HARD RED SPRING WHEAT

Taing Aung[1], F.R. Clarke[2], and R.M. DePauw[2]

[1]Cereal Research Centre, Agriculture and Agri-Food Canada,
195 Dafoe Road, Winnipeg, MB Canada R3T 2M9
[2]Agriculture and Agri-Food Canada, Semiarid Prairie Agricultural Research Centre,
P.O. Box 1030, Airport Road, Swift Current, SK, Canada, S9H 3X2

Wheat stem sawfly resistance in hard red spring wheat cultivars is derived from the high level of the expression of stem solidness trait. The "D" genome of the hexaploid spring wheat suppress the expression of the solid stem trait confer by the "AB" genome of the tetraploid durum wheat cultivar Golden Ball. A non-suppressor gene located in the "D" genome of a wild diploid wheat *Aegilops squarrosa* (= *Triticum tauschii*) was identified in a synthetic hexaploid wheat line P89-77-1, developed by E.R. Sears, University of Missouri. Solid stem trait was partially expressed in the F1 hybrids produced from a cross between spring wheat cultivar AC Elsa and the synthetic hexaploid P89-77-1. Through backcrossing procedure the gene from Golden Ball which confer stem solidness trait and the non-suppressor gene from the diploid *Ae. Squarrosa* were transferred into spring wheat cultivar AC Elsa. In all the backcross generations corn-pollen-mediated Doubled Haploid wheat (DH) production technique was used to generate large populations of solid stemmed plants. In these plants, both the stem solidness gene and the non suppressor gene are in complete homozygous state and they expressed a high level of resistance to wheat stem sawfly. Cytologically stable AC Elsa lines that exhibit the full expression of the stem solidness trait were developed from the DH populations in the backcross seven and from the selfed progeny of the backcross eight populations. The solid stemmed AC Elsa lines that are highly resistant to wheat stem sawfly were developed. The solid stem trait and the non suppressor trait are inherited as dominant genes. All the wheat stem sawfly resistant, solid stemmed, spring wheat cultivars previously developed in the US and in Canada were based on four to five recessive genes that confer stem solidness trait. Traits that are conferred by recessive genes are complicated to detect and difficult to evaluate their expression. The two dominant-genes system (solid stem gene from Golden Ball and the non suppressor gene from *Ae. squarrosa*) expressing in a complementary manner significantly simplifies the inheritance of the stem solidness trait which provides the resistance to wheat stem sawfly. A significantly high level of resistance to wheat stem sawfly was achieved in the newly developed solid stemmed AC Elsa lines (G9608B1-L-12J11BF02 & G9608B1-L-12J13AU01) that were released in 2003. We have $BC_3$s to $BC_9$s at various stages in the breeding program with the $BC_9$s being entered into the early generation tests to a $BC_3$ Double Haploids and 10 $BC_5$ Doubled Haploids with good enough yield, protein and preliminary baking quality being entered in the pre-registration trials. We have completed ten rounds of backcrosses. This material is starting to look very much like AC Elsa. We are also cross-checking this 'solid' AC Elsa with other sources of solidness, comparing the sawfly fecundity in this 'solid' AC Elsa with other sources of sawfly resistance, and determining the inheritance of this source of solidness.

# PARASITISM OF *LYGUS* SPP. (HETEROPTERA:MIRIDAE) NYMPHS IN THE ALFALFA SEED GROWING REGION OF THE PACIFIC NORTHWEST

Jim Barbour, Thomas Mowry, and Lorraine Seymour

University of Idaho, Department of Plant, Soil, and Entomological Sciences,
Parma Research & Extension Center, 29603 U of I Lane, Parma, ID 83660

Species of *Lygus* (Heteroptera: Miridae) attack more crop species than any other insect pest in the US. The *Lygus* spp. complex in the western U.S. is dominated by *L. hesperus* Knight, with other species such as *L. elisus, L. keltoni*, and *L. lineolaris* of local importance on some crops or in particular areas. With few exceptions *Lygus* populations have been managed primarily by application of organophosphate, carbamate and pyrethroid insecticides. Establishment of an effective biological control program for *Lygus* spp. would benefit production of many field, fruit and vegetable, and seed crops attacked by *Lygus* spp. by minimizing the disruption of beneficial natural enemies and pollinators through reduced insecticide use, and by delaying or preventing the development of insecticide resistance. A recently discovered species of braconid wasp, *P. howardi* Shaw (Hymenoptera: Braconidae: Euphorinae), apparently native to the Pacific Northwest, has been found to parasitize a high percentage of *L. hesperus* in some Idaho and Washington locations, and may be a potentially important biological control agent for *Lygus* spp. in alfalfa seed and other seed, vegetable, fruit, and forage crops. Research examining the significance of this parasite in alfalfa seed and other crops has been hindered because the reduced morphology of larvae makes them indistinguishable from other parasites in the genera *Peristenus* and *Leiophron*. In addition, rearing parasites to the adult stage for identification requires a 9-10 month delay and is associated with high parasite mortality. As a result, a number of currently published surveys contain information on percentage parasitism of *Lygus* spp., but do not provide information on the species of parasite(s) involved.

The goal of this study was to determine parasitism rates of *Lygus* spp. nymphs collected from crop and non crop *Lygus* spp. hosts in the alfalfa seed producing region of southwestern Idaho and eastern Oregon. *Lygus* were collected from host plants every two weeks from late May through August using sweep nets and held in 95% EtOH for determination of parasitism. Percentage parasitism was determined by dissecting 2$^{nd}$ through 5$^{th}$ instar Lygus nymphs. Parasite eggs and larvae recovered from *Lygus* spp. nymphs were held in 95% EtoH for identification. A molecular procedure incorporating polymerase chain reaction (PCR) of the COI gene followed restriction endonuclease digestion of PCR products *Sfc*I endonuclease was used to distinguish *Peristenus howardi* from four other *Peristenus* spp.

Percentage parasitism of *Lygus* spp. collected from unsprayed alfalfa seed at the Parma Research and Extension Center reached 80% or greater, with seasonal average percentage parasitism of 30% & 20% in 2002 and 2003 respectively. The percentage parasitism in other crop and non-crop plant hosts ranged from 0%-10% for both years. The mean number of parasitoids testing positive as *Peristenus* spp. was 57% ± 10% in 2002 and 79% ± 3% in 2003. Subsequent restriction endonuclease digestion of PCR fragments indicated that *P. howardi* accounted for only 50% to 60% of the parasitism of *Lygus* spp. by *Persistenus* spp. It appears that other

parasitoid species are responsible for a significant proportion of the observed *Lygus* spp. parasitism in some Pacific Northwest regions.

## SPECIES DISTRIBUTION, REGIONAL ASSEMBLAGES, AND PARASITISM OF *LYGUS* IN MONTANA CANOLA FIELDS

Rebecca A. Baril[1], Andrew W. Lenssen[2], Sue Blodgett[3] and Mark L. Taper[1]

[1]Montana State University, Dept. of Ecology, Bozeman, MT
[2]USDA-ARS-NPARL, Sidney, MT
[3]Montana State University, Department of Entomology, Bozeman, MT

Season-long sweep net sampling of canola (*Brassica napus* L.) was conducted in 2002 and 2003 to determine *Lygus* (Heteroptera: Miridae) species composition, assemblages and parasitism levels in four regions of Montana. Combined densities of lygus nymphs and adults varied during the season, with physiological developmental stage of the plant and region where samples were collected. Canola in all regions had increased lygus population densities as crops matured. The southwest and central regions had infestations that exceeded the economic threshold of 1.5 bugs/sweep at the late flowering stage. *Lygus* species composition was identified and analyzed for differences among regions and crop stage. Regardless of region or seasonal change, *Lygus elisus* (Van Duzee) was the dominant species in all canola fields sampled, averaging 60 – 99% of the total adult populations. *Lygus borealis* (Kelton), *Lygus keltoni* (Schwartz) and *Lygus lineolaris* (Palisot) also made regular appearances, but in much lower quantities. Species assemblages in the southwest and central regions changed with crop maturity, primarily due to increased proportions of *L. elisus*. Northeast and southwest regions of Montana demonstrated the greatest species diversity. Potential biological control of lygus populations by *Peristenus* spp. (Hymenoptera:Braconidae) was investigated by dissecting nymphal stages III-V. Parasitism was found to be negligible in the dissection of 1,016 nymphs.

## CHAOS TO REDUCE RISK: ASSESSING ALTERNATIVE FARMING STRATEGIES TO MITIGATE WHEAT STEM SAWFLY DAMAGE ON THE SOUTHERN PRAIRIES OF CANADA

Brian L. Beres[1] , Hector A. Carcamo[1], Robert J. Byers[1], Fran R. Clarke[2], and Ron M. DePauw[2]

[1] Lethbridge Research Centre, Agriculture and Agri-Food Canada, Lethbridge, Alberta, Canada
[2] Semi-Arid Prairie Research Centre, Agriculture and Agri-Food Canada, Swift Current, Saskatchewan, Canada

Increasing wheat stem sawfly damage was first observed in fields near Skiff, Alberta in the late 1990s. This resurgence has now spread across the entire region prone to attack in the southern Prairies of Canada and it is anticipated that outbreak status will apply to many areas within this

region. At the time of resurgence, there was no IPM program in Canada as all efforts were dedicated to solid-stem cultivar development. Availability of resistant cultivars is an issue as there are currently only two registered solid-stem varieties available to producers in Canada, and both are from the same wheat class. There is also a reluctance to adopt resistant varieties as some producers feel they can offset losses sustained by sawfly damage by using a high yielding and high quality hollow-stem variety. Those producers wishing to grow wheat from classes that do not have any solid-stem cultivars require novel strategies to mitigate the impact of wheat stem sawfly infestations. Since chemical control has proven to be an ineffective control strategy we have focused our efforts on assessing alternative farming strategies that may offer some degree of control and would complement today's on-farm technologies.

In 2003, study sites were established near Nobleford and Foremost, Alberta, and near Indian Head, Saskatchewan. The objective of this study was to assess the effect of alternative seeding systems on wheat stem sawfly. Five treatments, arranged in a RCBD and replicated three times, were seeded using commercial scale, direct seeding systems. The treatments consisted of: 1) 20 m trap or border strip seeded to solid-stem cultivar AC Eatonia or AC Abbey, and interior of plot seeded to hollow-stem cultivar AC Barrie, 2) 20 m trap or border strip seeded to oats and interior of plot seeded to hollow-stem cultivar AC Barrie, and 3) Entire plot seeded to a 1:1 blend of solid-stem cultivar AC Abbey or AC Eatonia and hollow-stem cultivar AC Barrie. These three alternative seeding strategies were compared to traditionally seeded plots of A) hollow-stem cultivar AC Barrie, and B) solid-stem cultivar AC Eatonia or AC Barrie. Spatial distribution of sawfly during adult flight was collected using sweep nets at intervals across entire treatment. Prior to harvest, two-1 $m^2$ samples were collected at regular intervals across treatments to quantify harvest losses attributed to sawfly cutting. At harvest, we swathed a 2 m strip from each plot to assess the effect of swathing vs. straight cutting harvesting operations. The plots were sub-sampled using a Wintersteiger nurserymaster Elite combine. Following harvest, 1 m row samples of stubble were collected at regular intervals across treatments to elucidate the effect of treatment on larva survivorship.

A successful treatment would be one that was both productive in terms of grain yield, but also lowered the overwintering field population of sawflies to below the threshold level of 10% live larvae. Our preliminary finding from Alberta is novel in that it disproves the common notion that a producer suffers a yield penalty by growing the resistant cultivar AC Eatonia. At both sites, AC Eatonia was the highest yielding treatment, followed by the cultivar blend treatment. AC Eatonia and the cultivar blend were the only treatments that reduced overwintering larvae populations to below 10%. It appears that our sawfly infestation was very high and extended well beyond the trap or border treatment, thereby reducing the efficacy of the trap crop strategy. In addition, it appears the adult sawflies avoided the oat trap and instead moved directly toward the interior hollow-stem hosts. The yield of hollow-stem cultivar treatments was enhanced when a swathing operation was incorporated. The highest yielding treatment in the swathing operation was the cultivar blend. These preliminary results suggest that producers adopting solid-stem cultivars will attain comparable yields to conventional varieties, and more importantly, solid-stems will reduce the population of overwintering larvae. Our results also support previous findings that cultivar blends may indeed have a role to play in an IPM strategy for the control of wheat stem sawfly. In the future, we hope to increase our research efforts towards improving the integration of host plant resistance with agronomic and biological control strategies.

## IMPACT OF SHEEP GRAZING ON OVERWINTERING WHEAT STEM SAWFLY, CEPHUS CINCTUS NORTON, POPULATIONS

Sue Blodgett[1], Theresa Spezzano[2], P.L. Hatfield[2], and H.B. Goosey[2]

[1]Department of Entomology and [2]Department of Animal and Range Sciences,
Montana State University, Bozeman, MT 59717

Wheat stem sawfly (WSS) continues to be the number one pest of wheat in Montana, currently resulting in an estimated damage of $25- $30 million per year. It has been intractable to many traditional insect control techniques and has required novel research approaches to develop management options that Montana growers can use to reduce the impact of this insect. Spring, fall and spring plus fall sheep grazing were compared with burning, tillage, hand clipping (to simulate grazing alone) and trampling (muzzled sheep were prevented from feeding) in a series of experiments. In the first experiment, WSS mortality across all grazing treatments (68.4%) resulted in significantly greater mortality than either the control (43.4%) or tillage (46.6%) treatments. There were no differences in WSS mortality between fall (67.2%) and spring (64.0%) grazed plots but mortality was greater in the fall plus spring graze treatment (73.9%) (additive stocking rate of fall and spring graze). In the second experiment, WSS mortality did not differ among fall burn, control or tillage treatments but fall graze had significantly greater mortality (63.1%) than fall burn treatment (51.9%). In the third experiment, mortality was greatest in the trample plots (57.3%) than either the control (32.8%) or hand clip treatment (32.3%). Mortality was greater in the fall plus spring graze treatment (70.6%) than either the fall or spring graze alone (54.3% and 46.9%, respectively) which did not differ. There was no difference between grazing and trampling treatments. Generally, doubling sheep grazing intensity by imposing two, 400 sheep-day/ha fall and spring grazing treatments increased WSS mortality although it was not doubled. Trampling by muzzled sheep in the third experiment was the primary source of WSS mortality, suggesting that hoof action rather than feeding caused WSS overwintering mortality. Integrating sheep grazing into a wheat production system offered several benefits to producers including increased wheat stem sawfly mortality over an untreated control, reducing crop residues and utilizing grain stubble as a low cost feed source.

## NORTHERN GREAT PLAINS LYGUS BUG SPECIES COMPLEX AND MANAGEMENT

Sue Blodgett[1], Rebecca Baril[1], Ruth O'Neill[1], Cecil Tharp[1] and Ken Kephart[2]

[1]Department of Entomology, Montana State University, Bozeman, MT 59717
[2]Southern Agricultural Research Center, MSU, Huntley, MT

Lygus spp. is a serious insect pest of canola and alfalfa seed production in Montana and the Northern Great Plains. A recent survey of canola has provided information about the lygus species complex and seasonal occurrence in four Montana production areas. *Lygus elisus* was found to dominate the canola lygus species complex in all four sampled areas of the state,

ranging from 60 – 99%. *Lygus borealis* (Kelton), *L. keltoni* (Schwartz), and *L. lineolaris* (Palisot) were also found in significant numbers. The northeast and southwest parts of the state had greater species diversity than the northcentral or central production areas.

Producers typically control lygus by application of 2-3 pesticide treatments per year but pesticide applications for lygus bug have resulted in documented instances of resistance development in other states. Assessing biologically-based pesticides for lygus efficacy on target pests and natural enemies would provide producers with valuable information about the benefits of applying less toxic, broad spectrum insecticide materials. Valoram, pyriproxyfen, azadirachtin, novaluron and bifenthrin were compared with an untreated control. In the first year of this study there were no significant differences in lygus numbers post-treatment. There were differences in nabid numbers. At one site in southcentral MT there were significantly greater numbers of nabids per 5 sweeps in novaluron treatments compared with bifenthrin at 7 days post-treatment. At a second southcentral MT site there were significantly greater numbers of nabids per 5 sweeps in the untreated control plots compared with bifenthrin at 5 days post-treatment. There were no significant differences in alfalfa seed yield at any of the three sites.

No detectable parasitism of lygus nymphs by *Peristenus* spp. was found following dissection of 1,016 instars III-V extracted from canola. While lygus immature populations peaked in alfalfa on July 27$^{th}$, parasitism peaked on July 1, with 29.1% detected by dissection of instars III-V, no parasitism was detected after July 10.

## BIONOMICS OF PEA POD WEEVIL IN DRY PEAS

David E. Bragg

Washington State University Extension Entomology
P. O. Box 190, Pomeroy, WA 99347-0190
(509) 843-3701

The adult pea weevil, *Bruchus pisorum* (L.), Family Bruchidae is ca. 5 mm, brownish, with white, black, and gray patches. The top of the abdomen is exposed behind the wing covers as is typical of Bruchid weevils. Pea weevil adults over winter as adults, and invade pea fields at about the 7$^{th}$ node (clam shell stage). Adults feed on pollen from pea flowers to mate and mature eggs. Eggs are laid by mated females as the small pea pods develop up to the time of early pea seed development within the pod. Counts of over 250 eggs per pod occur in outbreak years. Larvae feed in individual peas within pods. Damaged peas (cull peas due to dimples and actual larval feeding may reach 85% in the PNW Region. Damaged peas of ca. 30% are typical in both foliate, and afila type, spring dry peas, on the Palouse of Washington and Idaho. Larvae are C-shaped, up to 6 mm long, legless, brown-headed, and cream-colored. Pupation occurs within the pea. Harvesting does not reveal damage. Typically, adults emerge as many as 5 months later from stored peas. Hollow peas and the dimpled, shriveled peas left after cleaning are sold as "cull peas". A market for cull peas exists in India, where weevils in the peas are a matter of concern.

## MANAGEMENT OF SEED POD WEEVIL IN DRY PEAS USING SOFTER INSECTICIDES TO REPLACE "OP" COMPOUNDS

David E. Bragg

Washington State University Extension Entomology
P. O. Box 190, Pomeroy, WA 99347-0190

An early trial to test the efficacy of dry pea foliar insecticides selected by FMC Corp. was established 7-01-03 at Farmington, WA, using the variety "Juene", a foliate variety determinate nature. The trial was RBCD in 4 replicates of 10 x 20 feet per treatment. Applications were made by CO2 back sprayer set at 20 gpa/20 psi. A late trial was sprayed on 7-10-03 in the same manner. Peas were collected at harvest in samples of 100+ peas per replicate on 7-31-03. Peas were stored until December 18, at which time adult bruchid weevils began to emerge in the lab. Counts of weevils per 100 peas were made. All treatments in the trials were competitive, compared with the UTCs. Cygon-Imidan was applied as a standard dry pea treatment. The new liquid formulation of Imidan was used. No pea aphid appeared in the trials in 2003; only pea pod weevil data were evaluated. Mustang Max (Zetacypermethrin) was tried as replacement for the standard, and Capture (Bifenthrin). The Baythroid (Cyfluthrin)/Provado (Imidicloprid) tank mix was effective against weevils in both trials, but may not be cost effective. Data were analyzed by ANOVA; LSD t Test. More tests are underway in 2004.

## MORPHOLOGICAL AND MOLECULAR PHYLOGENY OF THE CLITELLARIINAE (DIPTERA: STRATIOMYIDAE)

Colin A. Brammer and Carol D. von Dohlen

Department of Biology, Utah State University, Logan, UT 84322-5305, USA

Stratiomyidae is a diverse, cosmopolitan family of Diptera (true flies). One of its twelve subfamilies, Clitellariinae, is distributed in all major biogeographic regions except Antarctica. Understanding the evolutionary history of Clitellariinae is key to reconstructing the phylogeny of Stratiomyidae as a whole, because this subfamily is probably not monophyletic: Clitellariinae appears to be united only by shared ancestral characters. The current research investigates the relationships between the genera currently placed within the Clitellariinae, and the relationships of all the subfamilies of Stratiomyidae using morphological and molecular techniques. Morphology was analyzed at the generic level using 93 adult characters. Molecular analysis was performed using partial sequences of the Elongation Factor one alpha and 28S ribosomal genes. Morphological and molecular trees were not wholly congruent with respect to clitellariine genera, but were congruent with respect to monophyly of all other subfamily clades within Stratiomyidae. Both morphology and gene sequences supported the groupings of (*Dicyphoma* + *Cyphomyia*), and (*Abavus* + *Acropeltates*), as well as subfamilial relationships of (Sarginae + Hermetiinae) and (Stratiomyinae + Raphiocerinae). Combined morphological and molecular analyses, aspects of character evolution, and biogeographical distribution were also explored.

# DEVELOPMENT OF SOLID-STEM WINTER WHEAT CULTIVARS FOR MONTANA

Phil L. Bruckner

Montana State University, Department of Plant Sciences & Plant Pathology, Bozeman, MT

Wheat stem sawfly (*Cephus cinctus* Norton), a wasp endemic to North America, remains the major insect pest of wheat in Montana. Originally, a stem-boring insect of the large-stemmed wild grasses, wheat stem sawfly adapted readily to spring wheat, and more recently to winter wheat. The Montana winter wheat program has been actively involved in development of cultivars with tolerance to wheat stem sawfly for the past 15 years. For all practical purposes, stem solidness is the only known effective source of resistance to wheat stem sawfly. Diverse sources of stem solidness have been found quite readily and are fairly common in "modern" foreign germplasm. Although it is unknown whether any of these diverse sources of stem solidness are genetically distinct from stem solidness already deployed through S615 and 'Rescue', all of these diverse solid-stem lines carry GWM340, a microsatellite marker linked to a single solid stem QTL on chromosome 3BL reported by Cook et al., 2004. We have used conventional breeding methods in our program to first transfer stem solidness from HRS wheat into winter wheat, then secondarily attempt to improve winter hardiness and yield potential of lines with high stem solidness. In our experience, stem solidness is a highly heritable trait that has been fairly easy to select for in field environments. A key component of our field selection program has been evaluation and selection of winter wheat lines under moderate to heavy insect pressure. In 1995 and 1996, respectively, 'Vanguard' and 'Rampart' were released as sawfly-resistant winter wheats for Montana. Yields of Vanguard and Rampart are superior to most hollow-stemmed cultivars in sawfly-infested environments but are not yield-competitive where sawfly is not a consistent problem. Even with relatively low yield potential and marginal winter hardiness, Rampart became the leading winter wheat cultivar in Montana based on planted acreage in 2003, accounting for about 25% of the total acreage. We are now in the process of releasing 'Genou', a solid-stem line with improved yield potential and cold tolerance. We have had difficulty in combining higher yield potential and improved winter hardiness with high levels of stem solidness. Improvement in yield potential of solid-stem germplasm has not occurred at the same rate as in hollow-stemmed germplasm. In comparative trials evaluating simultaneously-developed hollow- and solid-stem experimental lines from our breeding program, the solid-stem lines are generally not competitive with hollow-stem contemporary lines for either yield performance or cold tolerance. Because our primary winter wheat production areas are heavily infested by wheat stem sawfly, we continue to diversify the solid-stem winter wheat germplasm by combining solid stem with other useful traits such as hard white kernel color and IMI herbicide tolerance.

## MATING DISRUPTION AND POPULATION DYNAMICS OF THE NAVEL ORANGEWORM IN CALIFORNIA DRIED FRUIT AND NUT CROPS

Charles S. Burks[1], Bradley S. Higbee[2], and David G. Brandl[1]

[1]USDA-ARS, 9611 S. Riverbend Ave., Parlier, CA
[2]Paramount Farming, Western Regional Technical Center, 33141 E. Lerdo Highway, Bakersfield, CA

The navel orangeworm is an orchard pest of dried fruits and nuts which is carried over into postharvest storage, and which is an important cause of fumigation treatments. We are trying to decrease fumigation and crop damage by improving treatment in the field, and therefore have studied mating disruption against this pest over the last several years in figs, almonds, and pistachios. A two-year comparison of paired treatment and comparison plots in figs showed that aerosol dispensers placed peripherally around 16-ha treatment plots could significantly reduce females captured in female-baited flight traps throughout the plot, but that complete trap shutdown was more consistently achieved in more shaded orchards and when the aerosol material was placed in the orchard later in the season. Comparison of aerosol dispensers placed peripherally around 16-ha plots of almonds and pistachios with aerosol or membrane dispensers gridded throughout such plots suggested that the gridded aerosol dispensers were most effective in reducing males captured in female-baited flight traps and females mated in assays, and showed that this was the most effective of the mating disruption treatments for reducing navel orangeworm damage in almonds. We found very low prevalence of navel orangeworm in almonds and figs during the second cohort, but higher prevalence in pistachios. Increasing abundance of navel orangeworm had a more direct effect on damage in almonds compared to figs or pistachios, and under the current circumstances this crop seems to offer the best opportunity for cost-effective use of mating disruption against the navel orangeworm.

## EFFICIENCY OF ChamP AND PLASTIC McPHAIL TRAPS IN MONITORING THE OLIVE FRUIT FLY (*BACTROCERA OLEAE*) IN CALIFORNIA

Hannah J. Burrack and Frank G. Zalom

University of California, Department of Entomology, One Shields Avenue, Davis, CA

The olive fruit fly was first detected in California in 1998 and has since been detected in all olive producing regions in the state. Statewide monitoring for the olive fruit fly has been conducted since 2002 in 22 locations in 13 counties and will continue through 2004 with the goal of producing a degree-day model for the pest. Two of the most common traps used in monitoring the olive fruit fly are the yellow panel sticky trap baited with ammonium bicarbonate food lure and spiroketal pheromone lure (ChamP trap) and the plastic McPhail trap (IMPT trap). It is important for the accurate tracking of olive fruit fly population dynamics to determine which trap most efficiently attracts and captures the fly. In order to determine which trap was the most efficient in monitoring this pest, four ChamP traps and two McPhail traps were placed at three

locations throughout the Sacramento Valley of California during Spring, Summer, and Winter 2003. Traps were checked weekly, and fly counts were recorded by sex as flies per trap per day. Fly captures between the two types of traps were compared within locations using Student's t-test. The plastic McPhail trap captured significantly more flies of both sexes than the ChamP trap with the exception of the winter months during which there were very few flies captured in either type of trap.

## FLORAL CHEMICAL LURES FOR ATTRACT AND KILL SYSTEMS TO CONTROL ALFALFA LOOPER AND CORN EARWORM (LEPIDOPTERA: NOCTUIDAE)

Leonardo De A. Camelo[1], Peter J. Landolt[2], Richard S. Zack[1], and Daryl L. Green[2]

[1]Washington State University, Department of Entomology, 166 FSHN Bldg., PO Box 646382, Pullman, WA

[2]USDA/ARS, 5230 Konnowac Pass Road, Wapato, WA

Pesticide applications and genetically engineered crops are the most common methods for controlling caterpillars of noctuid moths in North America. The large agricultural damage caused by this group and its vast distribution is well known. The Food Quality and Protection Act, growing environmental issues, and worker safety related concerns have led scientists to research and develop alternative approaches of controlling these insects such as "attract and kill" systems. We have developed a series of floral chemical lures from compounds derived from "noctuid-visited" flowers. Lures are dispensed from polypropylene vials that provide controlled release rate for extended periods of time. A killing station is being tested in the field for use in combination with these lures as an "attract and kill" system. Bait stations are implemented to reduce numbers of female moths before they are able to lay eggs. Male/female attraction ratio to developed lures is 1/1. Field trials were conduced in alfalfa fields at the Yakima Valley during the 2003 and 2004 growing season. Reproductive state of captured moths was assessed by dissecting females in the laboratory. Seasonal distribution of both species in the Yakima Valley was recorded using the developed floral chemical lures and pheromones commercially available for each specie.

Species 1: Lepidoptera Noctuidae *Autographa californica* (alfalfa looper)
Species 2: Lepidoptera Noctuidae *Helicoverpa Zea* (corn earworm)
Keywords: floral chemical lure, attract and kill

## INFLUENCE OF IMMIGRATION ON THE INTERPRETATION OF PEST MONITORING PROGRAMS IN FOOD PROCESSING FACILITIES

James F. Campbell

USDA ARS Grain Marketing and Production Research Center
1515 College Ave., Manhattan, KS

Immigration of stored product insects into food processing facilities may be an important source of infestation and may influence the interpretation of pheromone monitoring programs. To evaluate the impact of immigration a long term monitoring program was conducted inside and outside a flour mill in Kansas. For some species, the data suggest that source patches for the insects lay over a spatial scale greater than the mill itself and there was considerable movement of individuals across this larger spatial scale, effectively linking activity inside and outside the mill. This pattern applied to *Plodia interpunctella* and *Trogoderma variabile,* where pheromone trap capture levels outside were higher than inside the mill, inside and outside trap captures were correlated, both indoor and outdoor trap captures tended to cycle according to a seasonal pattern, fumigations did not consistently influence pheromone trap captures, and rarely were they found in product samples. Mark-recapture data demonstrated that *P. interpunctella* was capable of entering the building from outside. For these species, because of the apparently high level of immigration, pheromone trap capture data primarily indicated the infestation potential, not the level of infestation within the mill. The second pattern observed in this study suggests source patches for the insects lay over a spatial scale contained within the mill itself with pheromone/food traps capturing primarily insects moving among these internal patches. *Tribolium castaneum*, the major pest at this mill, followed this pattern. Trap captures tended to be lower outside compared to inside, and followed a pattern of sharp decline after fumigation treatment and then steady increase in numbers until the next fumigation. This rebound, other than potentially the rate of increase, was not impacted by season and outside trap capture levels, and *T. castaneum* was the most prevalent species in product samples. Rebound after fumigation may result from persistence of individuals within some of the patches within the mill and, probably to a lesser extent, immigration of new individuals into the mill either actively or in infested products. Pheromone monitoring of this species inside the mill provided a good indication of product infestation.

## WHEAT STEM SAWFLY POPULATION DYNAMICS IN SOUTHERN ALBERTA: HOST EFFECTS, OVERWINTERING AND PARASITISM

Héctor A. Cárcamo[1], Brian L. Beres[1], J. Robert Byers[1], Fran R. Clarke[2], and Ron M. DePauw[2]

[1]Agriculture and Agri-Food Canada, Lethbridge, Alberta, Canada
[2]Agriculture and Agri-Food Canada, Swift Current, Saskatchewan, Canada

Since the mid 1990s, the wheat stem sawfly has resurged in Alberta and Saskatchewan and has again become a major economic concern for wheat producers throughout its historical range. Our

studies on the population dynamics of this insect aim to quantify effects of current and novel wheat germplasm on larval weights, overwintering survivorship, female fecundity and interactions of cultivars with rates of parasitism by *Bracon cephi*.

In 2000, the study site was located about 100 km SE of Lethbridge near Skiff. In 2001-2003 we repeated the study at Skiff and re-established a research site at Coalhurst, 10 km W of Lethbridge. We also obtained samples from a long term research site at Swift Current, Saskatchewan. We collected wheat stubble in the spring to rear adults to determine fecundity and in late summer or early fall to obtain larval weights. Cultivars sampled at each site were currently grown durum wheats (AC Navigator, AC Avonlea, Kyle), and solid- (AC Abbey, AC Eatonia) and hollow-stemmed (AC Barrie, AC Cadillac, AC Intrepid, CDC Teal, Katepwa, McKenzie) hard red spring wheats. In 2002, we added a study of a novel solid-stemmed synthetic hexaploid line, P89-77-1, from a cross made by E.R. Sears between Golden Ball (2n=28, AABB) and *Triticum tauschii* (2n=14, DD) obtained from the University of Missouri in 1993. In 1994, P89-77-1 was crossed with AC Elsa, and solid-stemmed selections have been repeatedly backcrossed to AC Elsa to produce Golden Ball/*T. tauschii* //#*AC Elsa. Three lines from this material were included in this study (G9608B1-L12J11BF02, B9973B03&AG2AT, B9973B03&AC4AW) to quantify their effects on the sawfly. In 2003, we expanded the study to elucidate the interaction between host quality and over-wintering survival and rates of parasitism by *B. cephi* at the Coalhurst site.

Our study confirmed that AC Abbey and AC Eatonia, two solid-stemmed hard red spring wheat cultivars bred for sawfly resistance, in addition to having reduced levels of cutting will also reduce larval size and subsequent female fecundity of survivors. A study of larval mortality at cold temperatures (-20 °C), showed that larvae from the solid-stemmed AC Abbey had higher mortality after 20, 30 and 40 days of exposure than those from AC Cadillac, a hollow-stemmed cultivar. McKenzie, a cultivar with inconsistent pith expression in Alberta, produced variable larval sizes across sites and intermediate levels of female fecundity. Susceptible hollow-stemmed cultivars and durum wheats, such as Kyle, sustain high levels of cutting and produce large larvae that develop into highly fecund females. These cultivars should be avoided in areas experiencing sawfly infestation and replaced by solid-stemmed varieties. Preliminary results suggest that one of the novel germplasm lines (G9608B1-L12J11BF02) had the lowest cutting levels and consistently produced the smallest larvae; however the few adults (n=8) that were obtained in 2003 had high and variable egg loads (mean ± se = 38 ± 7). The parasitoid *B. cephi* was effective at parasitizing sawfly larvae in both hollow- and solid-stemmed varieties. One of the highest levels of parasitism was observed in the most resistant novel solid stem line (G9608B1-L12J11BF02), suggesting that the wasp could find most of the few sawfly larvae that developed in this line. The low overall population of *B. cephi* that was produced in this line, however, was similar to that produced by the durum cultivar AC Navigator which had both low parasitism and low sawfly infestation. The apparent difference in the response of the parasitoid to these two wheats warrants further study. Field scale evaluations and controlled green house experiments are required to clarify the interactions between AC Navigator, the sawfly and its parasitoid. In the future, we hope to increase our research efforts towards improving the integration of host plant resistance with agronomic and biological control strategies.

## THE IMPACT OF THE LOSS OF ORGANOPHOSPHATE INSECTICIDES ON CALIFORNIA AGRICULTURE: THE IMPACT ON BROCCOLI

William E. Chaney, Ph.D.

University of California, Cooperative Extension, 1432 Abbott St., Salinas, CA 93901

Broccoli and other crucifers are important year-round crops for the Central Coast areas of California. Because they are harvested as fresh market crops, the tolerance for insect damage is quite low. These crops face pests both above and below ground, but it is arguably the below ground pests that are the most difficult to predict and to control. Currently, control of these pests is primarily achieved through the use of preventative organophosphate (OP) insecticide use.

Although the key pests for broccoli in the soil are root maggots, other soil inhabiting pests such as symphylans, springtails and bulb mites may also affect the crop. Some of these, such as symphylans, may be perennial problems, re-occurring each year in the same areas of the same field. The loss of OPs in other crops may also affect the overall populations of these pests, increasing the pressure on broccoli.

The alternatives to OPs are limited and consist mostly of other chemical insecticides substituted in the soil. Pressures from land costs make many alternative management strategies unpopular. Economics in this production area do not leave any room for added costs to manage soil pests. Growers may well decide to choose alternate crops if OPs are lost.

## THEORETICAL EFFECTS OF MULTIPLE PREY AND HABITATS ON INTERACTIONS BETWEEN LADYBIRD BEETLES

Gary C. Chang

Washington State University, Department of Entomology, P. O. Box 646382,
Pullman, WA 99164-6384

*Coccinella septempunctata* and *Harmonia axyridis* are two species of ladybird beetles introduced into North America. In western Washington State, they have become the numerically dominant coccinellids and largely replaced species indigenous to North America such as *Hippodamia convergens* and *Coccinella transversoguttata*. However, in northern Idaho, *H. convergens* remains numerically dominant, and *C. transversoguttata* is found in appreciable numbers. Environmental differences between northern Idaho and western Washington include the availability of alternative prey and the severity of winter. I use a mathematical model to explore some of the factors that may affect when an introduced coccinellid becomes numerically dominant, and when it does not. The model is an extension of a general, heuristic model developed by Holt in 1977 that includes abundances of multiple prey species and has stable equilibria. I add a second predator to Holt's model and simulate several scenarios. Introduced predators may enter either a system where the indigenous predator and its prey are at

equilibrium, or a system that is perturbed by seasonal events. Consistent with other invasion models, replacement of indigenous species is greater in the perturbed system. The model illustrates the influence of alternative prey and alternative habitats on the relative abundance of ladybird beetles.

## COCKROACH GEL BAIT AVERSION AND THE DEVELOPMENT OF A NEW GEL BAIT FORMULA

Michael Chapman[1], Gary Braness[2], Nonggang Bao[3], Tom Macom[3], and Joe Barile[4]

[1]Bayer Environmental Science, 1856 Spahn Lane, Placentia, CA 92870
[2]Bayer Environmental Science, 7666 N. Atkins Place, Kansas City, MO 64152
[3]Bayer Environmental Science, 981 NC 42 East, Clayton, NC 27520
[4]Bayer Environmental Science, 7 Noreen Road, Mansfield, MA 02048

Cockroach baits are the most effective and widely used formulation for cockroach management in the United States. In limited locations, German cockroaches, *Blattella germanica*, have been avoiding gel bait placements. Bait aversion is particularly a problem in commercial establishments with a long history of exclusive bait use. Bayer Environmental Science, a leading manufacturer of cockroach baits is actively researching cockroach gel bait aversion. Basic laboratory and field studies have led to the development of a new gel bait formula that will be commercially available for use by pest management professionals. This presentation will provide basic information on cockroach bait aversion, update laboratory and field research, and offer recommendations for effective cockroach management stressing good IPM practices.

## VARIABLE EFFECTS OF WILD FESCUE–FUNGAL ENDOPHYTE ASSOCIATIONS ON BIRD CHERRY-OAT APHID SURVIVAL

Steve Clement[1], Leslie Elberson[1], Blair Waldron[2], and Ted Kisha[1]

[1]USDA-ARS, 59 Johnson Hall, Washington State University, Pullman, WA
[2]USDA-ARS, Utah State University, Logan, UT

Temperate grass–*Neotyphodium* fungal endophyte associations have widely varying effects (negative to positive) on insect herbivores. For example, earlier research at Pullman, Washington, showed that bird cherry-oat aphid (BCOA) survival was adversely affected by some but not all fescue–endophyte associations. Endophytes can influence plant suitability for insect herbivores, including BCOA, by deterring them or reducing their survival via production of specific alkaloids. In this poster, we provide more evidence that *Neotyphodium* infection does not always provide wild fescue from Tunisia with resistance to BCOA. Research has not fully characterized the taxonomy of the experimental fescues, which may represent one or two species, or hybrids. In this latest series of experiments, 14 of 17 *Neotpyhodium*–infected

accessions from Tunisia supported significant BCOA population growth and survival. We posit that variation in alkaloid type and concentration mediated BCOA responses to the different wild fescues.

## FILTH FLIES ARE NOT JUST FOR WASTE: CAGE POLLINATION OF *ALLIUM* GERMPLASM

Steve Clement[1], Barbara Hellier[1], Leslie Elberson[1], Marc Evans[2], and Russell Staska[1]

[1]USDA-ARS, 59 Johnson Hall, Washington State University, Pullman, WA
[2]Program in Statistics, Washington State University, Pullman, WA

The USDA-ARS Western Regional Plant Introduction Station, Pullman, Washington, maintains the leek (*Allium ampeloprasum*) collection for the National Plant Germplasm System. Leek accessions are regenerated each year to replenish seed stocks low in viability and supply. Leeks require insect pollination to produce seed, thus accessions for seed regeneration are caged to preclude cross-pollination and to maintain genetic integrity. Leek seed production was quantified in field cages (4 x 7 x 2 m) using three densities of houseflies, *Musca domestica* L., and bottle flies, *Calliphora vomitoria* (L.). A randomized block design with four replications was used. Cages without insects (controls) averaged 2.4 g of seed, whereas cages with 100, 250, and 500 houseflies averaged 11.8, 19.7, and 70.5 g of seed, respectively. By contrast, cages with 100, 250, and 500 bottle flies averaged 65.2, 175.3, and 340.7 g of seed, respectively (LSD = 34.0 for all mean comparisons, $\alpha = 0.05$). Thus, the bottle fly is the superior pollinator for leek seed regeneration.

## MOLECULAR PHYLOGENETIC ANALYSIS OF THE GOMPHOCERINAE GRASSHOPPERS

Daniel A. Contreras and William Chapco

University of Regina, Department of Biology, 3737 Wascana Parkway, Regina, Sk.

The Gomphocerinae, the slant faced grasshoppers, are a large subfamily of Acridid grasshoppers. Distributed throughout Eurasia, North America, South America, and Africa, they are found world-wide, excepting Australia and Madagascar. The origin and dispersal of North and South American taxa have been subjects of considerable speculation for many decades and recent studies have shed light on the issue. For example, phylogenetic methods employing mitochondrial genes were recently applied to test various biogeographic scenarios pertaining to the continental origin of the melanopline grasshoppers, found throughout the Americas and Eurasia. Contrary to the prevailing viewpoint in which South American taxa were established from the north, results indicate the reverse with North American melanoplines being derived from South America and, in turn, Eurasian forms derived from North America. Using a small

sample of species from the Gomphocerinae, this preliminary analysis explores the generality of these results with respect to intercontinental patterns using the DNA sequences of four mitochondrial genes sequences as markers. Although the data set is too small to give definitive support for any one conjecture, the study sets the groundwork for future studies as it provides, for the first time, a molecular phylogeny of the Gomphocerinae.

## IDENTIFICATION OF MICROSATELLITE MARKERS ASSOCIATED WITH A STEM SOLIDNESS LOCUS IN WHEAT

J. P. Cook, D. M. Wichman, J. M. Martin, P. L. Bruckner, and L. E. Talbert

Department of Plant Sciences and Plant Pathology, Leon Johnson Hall,
Montana State University, Bozeman, MT 59717

Wheat stem sawfly is a major insect pest in areas of the Northern Great Plains. The primary control measure is use of resistant cultivars containing solid stems. Environmental effects on expression of the trait can be problematic, thus genetic markers would be useful. In this study, a doubled haploid (DH) winter wheat population derived from a 'Rampart' (solid stems) X 'Jerry' (hollow stems) cross was analyzed to identify molecular markers linked to genes controlling stem solidness. The DH population was genotyped using GWM and BARC microsatellite primers that spanned the wheat genome. To efficiently genotype the population, bulked segregant analysis (BSA) was used to identify polymorphism between groups of solid stem and hollow stem individuals. Four microsatellite markers (GWM247, GWM340, GWM547, and BARC77) were found linked to a single solid stem QTL (designate *Qss.msub-3BL*) on chromosome 3BL. However GWM247, GWM340, and GWM547 were found to be more closely linked to the QTL then BARC77. Single marker analysis showed *Qss.msub-3BL* contributes at least 76% of the total variation for stem solidness. Additionally, no significant relationship existed between *Qss.msub-3BL* and other agronomic traits, including yield. These microsatellite markers GWM247, GWM340, and GWM547 will be useful for selecting solid-stemmed wheat cultivars to help control the wheat stem sawfly.

## REGULATORY REQUIREMENTS AND CONSIDERATIONS DURING ANT BAIT DEVELOPMENT IN THE URBAN SETTING

David L. Cox

Syngenta Crop Protection, 14446 Huntington Rd., Madera, CA

Ants are the number one problem for professional pest control operators in the United States and result in the greatest number of "call backs" or retreatments to residential and commercial accounts. Customers and regulatory authorities have high expectations for ant control products. Therefore, the process for development of efficacious products is demanding. Syngenta has been developing ant baits for several years, and will share some of the challenges of bringing an ant

bait into this demanding urban market. In order to develop an ant bait, bait acceptance and efficacy must be demonstrated. Efficacy is defined in terms of speed and level of kill to workers, queens and colonies. With a "daughter" dosing system, bait attraction, placement and durability of bait are important parameters that affect efficacy and are tested to support label claims. Efficacy must be demonstrated with the major ant pests common to most regions of the U. S. In addition, data on ant species of regional importance is usually desired. The collection of efficacy data under GLP for those ants listed by the EPA as public health pests has important implications to researchers and manufacturers compiling these data. Finally, packaging is a critical process in the development of ant baits. Not only does packaging influence efficacy, it is also examined as part of the regulatory approval process.

## COMPARATIVE ANALYSIS OF THE INSECT COMMUNITY STRUCTURE ON *LEPIDIUM DRABA* IN ITS INDIGENOUS AND INTRODUCED RANGES

Michael G. Cripps[1], Jessica L. McKenney[1], Hariet L. Hinz[2], and Mark Schwarzlaender[1]

[1]University of Idaho, Plant Soil and Entomological Sciences Department, Division of Entomology, Moscow, ID

[2]CABI Bioscience Switzerland Centre, 1 rue des Grillons, 2800 Delémont, Switzerland

*Lepidium draba* L. (Brassicaceae) is an exotic perennial herb indigenous to Eurasia that successfully established in North America in the late 1800s. The niche saturation hypothesis predicts that in the indigenous range, long coevolved insect-plant relationships will result in niche saturation, and plants introduced to exotic ranges will 1) primarily be utilized by polyphagous species and 2) will be comprised of vacant niches. In 2002 and 2003, the insect community associated with *L. draba* was surveyed in the northwestern United States, and in its indigenous range in eastern Europe. The diversity of the insect community in the indigenous range was greater for both species richness and evenness. The community structure was predominated by polyphagous species in the introduced range and specialists in the indigenous range. Total insect abundance was greater in the introduced range, but differences in the insect diversity between origins was most strongly influenced by one dominant polyphagous herbivore, *Lygus hesperus* Knight, which represented over 50% of the total insect abundance in the northwestern U.S. However, an indigenous American species, *Ceutorhynchus americanus* Buchanan, was found utilizing the stems of *L. draba,* which demonstrates a host shift to a specialized niche on a related exotic plant. Guild analyses indicate that unoccupied niches exist in the introduced range, whereas niche saturation by specialist herbivores is evident in the indigenous range. Our data corroborate well with the niche saturation hypothesis and provide one mechanism that may be used to explain the invasiveness of *L. draba* in the northwestern U.S.

## USING SADIE (SPATIAL ANALYSIS BY DISTANCE INDICES) TO EVALUATE BIOCONTROL EFFICACY OF *MECINUS JANTHINUS* ON DALMATIAN TOADFLAX

Cale Davis[1,2], Sharlene Sing[1], and David Weaver[3]

[1]USFS – Rocky Mountain Research Station, Forestry Sciences Lab, Bozeman, MT
[2]Montana State University, Department of Mathematical Sciences, Bozeman, MT
[3]Montana State University, Department of Entomology, Bozeman, MT

Quantitative evaluations of biocontrol efficacy have relied on geostatistical interpolation methods such as kriging. However, such interpolation methods have proven to smooth insect density peaks. An ideal biocontrol assessment would take into consideration the weed spatial distribution with respect to the biocontrol agent spatial distribution. SADIE (Spatial Analysis by Distance Indices) computes a clustering value *v*, which is a quantitative measure of whether a weed or biocontrol agent is part of a patch or gap. After computing clustering values for both weeds and biocontrol agents, SADIE then performs a species association analysis. *Mecinus janthinus*, a stem boring weevil, is identified as the best available biocontrol agent against Dalmatian toadflax. *Mecinus janthinus* has been released at a number of sites across Montana with high toadflax infestations. SADIE analyses have been performed on data from all the sites to assess the individual spatial distributions of both *Mecinus janthinus* and Dalmatian toadflax. Inter-species association analyses have been performed to evaluate same year and consecutive year association between *Mecinus janthinus* and Dalmatian toadflax. As expected, *Mecinus janthinus* observed in 2002 cluster near the release point. In 2003, *Mecinus janthinus* spread out to form a less aggregated arrangement. Significant inter-species association has also been observed in the 2002 observations. However, association declined in the 2003 as insects spread from the release point.

## LABORATORY AND FIELD EFFICACY EVALUATIONS FOR THE CONTROL OF CARPENTER ANTS (*CAMPONOTUS MODOC, C. VICINUS*) IN CALIFORNIA

William A. Donahue, Jr.

Sierra Research Laboratories, 5100 Parker Road, Modesto, CA 95357

Several laboratory and field efficacy evaluations were developed to test candidate insecticide formulations as either contact toxicants or baits against carpenter ants. Initial screening usually was conducted in the laboratory using field collected ants (polymorphic workers) acclimated to laboratory conditions. Insecticide formulations were applied to selected substrates, such as wood, concrete and soil to determine residual activity after sustained outdoor exposure. Dose response bioassays were routinely employed to target field application rates supporting EPA registration and proposed product labeling.

Carpenter ant bait evaluations were conducted both in the laboratory (Modesto, CA) and under field conditions in the central Sierra Nevada foothills. Bait acceptance, worker recruitment, bait

consumption and toxicity was evaluated using several laboratory bioassays. Small laboratory carpenter ant colonies with workers and brood were often used to evaluate slower acting toxicants added to baits or to observe treatment effects on the colony over a period of days to weeks. Carpenter ant behavior was observed in both laboratory and field tests. Field evaluations of carpenter ant baits were conducted from spring through summer in the Sierra Nevada foothills to determine bait acceptance, worker recruitment, bait consumption and toxicity under field conditions. Single family dwellings were used as test sites for residual insecticide perimeter treatments and toxic bait evaluations in several Sierra Nevada foothill counties. Trail counts, food bait stations and visual observations were used to assess treatment success and ant behavior.

## SPATIO-TEMPORAL DISTRIBUTION PATTERNS OF THE CABBAGE SEEDPOD WEEVIL AND ITS PARASITOIDS IN CANOLA CROPS

Lloyd M. Dosdall[1], Bryan J. Ulmer[1], Héctor A. Cárcamo[2], and Dan L. Johnson[3]

[1]University of Alberta, Department of Agricultural, Food and Nutritional Science, Agriculture-Forestry Centre, Edmonton, AB
[2]Agriculture and Agri-Food Canada, Lethbridge Research Centre, Lethbridge, AB
[3]Department of Geography, University of Lethbridge, 4401 University Drive West, Lethbridge, AB

The cabbage seedpod weevil, *Ceutorhynchus obstrictus* (Marsham) (Coleoptera: Curculionidae), is native to Europe and has recently become an important pest of canola (*Brassica napus* L. and *Brassica rapa* L.) crops in western Canada. An analysis of weevil spatio-temporal population dynamics in relation to its parasitoids and crop phenology was undertaken to provide important foundation information for developing an integrated management strategy for this pest. Sweep net collections and samples from bowl traps held at the level of the crop canopy determined that adult weevil populations were initially clustered along field edges when crop plants were predominantly in the bud to early flowering stages. Adult distributions became more homogeneous in full to late flowering. Larval weevil populations were also clustered within fields, and on individual plants, larvae occurred more abundantly on lower regions of canola racemes than higher up. Highest densities of the larval ectoparasitoids, principally the eulophid *Necremnus duplicatus* Gahan and the pteromalids *Chlorocytus* sp. and *Trichomalus* sp., aligned generally but not precisely with those of the weevil. The spatial ecology of these herbivores and their natural enemies indicates that the potential exists for spatially targeted insecticide applications to minimize negative impacts on biocontrol agents.

## RESISTANCE TO CHLORONICOTINYLS IN PEAR PSYLLA, *CACOPSYLLA PYRICOLA*

John E. Dunley, Bruce M. Greenfield and Tara Madsen

Washington State University, Tree Fruit Research and Extension Center
1100 N. Western Ave. Wenatchee WA. 98801

Pear psylla (*Cacopsylla pyricola*) has developed resistance to most insecticides used for control of this key pest. Resistance to organophosphate and pyrethroid insecticides occurred rapidly, and high levels still occur. Over the last 15 years our laboratory has been monitoring local populations of pear psylla for resistance. During this time abamectin has been the primary control tactic, and despite considerable use and observed changes in field efficacy, resistance to abamectin has not been documented. The recent development of chloronicotinyl insecticides has provided an effective alternative to abamectin for pear psylla management.

To bioassay response to chloronicotinyls, ten adult females were placed on their backs on an adhesive covered microscope slide, dipped in the respective concentration of pesticide for 5 seconds, and allowed to air dry. These were stored at 70˚ F and high humidity. The subjects were then examined for death at 48 and 96 hours post treatment, and probit analysis was performed on the results.

Resistance or tolerance to two formulations of chloronicotinyls was observed in localized populations in 2004. This resistance was found in bioassays of overwintering adult females; subsequent bioassays using nymphal stages will be conducted this year to confirm these initial findings.

## AREAWIDE ORGANIC PEAR PEST MANAGEMENT: TWO-YEARS OF ORGANIC-ISH IPM

John E. Dunley, Tara M. Madsen, and Bruce M. Greenfield

Washington State University, Tree Fruit Research and Extension Center,
1100 N. Western Ave, Wenatchee, WA

Areawide management programs for insect pests of apple and pear in the Western US have been successful since their inception a decade ago, targeting codling moth through mating disruption to replace organophosphate insecticides. Pear psylla, another important pear pest, is also appropriate for areawide management, being highly dispersive with potential natural enemies in surrounding habitat. Establishing organic orchards among conventional orchards has been difficult: pests readily migrate from adjacent conventional orchards, yet natural enemy movement is limited by the pesticide barriers. Organic IPM on an areawide basis provides opportunities for immigration of biocontrol agents. In 2002, an Areawide Organic Management Program was established on 310 acres of contiguous pear, surrounded by native vegetation.

Organic IPM practices were implemented for insect control throughout the project. However, other organic practices were not required (e.g., nutrient, rodent, and weed management), and approximately 50% of the acreage was Certified Organic. Over two years, there was a reduction in pesticide use and insecticide costs, with no differences in pest densities. However, there have been no correlated increases in natural enemy densities. Fruit yield and quality have been maintained, and alternative marketing programs have been attempted.

## STRENGTH OF TARSAL ATTACHMENT TO LEAVES AND THE RATES OF PREDATION ON APHIDS: CONTRASTING THE ABILITIES OF NATIVE AND INVASIVE COCCINELLID SPECIES

Sanford D. Eigenbrode[1], Hongjian Ding[1], Bill Snyder[2], and Stanislav Gorb[3]

[1]University of Idaho, Department of Plant, Soil and Entomological Sciences, Moscow, ID. 83844-2339
[2]Washington State University, Department of Entomology, Pullman, WA 99164-6382
[3]Evolutionary Biomaterials Group, Max-Planck-Institut für Metallforschung, Heisenbergstr. 3, D-70569 Stuttgart, Germany

Ecological comparisons among exotic and native species can help decipher the basis of competitiveness and invasiveness. In the Palouse region of northern Idaho and southwestern Washington, exotic and native coccinellids co-occur. *Coccinella septempunctata* and *Harmonia axyridis* are present but have not overwhelmed native coccinellid species to the extent that they have in some other parts of North America. We compared these two exotic species and three native coccinellids for their ability to forage for aphids on pea plants and for their ability to attach to leaves differing in waxy blooms. Larvae and adults of *H. axyridis* and adults of *C. septempunctata* generated greater attachment forces to leaves of either wax type than did the other coccinellid species, which might contribute to their greater competitive ability. On the other hand, *H. axyridis* was relatively most strongly impaired by waxy blooms than the other species, suggesting its competitiveness could be compromised in settings like the Palouse, where much of the aphid resource occurs on peas and *Brassica* crops, which have waxy blooms. The tarsal morphology of larvae and adults of each species, as revealed by SEM, helps explain some of the patterns observed in attachment forces generated by each species.

## HABITAT DISPLACEMENT OF NATIVE LADYBIRDS BY THE INTRODUCED SPECIES, *COCCINELLA SEPTEMPUNCTATA*

Edward W. Evans

Department of Biology, Utah State University, Logan, UT

As the newly arrived, Palearctic ladybird beetle *Coccinella septempunctata* (Coleoptera: Coccinellidae) increased in numbers in alfalfa fields of northern Utah from 1992 to 2001, densities of native species and pea aphids (their principal prey in alfalfa) decreased**.** Field experiments with induced aphid outbreaks were conducted to test the hypothesis that dispersing native adults have shifted their foraging efforts away from alfalfa as the introduced species has increased in numbers and depressed prey availability. As predicted, native ladybirds rapidly re-accumulated in alfalfa when prey became abundant. Their presence was brief, however, as they and especially the more numerous *C. septempunctata* quickly suppressed experimental aphid outbreaks. In another field experiment in which numbers of both aphids and larvae of the alfalfa weevil (*Hypera postica*) were manipulated in plots, the results supported a second hypothesis that the presence of alternative prey (weevil larvae) may act to retain especially *C. septempunctata* in alfalfa even when few aphids are present. Hence, native ladybirds appear more responsive than the introduced species to local aphid density in particular, rather than to the densities of alternative prey. *C. septempunctata*'s impact on aphid density in alfalfa appears to have reduced significantly the degree to which the habitat retains foraging native adults, thus contributing to their decline and replacement by the introduced species in this habitat.

## ATTRACT-AND-KILL STATIONS SHOW PROMISE FOR REDUCING SPOTTED CUTWORM (*XESTIA C-NIGRUM* (L.)) IN WASHINGTON WINE GRAPE AND MINT

Holly Ferguson[1], Douglas Walsh[1], Tim Waters[1], Peter Landolt[2], and Ron Wight[1]

[1]Department of Entomology, Washington State University, 24106 N. Bunn Road, Prosser, WA
[2]USDA-ARS, 5230 Konnowac Pass Road, Wapato, WA

Cutworms are major springtime pests in wine grapes and mint in Washington State. A feeding attractant designed for the Lacanobia fruitworm (*Lacanobia subjuncta* (Grote & Robinson)) also attracts spotted cutworm, bertha armyworm, and others. We utilized this feeding attractant in attract-and-kill bait stations fashioned out of modified badminton birdies (after Peter Landolt) in a Semillon wine grape vineyard and a first-year peppermint field. In early September of 2003, bait stations were deployed in replicated 5-acre plots at density treatments of 0, 49, and 256 stations per plot. Spotted cutworm (*Xestia c-nigrum (*L.)) populations were monitored with feeding attractant, pheromone, and light traps ten days before deployment of bait stations in grape and mint plots. Monitoring of populations continued post-deployment for 11 days in grape and seven days in mint. Numbers of spotted cutworms caught in feeding attractant traps were significantly reduced after introduction of bait stations in both grape and mint ($p < 0.0001$), but there was no treatment effect in mint post-deployment as numbers of spotted cutworms were

reduced in feeding attractant traps in all plots, including the controls. Numbers of spotted cutworms increased in pheromone traps post deployment in both grape and mint, which indicated an overall increase in spotted cutworm populations in the area. Light trap catches of spotted cutworm were variable for both grape and mint. Based on these data, the bait stations should prove very useful in wine grape for non-chemical reduction of overwintering spotted cutworms.

## EVALUATION OF SOIL APPLIED INSECTICIDES FOR CONTROL OF GARDEN CENTIPEDES

C. Fouché, R. Mullen and D. Colbert

University of California Cooperative Extension, 420 South Wilson Way, Stockton, California

Experimental plots were established at Hal and Keith Robertson Farms, Tracy, California, in order to evaluate the effectiveness of eight different materials against the garden centipede (*Scutigerella immaculata*) in a commercial tomato field. The plot area was selected by evidence of garden centipede damage to the growers' original transplants. The treatments were randomized based on the severity of damage in the field, and all original plants were removed. Treatments 9, 10 and 11 were dissolved in water, with 10 oz. (295.7 ml) of solution applied to the soil immediately after transplanting. The solution was applied to the base of the plant and allowed to penetrate the soil profile to a level just below the plug. Treatments 1-6 were applied to the beds before the transplanting in an 18 inch band, and then roto-tilled into the soil using a BCS 14-hp rototiller. Treatments 7 and 8 were a combination with the first materials incorporated into the bed, and Calypso applied as a drench solution after transplanting. All materials were applied on May 12, 2003. The tomato plants, variety H-9780, were spaced 18 inches apart in a 60-inch-wide bed. Plot size was one bed by 20 plants in the row. The field was furrow irrigated immediately after the application to help the transplants establish in the field. Stand vigor was evaluated based on the growth and vigor of the plants outside of the affected area. Plots were harvested on June 26, 2003. All plants were harvested by cutting at the soil surface, and were weighed immediately. All of the treatments, except the Diazinon granular and Diazinon drench, provided acceptable control of damage from garden centipedes. The thorough incorporation of these materials prior to transplanting, and the drench application at transplanting, should give growers the ability to protect young plants once the materials are registered for these types of applications. It is not known whether these materials will perform as well should the growers choose to shank them into the beds at the same time they apply their spring pre-plant fertilizers. Large plot field trials are planned for 2004 to investigate the methods appropriate for the effective placement of these pyrethroid-type materials.

## ABUNDANCE AND DIVERSITY OF ARANEAE AND OPILIONES IN IDAHO ALFALFA

Mary M. Gardiner[1], James D. Barbour[1], and James P. Pitts[2]

[1]University of Idaho, Department of Plant, Soil, and Entomological Sciences,
Parma Research and Extension Center, Parma, ID 83660-6699
[2]Utah State University, Department of Biology, 5305 Old Main Hill, Logan, UT 84322-5305

Beat cloth sampling of the plant canopy and pitfall traps were used to compare the diversity and abundance of Araneae and Opiliones in treated and untreated alfalfa seed, alfalfa hay, and feral alfalfa. In alfalfa seed and hay fields, samples were collected at the field border and 10 meters into each field. In feral sites, plants were sampled at random as no field borders existed. Sampling was done every two weeks from 18 Jun. to 15 Aug. 2003. All Araneae and Opiliones collected were counted and preserved in 70% alcohol.

There was no difference in the mean number of Araneae or Opiliones present in pitfall traps or beat cloth samples collected from the field border compared with 10 meters into the field, therefore these data were pooled for further analysis. In both beat cloth samples and pitfall traps, the mean number of Araneae collected from alfalfa hay, treated and untreated alfalfa seed and feral alfalfa was significantly different ($P<0.0001$). In beat cloth samples, feral alfalfa had the highest mean number of Araneae/0.71 $m^2$. For pitfall traps, alfalfa hay had the highest mean number of Araneae/trap in each sample period. The mean number of Opiliones collected in pitfall traps was also significantly different between sites ($P<0.0001$). Like the Araneae, the mean number of Opiliones/trap was highest in alfalfa hay. Opiliones remained much lower in feral alfalfa and in treated and untreated alfalfa seed.

## EFFECTS OF INSECTICIDES ON THE NESTING BEHAVIOR OF THE ALFALFA LEAFCUTTTING BEE

Mary M. Gardiner and James D. Barbour

University of Idaho, Department of Plant, Soil and Entomological Sciences,
Parma Research and Extension Center, Parma, ID 83660-6699

Insecticides used to control alfalfa seed pests may disrupt pollinating activities of foraging *Megachile rotundata,* the primary managed pollinator of alfalfa seed in Idaho, by either killing the bees (lethal effects) or by affecting pollinating-related behaviors (non-lethal effects). We examined the lethal and/or non-lethal effects of several insecticides that are either currently labeled, or have potential to be labeled for use in alfalfa seed. Dimethoate, bifenthrin, indoxacarb and thiacloprid showed increasing mortality over the dosage ranges of our topical applications. No mortality was observed for pyriproxyfen, tebufenozide, buprofezin and novaluron when applied topically at 10 times the field rate. The amount of time *M. rotundata* treated with 7 μg/ml (= $LC_{10}$) bifenthrin spent inside holes in the nesting block, the propensity to

switch nesting holes, disappearance during the study, and the number of cells produced per day did not differ from that of untreated bees. The contents of cells produced did not differ with the exception of empty cells, which were significantly higher in nests provisioned by bees treated with bifenthrin. These data show that at a dosage of 7 µg/ml, bifenthrin has little effect on the nesting behavior of *M. rotundata*. It is possible that at a higher dosage synthetic pyrethroids like bifenthrin may affect nesting behavior and this is currently being investigated.

## THE IMPACT OF THE LOSS OF ORGANOPHOSPHATE INSECTICIDES ON CALIFORNIA AGRICULTURE: THE IMPACT ON ALFALFA

Larry D. Godfrey
Dept. of Entomology, University of California, Davis, CA

California produces about 15% of the alfalfa hay in the United States and alfalfa is produced in most counties in the state. Production of hay, of which nearly 85% is alfalfa hay, surpassed cotton production as the state's highest-valued field crop in 2001 and it is the third most important crop overall. In addition, alfalfa produces important feedstocks in support of the dairy industry, the top value agricultural enterprise in the state and for the beef cattle industry. The primary growing regions are the Central Valley region (San Joaquin and Sacramento Valleys), which produces 60% of the state's alfalfa hay crop, and the desert region, which produces 26% of the state's alfalfa hay crop. The remaining 14% of the acreage is in the coastal and intermountain areas. Insect pests can inflict significant damage to alfalfa with the pest spectrum and severity depending on the production area. Insect damage results primarily from defoliation from chewing insects and removal of plant fluids from piercing/sucking insects. The defoliating insects include the weevil complex, alfalfa weevil, *Hypera postica*, and Egyptian alfalfa weevil, *Hypera brunnipennis,* and lepidopterous larval complex including the alfalfa caterpillar, C*olias eurytheme,* western yellowstriped armyworm, *Spodoptera praefica,* beet armyworm, *Spodoptera exigua,* alfalfa looper, *Autographa californica,* saltmarsh caterpillar, *Estigmene acrea*, and others. The piercing/sucking insects include the pea aphid, *Acyrthosiphon pisum*, blue alfalfa aphid, *Acyrthosiphon kondoi*, cowpea aphid, *Aphis craccivora,* and spotted alfalfa aphid, *Therioaphis maculata*. Populations of other arthropod pests such as spider mites, leafhoppers, and silverleaf whitefly, occasionally build to undesirable levels and cause damage to alfalfa.

The pest management strategies used for the major insect pests of alfalfa hay have been recently detailed by Summers (1998. Integrated Pest Management Reviews. 3: 127-154). In summary, cultural controls, i.e., fertility and irrigation regimes, date of seeding, crop rotation, etc., play a minor role in IPM of alfalfa arthropod pests. Early harvest can be used to mitigate threshold levels of Egyptian alfalfa weevil larvae, but effects on alfalfa productivity lessen the use of this technique. Host plant resistance is a primary line of defense against the aphid pests of alfalfa; commercially available alfalfa varieties are rated and promoted in terms of aphid resistance. Resistance to the other arthropod pests, weevils, lepidopterous larvae, etc., is not available in commercial alfalfa cultivars. Biological control is exceedingly important in alfalfa. The short-term perennial nature of alfalfa facilitates the build-up of arthropod populations. A variety of generalist predators and specialized parasitoids exert important control on major arthropod

alfalfa pests. Preserving and encouraging populations of natural enemies is important for managing pests in alfalfa and for IPM from a regional perspective since alfalfa hay serves as a reservoir for beneficial insects for surrounding crops.

Insecticides are an important IPM tool in alfalfa, but not as commonly used as in other field crops or as in "higher value" vegetable and fruit crops. The reliance on other management strategies, and the higher tolerance for some arthropod damage in alfalfa compared with other crops, enables insecticides to be more judiciously used. In 2002, CA Dept. of Pesticide Regulation data showed that insecticide usage in alfalfa declined slightly (in terms of acres treated) compared with 2001 and there has been a steady decline (~20%) compared with 1998. Overall about 1.3 insecticide applications per acre were made state-wide to alfalfa. Insecticide use in pounds was reduced by 12% overall from 2001 and these decreases occurred in spite of an increase in acreage. Organophosphate insecticides are important components of management schemes in CA alfalfa. These materials have been under particularly strong scrutiny in alfalfa due to possible off-site movement into surface waters. Three of the most commonly used five insecticides in alfalfa (acres treated) were organophosphate insecticides in 2002. In addition, five of the top ten in terms of pounds active ingredient applied were organophosphate insecticides. New, reduced risk insecticides are being registered in alfalfa. Indoxacarb and tebufenozide were recently registered and indoxacarb usage in 2002 was nearly 100,000 acres. *Bacillus thuringiensis* products have been readily adopted by growers for use in alfalfa and in 2002 were used on ~75,000 acres. However, organophosphate insecticides are still cost-effective options in many pest management situations in alfalfa. Many species of natural enemies in alfalfa have reportedly built resistance to the OP materials and as such populations are not significantly reduced following application. The "fit" of OP insecticides in alfalfa is clearly understood, facilitated by years of use, research, and experience. In summary, the organophosphate insecticides are still important products for alfalfa production and this will likely continue until more reduced risk products are registered and their optimal use patterns clearly defined through research efforts.

## PLASTRON STUDIES OF *ABEDUS HERBERTI* EGGS (HEMIPTERA: BELOSTOMATIDAE)

Christine L. Goforth[1] and Art Woods[2]

[1]University of Arizona, Tucson, AZ
[2]University of Texas, Austin

Although common in terrestrial eggs, few aquatic insect eggs are known to have a plastron network. In the Belostomatidae, the back brooding Belostomatinae are thought to have none. Morphological examination of one belostomatine, *Abedus herberti*, suggests this is not the case. A microelectrode study was undertaken to determine whether the eggs are capable of binding a film of air, thus having a functional plastron network. Eggs of three different ages were used. Half were left unaltered and half were treated to remove the air film surrounding the eggs. The

eggs were submerged in water and an oxygen microelectrode inserted just below the egg surface. $O_2$ partial pressures were recorded. The eggs of *A. herberti* appear to have a functional plastron network at the beginning of development, but its ability to supply the egg with oxygen decreases sharply with age. It is likely the plastron is able to supply young embryos with oxygen, but as the demands of the embryo increase, the plastron is no longer able to make a difference in the internal partial pressure of oxygen of the eggs, rendering the plastron network non-functional for most of development.

## IMPACT OF ORGANOPHOSPHATE INSECTICIDES ON COTTON INSECT MANAGEMENT

Peter B. Goodell

University of California, Kearney Agricultural Center, 9240 South Riverbend Ave., Parlier, CA

Multiple insect classes attack California cotton including Hemiptera (*Lygus hesperus)*, Homoptera (*Aphis gossypii* and *Bemisia argentifolii*), Lepidoptera (*Spodoptera exigua*, *Pectinophora gossypiella*), Thysanura (*Frankliniella occidentalis)* as well as spider mites (*Tetranychus spp)*. This broad range of pests has various feeding habits, attacks all parts of the plant and occurs throughout the season. Managing such an array of insect and mite pests has been a major challenge since synthetic pesticides were introduced into the production system in the 1950s. The organophosphate insecticide class has been utilized in cotton pest control since the 1960s playing a key role as a replacement for the organochlorines such as DDT and toxaphene.

Organophosphates still play a key role in cotton pest control for particular pests such as aphids, thrips and worms but are less effective against Lygus, mites and whiteflies. New classes of insecticides and miticides are being introduced that are reduced-risk and more selective, especially against worms. However, aphid management still relies on organophosphates, especially very late in the production system when exposed cotton lint is most vulnerable to honeydew deposition. The major pest management issue for the cotton industry has become ensuring quality cotton through the prevention of sticky cotton.

Managing late season aphid populations with organophosphate alternatives is a challenge. For example, chloronicotinyl insecticides that rely on trans-laminar movement can be less effective late in the season when leaves have aged or dust builds on the leaf surface. Even when reduced-risk products are used mid-season, many of the organophosphate alternatives are slower acting, suggesting that populations should be managed at much lower densities then current decision-making guidelines indicate. Finally, as more reliance is placed on new chemistry, organophosphates can play an important role in managing insecticide resistance for these reduced-risk products by providing rotation options that utilize different modes of action.

## MANAGING LYGUS IN AN ECOLOGICAL CONTEXT

Peter B. Goodell

University of California, Kearney Agricultural Center, 9240 South Riverbend Ave., Parlier, CA

*Lygus hesperus*, the western tarnished plant bug, is an indigenous species in the San Joaquin Valley (SJV) of California. As agriculture developed in the SJV, *Lygus* became a key pest in many of the food and fiber crops introduced into the SJV. In addition to its pest status in cotton, alfalfa seed, cowpeas, lima beans, lettuce, and stone fruits, *Lygus* populations can develop on a wide variety of plants including weeds and crops.

One key ecological principle is the recognition of source and sink relationships between host availability and *Lygus* population dynamics. *Lygus* population densities dip to low levels during the winter as the insects overwinter as presexual adults in the Valley and in the rim of hills surrounding the SJV. Populations increase through the spring and summer and decline in September when day-length triggers a weak diapause. *Lygus* populations initially develop on spring weeds and move into crops as these weeds become unsuitable. Rainfall patterns can influence the weed community in an area, the duration of host suitability and thus, the potential localized population density. In the Mediterranean climate of California, all non-irrigated plant hosts rapidly become unavailable by late spring, forcing *Lygus* into developing crop hosts.

The crop mosaic within an area is spatially unique through time. As population densities reach their maximum in summer, many acres of crop hosts are being removed from the system as a result of harvest, concentrating *Lygus* into the fewer remaining acres. July is the month in which *Lygus* are most problematic in cotton fields located in landscapes that have little alfalfa hay. Populations can exceed threshold and require applications of broad spectrum insecticides that can result in secondary pest outbreaks or increase the risk for the development of insecticide resistance in other pests.

Alfalfa hay is a preferred host and will retain *Lygus* populations if managed. When as little as 2.5% of the field is left unharvested, sufficient habitat will be provided to retain *Lygus* and prevent movement into adjoining cotton fields. The reasons for alfalfa preference by *Lygus* are not fully understood but may include dense plantings that allow nymphs easy movement between plants, high humidity that reduces physiological stress, and abundance of floral buds. Alfalfa hay is the only crop widely grown in which the vegetative portions are harvested instead of reproductive structures. This is important since it prevents plants from going into physiological stress prior to harvest. Thus the plants are suitable, vigorously growing hosts up to the moment of harvest. Cutting appears to reset the generational development by allowing concentration of adults and perhaps $5^{th}$ instar as the surviving cohorts. When provided with minimal habitat refugia, movement from alfalfa to cotton by *Lygus* adults will be limited.

Our work continues to study the mosaic of crops that surround cotton fields and the influence of various crop associations on *Lygus* population densities and treatments in cotton. We are utilizing limited remote sensing but relying more on community participation to build current crop use maps and GIS mapping tools for analysis.

## THE IMPACT OF THE LOSS OF ORGANOPHOSPHATE INSECTICIDES ON CITRUS

Elizabeth E. Grafton-Cardwell

University of California, Department of Entomology, Riverside, CA 92521

San Joaquin Valley California citrus has experienced a dramatic reduction (>70%) in the annual use of organophosphate (OP) and carbamate insecticides since 1997. The primary reason for the change was the replacement of methidathion, chlorpyrifos, and carbaryl with the insect growth regulator (IGR) pyriproxyfen for control of California red scale and the replacement of formetanate and dimethoate with spinosad for control of citrus thrips. A number of California red scale and citrus thrips populations throughout the region had developed high levels of resistance to OP and carbamate insecticides. In citrus, we have observed several dramatic changes in pest complexes due to the shift from an OP and carbamate chemical control system to IGRs, neonicotinoids, pyrethroids and miscellaneous 'softer' chemistries. First, several insects, notably forktailed katydid and citricola scale, that were coincidentally controlled by the OPs and carbamates applied for thrips and red scale have been released from control. These pests lack effective biological control and the new insecticides are generally less effective in controlling them. Chlorpyrifos is still the most effective control agent for katydids and citricola scale. Because OPs have been used for many years in citrus, many of the natural enemies have developed resistance to them. Thus, chlorpyrifos can be very selective and IPM-friendly if used at low rates. In addition, the predatory vedalia beetle, which has kept cottony cushion scale under control for many years, is very sensitive to many of the new insecticides. If vedalia is eliminated by the new insecticides, then organophosphate or carbamate insecticides are needed to control the cottony cushion scale.

## VEDALIA BEETLE POPULATION RESPONSE TO PEST MANAGEMENT AND ENVIRONMENTAL CONDITIONS

Elizabeth E. Grafton-Cardwell

University of California, Department of Entomology, Riverside, CA 92521

Vedalia beetle, *Rodolia cardinalis* has been the primary natural enemy regulating populations of cottony cushion scale, *Icerya purchasi* Maskell in the San Joaquin Valley of California since it was introduced in the winter of 1888-89 from Australia. Periodically, vedalia populations have been disrupted by the introduction of new insecticides and outbreaks of cottony cushion scale resulted. For more than 30 years the primary insecticide classes used to control key pests of citrus have been organophosphates and carbamates. During 1997-2002, six new insecticides, toxic to vedalia, including the neonicotinoids imidacloprid and acetamiprid, the pyrethroids cyfluthrin and fenproparthrin, and the insect growth regulators pyriproxyfen and buprofezin, were registered and used for various pests in California citrus. Sporadic, serious outbreaks of cottony cushion scale occurred during this time and are likely to continue as vedalia adjusts to these insecticides. These recent cottony cushion scale outbreaks stimulated research on the

environmental factors influencing the success of vedalia beetle in the San Joaquin Valley. This region experiences extremes of winter and summer temperatures. Vedalia beetle populations decline in June or July even in the presence of adequate prey. The decline appears to be related to increasing temperature and lack of adult stages of cottony cushion scale for egg laying. In addition, the arrival of vedalia beetle in citrus orchards in the springtime varies widely from year to year, possibly affected by winter temperature. Growers can maximize the predatory effect of vedalia by introducing them to new cottony cushion scale infestations and by avoiding pesticide use during the critical months (Mar-May) before summer heat reduces vedalia growth and development.

## STATISTICAL ANALYSES TO DETERMINE EFFICACY OF ANT PESTICIDE TREATMENTS

Dr. Les Greenberg

Department of Entomology, UC Riverside, Riverside, CA 92521

Pesticide treatments of ants (and other insects) require estimating ant abundance before and after a treatment, or at regular posttreatment intervals. Due to the fact that we may be measuring the same foragers or colonies repeatedly over the course of the field trials, the subjects may not be independent of one another at the different test periods. Repeated Measures Anovas were designed for this situation of the repeated testing of subjects, and are common in the behavioral sciences. The simplest experimental design of this type involves a comparison of pre- and posttreatment variables using a paired t-test, or the nonparametric equivalent, the Wilcoxon Paired Ranks test. Repeated Measures designs are necessary when there are more than two comparisons or time periods. (Split-plot designs are an equivalent procedure for analyzing these data.) Repeated Measures designs are a subset of a "profile analysis", and when there are both grouping and time variables, they can be illustrated by a regression line for each group over time. Three major hypotheses can be tested with these designs: (1) the lines are not horizontal (i.e., there is a treatment effect); (2) the lines are at different heights (i.e., the grand means are different); and (3), the lines are not parallel (i.e., the treatment effect is not the same for the different groups). The importance of these three hypotheses depends on the nature of the experiment. However, applying this analysis to real data can be difficult. We frequently encounter data with periodic "ups and downs", making difficult the interpretation of these data profiles. Furthermore, in these analyses the degrees of freedom for the error term for group differences depends on the number of plots, and frequently we do not have 8-10 plots per treatment, which would be necessary for the test to have adequate statistical power. I discuss the advantages and disadvantages of some other approaches to analyzing these data, such as simple comparisons of each posttreatment variable with its pretreatment value. Another approach is to analyze the differences from the pretreatment values at each subsequent date. Finally, ANOVAs at each time period can show where differences between the groups were evident.

## MYCOSIS OF THE WHEAT STEM SAWFLY (HYMENOPTERA: CEPHIDAE) BY *FUSARIUM* SPP.

William E. Grey[1], Anna Wenda-Piesik[2], Wendell L. Morrill[3], and David K. Weaver[3]

[1]Dept. of Plant Sciences and Plant Pathology, Montana State University, Bozeman, MT
[2]Dept. of Soil and Plant Cultivation, University of Technology and Agriculture, Bydgoszcz, Poland
[3]Department of Entomology, Montana State University, Bozeman, MT

*Fusarium pseudograminearum* (Gr1), *F. culmorum, F. avenaecum, F. equiseti*, and *F. acuminatum* were isolated from larval cadavers of field-collected wheat stem sawfly, *Cephus cinctus* Norton (Hymenoptera: Cephidae), in Montana. Healthy larvae were inoculated in vitro with a series of ten-fold concentrations from $10^1$ to $10^8$ macroconidia per ml, as a topical application, and mortality was recorded on a daily basis. *F. culmorum* was highly virulent on the diapausal larvae at the concentrations from $10^4$ to $10^8$ in less than 10 days. *F. pseudograminearum* (Gr1) and *F. avenaceum* at the highest concentration required 8 days for larval mortality. *F. acuminatum* and *F. equiseti* required 15 and 12 days, respectively, for a lethal reaction on diapausal larvae at the highest concentration. In greenhouse and field experiments, spring wheat plants inoculated with *F. avenaceum, F. pseudograminearum (Gr I) or F. culmorum* and infested with adult sawfly had a higher larval mortality than plants inoculated with *F. acuminatum*, *F. equiseti* or non-inoculated plants. Plants with symptoms of Fusarium crown and stem rot had a higher incidence of larval mortality than non-symptomatic plants containing sawfly larvae. Isolation and identification of the *Fusarium* species from the larval cadavers confirmed pathogenicity in laboratory, greenhouse and field experiments.

## USE OF OLFACTORY CUES FOR NEST RECOGNITION: BEHAVIORAL AND CHEMICAL EVIDENCE

Christelle Guédot[1], Theresa L. Pitts-Singer[1], James Buckner[2], Jordi Bosch[1], and William P. Kemp[1]

[1]USDA-ARS Bee Biology and Systematics Laboratory, Department of Biology, Utah State University, Logan, UT

[2]USDA-ARS Biosciences Research Laboratory, Fargo, ND

The use of olfactory cues for nest recognition by the solitary bee *Osmia lignaria* was studied in greenhouse environment in Logan, UT during spring 2003. The greenhouse was planted with *Phacelia tanacetifolia* and contained an observation room. Twenty-five glass tubes were suspended perpendicularly from the central wall of the observation room for bees to use as nesting cavities, so that in-nest behavior could be observed. Each glass tube had been cut into three sections: an outer section (2 cm) opening to the greenhouse, a middle section (4 cm), and an inner section (8 cm) plugged at the end. We observed that nesting females drag their abdomen

along the tube before exiting, sometimes depositing tiny fluid droplets from the tip of the abdomen. During manipulations we recorded the behavior exhibited by tested females upon arrival to the nesting site and inside the nesting tubes. Three treatments were conducted in which we removed and replaced by similar clean glass tube sections: 1) the outer section; 2) the middle section; 3) both sections. In the control treatment we disassembled and reassembled the glass tube. The confusion displayed by females returning to nests after non-control treatments clearly indicates the presence of some olfactory cue used for individual nest recognition. The presence of chemical compounds was confirmed using gas chromatography. The identification of those compounds using mass spectrometry is in progress.

## PLANT RESPONSES TO BIOTIC AND ABIOTIC STRESSORS: CHANGES IN PLANT TOLERANCE AND FITNESS FROM INSECT DEFOLIATION AND MOISTURE STRESS INJURIES

Fikru Haile

Dow AgroSciences, Western Research Center, 7521 West California Avenue, Fresno, CA 93706

Plants face multiple stresses that can limit their growth, development, and fitness. Little research has focused on understanding the interactions of arthropod injury and abiotic factors such as moisture stress. Knowledge of the combined effects of biotic and abiotic factors is crucial to our understanding of plant tolerance to arthropod injury. This is because plant tolerance to arthropod injury is greatly mediated by environmental variables. Studies have been conducted in soybean, sunflower, and wheat to understand how arthropod injury and moisture stress affect plant tolerance and fitness. These studies indicate that plants grown under optimal environmental conditions tolerate arthropod injury better than plants grown under sub-optimal or stress conditions.

## PERFORMANCE OF INTREPID*, METHOXYFENOZIDE, AGAINST THE WESTERN YELLOWSTRIPED ARMYWORM, S*PODOPTERA PRAEFICA*

Fikru Haile, Randy Smith, Gary Thompson, and Jesse Richardson

Dow AgroSciences, Western Research Center, 7521 West California Avenue, Fresno, CA 93706

Intrepid, methoxyfenozide, belongs to a new class of growth regulator insecticides from Dow AgroSciences. This product is considered “green chemistry” because of its reduced environmental risk. This class of chemistry was a recipient of Presidential Green Chemistry Challenge Award in 1998. The primary target pests of methoxyfenozide are Codling moth, Cotton Bollworm (Corn Earworm) Tobacco budworm, and Beet Armyworm primarily in apple, cotton, and vegetables. Although methoxyfenozide has a broad Lepidopteran spectrum, its efficacy against Yellow striped Armyworm, *Spodoptera praefica,* has not been well studied.

Current studies were conducted to determine the relative efficacy of methoxyfenozide against Western Yellow striped Armyworm.. Intrepid 2F provided excellent control of Western Yellow striped Armyworm and Beet Armyworm. Intrepid 2F, which is reasonably priced for use in alfalfa and cotton, provides another tool for controlling Lepidopteran pests and for rotation to avoid resistance selection.

* Trademark of Dow AgroSciences.

## EFFICACY OF INTREPID*, METHOXYFENOZIDE, AGAINST PEACH TWIG BORER, *ANARSIA LINEATELLA,* AND NAVEL ORANGEWORM, *AMYELOIS TRANSITELLA* IN ALMOND AND PISTACHIO

Fikru Haile, Barat Bisabri, and Mark Hertlein

Dow AgroSciences, Western Research Center, 7521 West California Avenue, Fresno, CA 93706

Intrepid, methoxyfenozide, belongs to a new class of growth regulator insecticides from Dow AgroSciences. This product is considered "green chemistry" because of its reduced environmental risk. This class of chemistry was a recipient of the Presidential Green Chemistry Challenge Award in 1998. Studies were conducted in California to evaluate the performance of Intrepid 2F against peach twig borer, *Anarsia lineatella* in almonds and navel orangeworm, *Amyelois transitella*, in pistachios. Intrepid 2F provided significantly better control of *A. lineatella* and *A. transitella* compared to the standard treatments. Comparison of bloom time applications in almonds showed that split applications, two half rates each applied at 30 and 70% of *A. lineatella* emergence from hibernacula, provided better control than single full rate application at either 30 or 70% of *A. lineatella* emergence. Intrepid 2F, which has an excellent activity against these Lepidopteran pests is also safe to honey bees for bloom time application in almonds. Dow AgroSciences provides environmentally safe and price competitive product(s) to manage broad-spectrum insect pests in various crops.

* Trademark of Dow AgroSciences.

## EFFECTS OF SPOTTED KNAPWEED INVASION ON GROUND BEETLE (CARABIDAE) ASSEMBLAGES IN ROCKY MOUNTAIN SAVANNAS

Allison K. Hansen and Diana L. Six

College of Forestry and Conservation, University of Montana, Missoula, MT

Spotted knapweed, an exotic plant that has invaded much of the western United States and Canada, alters environmental characteristics and severely reduces native plant diversity and abundance. In order to investigate impacts of spotted knapweed on savanna communities we

initiated a study comparing ground beetle (carabid) diversity and abundance in invaded and un-invaded communities. Environmental variation is important in shaping carabid species assemblages, and in turn changes in abundance and distribution of particular species can indicate changes in environmental conditions. There was no significant difference in species richness and evenness between invaded and un-invaded sites; however, when species were delineated into trophic groups evenness was significantly higher in three of the four un-invaded sites. Indicator values (IndVal) were calculated for all species based on eight partitions for all sites and species assemblages were identified per partition. Species assemblages clumped by environmental tolerances. Comparison of indicator species biologies to site and/or site groupings and results from non-metric multidimensional scaling (MDS) reveal that carabid assemblages are primarily shaped by soil texture, litter layer (litter, bare ground), and plant structure, and not by whether the site is invaded or not. Assemblages among invaded sites differ dramatically along a moisture gradient, however, they related to each other in preference to litter and vegetative structure.

## CARPENTER ANT: BEHAVIOR, SPECIES RECOGNITION AND GEOGRAPHICAL DISTRIBUTION AS IT RELATES TO CONTROL

Laurel D. Hansen

Biology Department MS 3180, Spokane Falls Community College, 3410 W. Fort Wright Drive, Spokane, WA 99224

The three most important carpenter ant species occurring in the Western United States are *Camponotus modoc, C. vicinus,* and *C. essigi.* Other species occurring less frequently are *C. laevigatus, C. herculeanus,* and *C. noveboracensis.* The latter two species are found in Washington , Oregon, and Idaho and only *C. herculeanus* is found in northern British Columbia and Alaska. Of the first three, *C. modoc* most often nests in sound wood and inhabits areas with high humidity; *C. vicinus* nests in wood with some degree of wood decay and is frequently found in drier, warmer areas. *C. essigi* is considered a nuisance pest rather than a structurally damaging organism. Within structures it is found in attic areas and foraging occurs within the structure after December. In May or June, this ant leaves structures and is found in evergreen trees. Parent colonies of all species are more frequently found outside the structure, with satellite colonies inside structures. The number of satellite colonies varies from southern to the northern states with more satellite colonies found in the northern areas. Although all species may frequent water and sugar sources within structures before swarming, seasonal foraging occurs outside the structure on aphids and other insects during the foraging season. Because ants leave the structure to forage and to maintain contact between parent and satellite colonies, baits placed on the exterior of the structure and perimeter sprays are effective control strategies.

## HEAT TREATMENTS IN SUSTAINABLE MANAGEMENT SYSTEMS

Arnold H. Hara

University of Hawaii, Dept. of Plant and Environmental Protection Sciences
461 West Lanikaula St., Hilo, Hawaii 96720

Heat treatments offer a sustainable pest management practice for pests of floriculture crops. Most insects on or in flowers, foliage and roots, including ants, foliar and root aphids, armored scales, soft scales, foliar and root mealybugs and whiteflies are killed at 49 °C (120 °F) from 5 to 12 minutes. Hot water treatment has been observed to improve the postharvest quality of certain cut flowers and foliage by protecting against physiological disorders, enhancing natural resistance to pathogen infection and/or reversibly inhibiting maturity. The limiting factor for disinfesting cut flowers and foliage with hot water is phytotoxicity to certain plant species including anthurium, dendrobium orchid and protea. Certain cut flowers, such as red gingers, are more susceptible to heat injury during the cold, rainy season. Conditioning flowers in hot air at 39 to 40 °C (102 to 104 °F) for 2 h or in hot water at 40 °C for 15 min before hot water treatment [49-50 °C (120-122 °F) for 10-12 min] eliminates acute phytotoxicity in red ginger during the cold, rainy season and in certain cut foliages. Probably, heat shock proteins in flowers and foliage are produced by conditioning in hot air; these induce heat tolerance. Growers who adopted the heat treatments report increased benefits with lower labor cost and increased environmental protection. For example, with the implementation of a hot water treatment for a flower exporter, disposal of pesticide solutions have been reduced by 175 gallons per week.

## CANADIAN PERSPECTIVE ON WSS

Scott Hartley[1] and Scott Meers[2]

[1]Insect / Vertebrate Pest Management Specialist, Crop Development Branch, Saskatchewan Agriculture, Food and Rural Revitalization, 125 - 3085 Albert Street, Regina, Saskatchewan, S4S 0B1, Canada
[2] Pest Risk Management Specialist, Entomology, Crop Diversification Centre South, Alberta Agriculture, Food and Rural Development, SS #4, Brooks, Alberta, T1R 1E6, Canada

The Canadian Prairies have had a long history of problems with Wheat Stem Sawfly since Criddle first noted sawfly as a wheat insect in Manitoba. Since that time the pest has gone through several outbreaks. In between these outbreaks Wheat Stem Sawfly becomes an almost invisible quantity, almost completely disappearing from the wheat production scene. The current outbreak is now several years old and has nearly reached the extent of its historical range. A new generation of producers is now struggling with management options. Leading the way is the use of solid stem wheat, but producers are looking to embrace a wide array of possible management tools. A recently produced forecast map shows the situation for 2004 appears to be

worse again than last year and we can expect the Wheat Stem Sawfly to be one of the major wheat pests of this coming summer.

## TILLAGE ACROSS CROPS DIFFERENTIALLY AFFECTS THE CAPTURE EFFICIENCY OF PITFALL TRAPS FOR GROUND BEETLES

Timothy D. Hatten, Nilsa A. Bosque-Pérez, and Sanford D. Eigenbrode

University of Idaho, Department of Plant, Soil and Entomological Sciences,
P.O. Box 442339, Moscow, ID 83844-2339

Tillage effects within and across crops on the capture efficiency (CE) of pitfall traps for three species of ground beetles (Coleoptera: Carabidae) were studied at the Kambitsch Research Farm, Idaho. Beetles were released in equal numbers into 1.69m$^2$ cages containing traps. The cages were situated within conventional (CT) and no-till (NT) plots of spring peas and spring wheat. Beetles were captured, counted and re-released daily throughout the remainder of six experiments. Beetle gender had no significant influence on CE. Tillage, however, significantly influenced CE for each species examined, but the effect of tillage differed with crop. In wheat, the proportions of *Poecilus lucublandus* (Say), *Poecilus scitulus* (LeConte) and *Pterostichus melanarius* (Illiger) re-captured were significantly greater in CT than in NT in at least half of the experiments. In peas, the proportion of *P. scitulus* and *P. lucublandus* re-captured was greater in NT than in CT. Data loggers deployed during the experiments indicated that temperature and humidity at the soil surface differed between tillage and crop systems. These variables were correlated with the CE of individual species, suggesting a mechanism for the differential effects of tillage on the CE of ground beetles.

## EVALUATION OF POSTHARVEST TREATMENTS TO BULK CITRUS FOR CONTROL OF THE GLASSY-WINGED SHARPSHOOTER, *HOMALODISCA COAGULATA*

David R. Haviland[1] and Nick Sakovitch[2]

[1]UC Cooperative Extension – Kern County, 1031 S. Mount Vernon, Bakersfield, CA 93307
[2]UC Cooperative Extension – Ventura County, 669 County Square Drive, #100,
Ventura, CA 93003

State regulations require that bulk citrus leaving a geographic area infested with glassy-winged sharpshooter (GWSS), or transiting an area under an active government GWSS control program, be free from this pest. Currently, there are no economically feasible post-harvest treatment programs capable of cleaning up bulk citrus after harvest. We conducted six experiments to test EverGreen® (pyrithrins + pipronyl butoxide) and chlorine (used in packing houses) as post-harvest treatments for GWSS in bulk citrus. In drench experiments, EverGreen provided some, but not complete control of GWSS. Chlorine had little to no effects on mortality even when sprayed directly on the insects. Two hours after treatment, fogging experiments with EverGreen in a citrus degreening room resulted in 100% mortality to GWSS in cages outside of bins, but

only about 80% of GWSS inside of bins. An additional experiment on holding periods showed that 60% of cages with GWSS in lemon bins still had at least one survivor 24 hours after being placed within the bin and shipped from Ventura to Kern County, California.

## BARK AND WOODBORING BEETLES ASSOCIATED WITH WESTERN JUNIPER AND RESPONSES TO HOST VOLATILES AND WOUNDING

Jane L. Hayes[1], Patricia L. Johnson[1],
Andris Eglitis[2], Donald W. Scott[3], Lia H. Spiegel[3], Craig L. Schmitt[3], Steve E. Smith[4]

[1]Pacific Northwest Research Station, Forestry and Range Sciences Laboratory,
1401 Gekeler Lane, La Grande, OR
[2] Central Oregon Insect and Disease Service Center, 1645 Highway 20 East, Bend, OR
[3]Blue Mountains Pest Management Service Center, 1401 Gekeler Lane, La Grande, OR
[4]School of Natural Resources University of Arizona, 325 Biological Sciences East, Tucson, AZ

Western juniper (*Juniperus occidentalis*) forests have increased in density and in acreage throughout their distribution. In central Oregon, management activities by landowners and resource managers have included use of prescribed fire and mechanical treatments to control western juniper. After these treatments several species of bark and woodboring beetles have been observed on dead and dying trees and also on occasional live trees outside of management areas. In this study we characterize insects that attack western juniper and assess if these naturally occurring disturbance agents can be predictably manipulated for use in juniper management. Using funnel traps baited with host volatiles, including juniper berry oil, cade oil and ethanol, we compiled a comprehensive list (25 species in 21 genera) of bark and woodboring beetles in Scolytidae, Buprestidae, and Cerambycidae and of known predators in Trogositidae, and Cleridae. Cedar bark beetles, *Phloeosinus spp.* (Scolytidae), which have been reported to kill juniper, were the most prevalent insects captured on sticky traps attached to trees treated with host volatiles and/or wounded by pruning. These beetles showed highly significant treatment effects; treatments with ethanol plus wounding were most attractive. However, there was little damage and no insect-caused mortality of treated trees in either year of this study.

## EFFECTS OF TILLAGE ON WHEAT STEM SAWFLY SURVIVAL AND EMERGENCE IN THE CENTRAL HIGH PLAINS

Gary L. Hein[1], John A. Thomas[1], Walt Stroup[2]

[1]University of Nebraska-Lincoln, Panhandle Research and Extension Center,
Scottsbluff, NE 69361
[2]University of Nebraska-Lincoln, Department of Statistics,
103 Miller Hall, Lincoln, NE 68583

The wheat stem sawfly, *Cephus cinctus* Norton, has occurred in southeastern Wyoming and the western counties of Nebraska since the mid 1980s. The wheat stem sawfly has long been present in this region but for years was not considered a significant problem; however, through the last few decades sawfly occurrence has resulted in severe losses in many years. Most of the severe losses, however, have remained confined to localized hot spot areas. Apparently, this problem has resulted from the sawfly adapting to the seasonal synchrony of the winter wheat in this region.

The objectives of our study were to determine the seasonal occurrence of the sawflies in western Nebraska and the impact of tillage on sawfly emergence. Tillage treatments included no-till, summer blading (occurring just after harvest), spring disking, summer blading plus spring disking, and moldboard plowing. A randomized complete block design was used and replicated four times. Sawfly emergence was monitored with screen covered cages ca. 0.4 $m^2$, and sawfly infestations in the winter wheat growing adjacent to the treatment plots were also monitored. Tillage significantly reduced emergence of wheat stem sawfly and the infestations in the adjacent wheat. Treatments that included spring disking had the greatest impact on sawfly populations, reducing infestations in adjacent wheat by 77%. Compared to the no-till plots, the cumulative effect of the tillage plots was effective in reducing sawfly infestations over two years. Peak emergence during the years sampled occurred between May 25 and June 7. This corresponded with the early heading stages of the wheat. In addition to a direct effect on survival, tillage also had an impact on emergence rate. The spring disking delayed emergence by about 8 days compared to the no-till and summer blading alone. The faster development of the sawfly in the no-till and summer bladed plots may be a factor in the adaptation of the sawfly winter wheat in the region.

## SUSTAINABLE BIOLOGICAL CONTROL BASED IPM IN GREENHOUSE GROWN ORNAMENTALS

Kevin M. Heinz

Department of Entomology
Texas A&M University
College Station, TX 77843-2475

The use of biological control-based IPM programs has remained more of a concept than a reality in greenhouse grown ornamentals. There are a multitude of possible explanations for this absence, but most revolve and center on ease of use, economic feasibility, and sustainability within normal cultural practices. We have addressed these concerns in greenhouse grown poinsettias and chrysanthemums, and have developed practices that are easy for growers to implement, equivalent or less than the cost of traditional pesticide based control strategies, and are robust across most of the production zones within the Southern United States. Integration of commercially available parasitoids with compatible insecticide application practices have generated practical means for poinsettia growers to reduce their reliance on prophylactic insecticide applications. Proper timing of predatory mite releases have lead to lasting biological

control programs in potted foliage. These biological control based practices fit well with changes in state regulations that embrace IPM practices for remediation of pest problems in Texas greenhouses and nurseries.

## OVIPOSITIONAL RESPONSES OF NAVEL ORANGEWORM TO GROUND ALMOND, WALNUT AND PISTACHIO KERNELS

Bradley S. Higbee

Paramount Farming Company, 33141 E. Lerdo Hwy., Bakersfield, Calif., 93308

The navel orangeworm, *Amyelois transitella*, is an important pest of almonds, pistachios and figs, affecting nearly 1 million acres in California. Current monitoring tools rely on the almond-based fatty acid complex as oviposition attractants. Eggs laid by female moths on traps baited with the attractant are counted to establish a biofix and to track flight patterns and intensity. Due to differential attractiveness over time and between crops, this system lacks the resolution required to predict relative damage risk. In an effort to improve this monitoring tool, the relative attractiveness of ground almond, walnut and pistachio kernels to navel orangeworm was compared in laboratory and field tests, using both egg traps and universal moth traps. With one exception, navel orangeworm (NOW) females laid more eggs on, or were captured in higher numbers in, traps baited with pistachio relative to almond or walnut. This trend was consistent in lab studies and field studies in both almond and pistachio orchards, except for the period from March to June in pistachio orchards. During this period, more females were captured in moth traps baited with almond relative to pistachio. Ground almond baited moth traps had better linear correlation to nut damage than pistachio in both crops.

## PLANT-INSECT ECOPHYSIOLOGY: WHERE ARE WE GOING?

Leon G. Higley

Department of Entomology, University of Nebraska-Lincoln, Lincoln, NE 68583-0816

Although the term interaction refers to mutual influences, when it comes to insects and plants, interest in how plants affect insects has tended to dominate research. But the other side of this question – how insects alter plant physiology, yield, and fitness – is gaining the attention it deserves. For certain types of insect injury, like defoliation, and certain types of plant response, like photosynthesis, broad understandings are emerging. Even some previously intractable systems, like plant responses to sucking injury, now seem accessible and offer the potential for understandings transcending a single plant-insect species combination. Moreover, new insights into the biochemical and genetic basis of plant stress from heat, water deficits, and diseases provide a foundation for examining insect-induced stress. These conceptual advances coupled

with new experimental opportunities in biochemistry and molecular biology provide exceptional opportunities for understanding the plant side of plant-insect interaction relationships.

## LEAVES AND STEMS: POTATO RESPONSE TO INSECT AND ARTIFICIAL DEFOLIATION

Wyatt Hoback

Department of Biology, University of Nebraska-Kearney, NE 68849

Research on Midwestern potato has been limited and growers are currently dependent on conservative economic thresholds to prevent insect damage. Over the past four years, photosynthetic response of potatoes to insect defoliator injury; yield and quality response of potatoes to simulated defoliation; and photosynthetic, yield, and quality responses to infestation by second-generation European corn borer larvae have been examined. As in other crops examined to date, injury from insect defoliation is primarily a function of light interception by the remaining leaf area. The injury caused by red-legged grasshopper (*Melanoplus femurrubrum*) showed no significant change in photosynthetic rates by remaining leaf tissue. A series of leaf removal experiments to simulate insect defoliation injury showed significant yield loss only in an indeterminate variety at high levels of defoliation. High defoliation also reduced number and weight of large tubers and increased in the number of small tubers. In contrast, infestation by European corn borer (ECB) infesting potato crops affected photosynthetic rate, yield and quality. ECB infestation at about 30% infested stems in some varieties resulted in economic loss. The results of these studies provide a better understanding of yield losses in potato crops in response to leaf feeding and stem boring insects.

## RECENT PROGRESS TOWARDS CLASSICAL BIOLOGICAL CONTROL OF THE WHEAT STEM SAWFLY

Kim A. Hoelmer[1], Thomas G. Shanower[2], and Marie-Claude Bon[1]

[1] USDA-ARS European Biological Control Laboratory, Campus International de Baillarguet, Montferrier-sur-Lez 34980, France
[2] USDA-ARS, 1500 N. Central Ave., Sidney, MT 59270, USA

Wheat stem sawfly, *Cephus cinctus,* is a key pest of wheat in the northern wheat belt of the U.S.A. and Canada. A morphologically similar (and possibly synonymous) species, *C. hyalinatus*, feeds on wild grasses in northeastern Asia (old records exist from Siberia and northern Japan) but it is not recorded as a pest of wheat in the region. Specimens of *C. hyalinatus* were recently found in surveys conducted in northern China. A related species, *C. fumipennis,* is a pest of wheat in northern China, but not in Siberia. The genetic variability of samples of *C. cinctus* from 48 localities in North America was assessed using PCR amplification

of a region within the COI gene. The analysis suggests that several distinct groups of *C. cinctus* are present in the U.S. Addition of Asian *Cephus* species to the phylogenetic analysis is in progress. We review the status of foreign exploration for *Cephus hyalinatus*, *C. fumipennis* and their natural enemies in Asia. An undescribed species of *Collyria* (Hym.: Ichneumonidae) is the only parasitoid thus far reared from field collections of overwintering *C. fumipennis* in China. Progress in evaluating this potential new biological control agent for *Cephus cinctus* is summarized.

## ELECTROPHYSIOLOGICAL RECORDINGS AND SCANNING ELECTRON MICROSCOPIC STUDY OF THE ANAL STYLI OF *HOMALODISCA COAGULATA*

N. A. Hummel, W. S. Leal, C. Y. S. Peng, F. G. Zalom

University of California, Davis, Department of Entomology
One Shields Avenue, Davis, CA 95616

The anal styli of both male and female *Homalodisca coagulata* (Cicadellidae: Proconini) (Taylor) were examined using a sensory physiology device originally designed for electroantennography (EAG) and a Hitachi S3500-N scanning electron microscope (SEM). This may be the first time EAG recordings have been taken of an insect anal stylus. The strongest electrophysiological response of the anal stylus was to water on filter paper. The scanning electronmicrographs revealed that the anal styli are covered with large-sized mechanosensory hairs, a large number of small hygroreceptive sensilla, and brochosomes. Each hygroreceptive sensillum is located in a pit from which protrudes a varying number of finger-like projections. The pit is often blocked by masses of brochomes and an unidentified dense material that appears to be produced by the sensilla. The sensilla type is most likely coeloconic, which is typical for hygroreceptive sensilla. One possible function of these sensilla may be for the detection of moisture levels of the host. *H. coagulata* are xylem feeders and may select hosts based on water content. Also, it is hypothesized that the presence of hygroreceptors on the anal styli is somehow coordinated with the production of brochosomes by nymphal and adult *H. coagulata*.

## SCREENING CANDIDATE FUNGICIDES FOR CONTROL OF CHALKBROOD DISEASE IN ALFALFA LEAFCUTTING BEES (*MEGACHILE ROTUNDATA*)

Craig Huntzinger, Rosalind James, Jordi Bosch, and William P. Kemp

USDA-ARS Bee Biology and Systematics Laboratory, Department of Biology,
Utah State University, Logan, UT

Chalkbrood, a bee disease caused by pathogenic fungi of the genus *Ascosphaera*, is one of the major mortality factors in alfalfa leafcutting bee populations managed for alfalfa pollination. Methods to effectively control the chalkbrood problem remain elusive. We studied the effect of

four fungicides, Benlate®, Rovral®, Captan®, and Orbit™ on: 1) growth inhibition in cultures of *Ascosphaera aggregata*, 2) adult bee mortality from topical fungicide applications, and 3) larval mortality and incidence of chalkbrood from fungicide applications incorporated into the pollen provision. Benlate, Rovral and Orbit were able to achieve 90% inhibition of fungal growth at concentrations of 5.65μg a.i./ml, 17.6μg a.i./ml, and $1.21 \times 10^{-6}$μl a.i./ml, respectively. Applications incorporating Benlate (1.2mg a.i./μl) and Rovral (0.8mg a.i./μl) into pollen provisions significantly increased the number of healthy larva and significantly decreased the incidence of chalkbrood when compared to the controls.

## UTILIZING GEOSPATIAL TECHNOLOGIES IN USDA'S NATIONAL TICK SURVEILLANCE PROGRAM

Angela James[1], Jerome Freier[1], James Keirans[2], Lance Durden[2], Jack Schlater[3], and James Mertins[3]

[1]USDA, APHIS, VS, CEAH, 2150 Centre Ave, Bldg B, Fort Collins, CO
[2] Georgia Southern University, IAP, Georgia Ave, Statesboro, GA
[3]USDA, APHIS, VS, NVSL, Pathobiology Laboratory, 13th and Dayton Road, Ames, IA

Geospatial technologies have had an important impact on the study of vector-borne diseases. We are using geospatial methods to determine the distribution of arthropod vectors affecting humans and livestock. Because ticks are important vectors of pathogens, knowledge of the geographic distribution of ticks and tick-borne pathogens in the United States is important in developing targeted surveillance and control strategies. Therefore, a National Tick Survey was initiated by USDA-APHIS to assess the geographic distribution of tick species that are injurious to livestock, equids, and poultry.

We have established a geographic database derived from records from the Smithsonian's U.S. National Tick Collection and USDA's National Veterinary Services Laboratories tick identification program to determine the distribution of 34 economically important tick species. This information is not only used to update distributions, but it is also combined with data on climate, vegetation, soil, elevation, and land use to identify environmental factors that may characterize present and future tick distributions.

*Dermacentor andersoni,* the Rocky Mountain Wood tick, and *Dermacentor variabilis*, the American Dog tick, are important vectors of anaplasmosis and two of five tick species chosen as part of the first phase of this project. Several county-level maps have been produced for *D. andersoni* and *D. variabilis* and these will be discussed in addition to host associations and relative abundance of each tick species. Using the information from the two large national tick databases, we attempted to estimate the influence of several climatic factors on the distribution of each tick species. We will discuss the possible effects of temperature, elevation, precipitation, and vegetation on the survival and distribution of the Rocky Mountain wood tick and the American dog tick in the United States. In addition, we will discuss the interactive nature of a website in development to disseminate information to the general public on the life cycles, host

associations, seasonal activity, identification keys, and distribution maps of several tick species in the United States that are of veterinary importance.

## TEMPERATURE AND CHALKBROOD INCIDENCE IN THE ALFALFA LEAFCUTTING BEE

Rosalind R. James and Craig Huntzinger

USDA-ARS Bee Biology and Systematics Laboratory
Logan, UT

*Ascosphaera aggregata*, the causative agent for chalkbrood in the alfalfa leafcutting bee (*Megachile rotundata*), is a major mortality factor when the bee is used as a pollinator in commercial fields. We tested the effect of temperature on *A. aggregata* hyphal growth, spore germination, and disease incidence. The lowest incidence of chalkbrood occurred at 35°C, yet this temperature was the optimum for fungal germination and growth on agar, and is stressful to the insect. Sporulation of *M. rotundata* cadavers that were infected with the fungus was highest at 25°C. Daily exposures to 40°C for 6 h did not affect disease incidence, but it negatively impacted spore production. A similar disease response to temperature has been seen by others for this bee, and other *Ascosphaera* spp in other bees, but it is not clear why the greatest likelihood for mycosis does not occur at either optimum temperatures for the fungus, or the temperatures most detrimental to the insect. A few hypotheses have been proposed, but empirical data are lacking.

## TOXICOLOGICAL IMPACTS OF THE POLLUTANTS SELENIUM AND MERCURY AT THE BOTTOM OF THE FOOD WEB

Peter D. Jensen and John T. Trumble

Entomology, University of California, Riverside CA 92521, USA

Selenium and mercury are significant anthropogenic pollutants in the western United States. We investigated the individual effects of the most prominent forms of these pollutants on the bottom of the food web in two representative ecosystems. The primary test organisms were *Megaselia scalaris*, a terrestrial detritivore, and *Culex quinquefasciatus*, a common vector of encephalitis. For *M. scalaris*, we found an LC50 value of 258 µg/g (wet weight) for selenate. We also found that larval development time was significantly increased with exposure to selenate at 100 µg/g and above, and that it affected the developmental rates differently in males and females. The LC50 value for methyl mercury was much lower for *M. scalaris* at 14 µg/g. Larval development time was significantly increased at only 10 µg/g, and puparial development time was also

significantly increased at 20 µg/g. However, methyl mercury did not affect the developmental rate of the sexes differently. For *C. quinquefasciatus*, we found an LC50 value of 11.8 µg/g for selenate in addition to delays in development, with a significantly different Growth Index value at the lowest level tested (2 µg/g). Methyl mercury affected *C. quinquefasciatus* at a much lower concentration, with an LC50 value of 46.42 µg/kg, but did not cause any significant delays in developmental time. In addition to these results, joint toxicity data for the two toxicants and two test organisms are discussed.

## MECHANISMS OF TOLERANCE TO ARTHROPOD HERBIVORY

John T. Trumble and Peter D. Jensen

Entomology, University of California, Riverside CA 92521, USA

Plant compensation for arthropod damage is a general occurrence and of considerable importance in both natural and agricultural systems. Plant species that can tolerate or compensate (e.g. recover equivalent yield or fitness) for herbivore feeding have obvious selective advantages leading to genotype maintenance and productivity. This presentation covers some of the historical problems that have impeded our understanding of compensation mechanisms, as well as both the endogenous (within plant control) and exogenous (outside of plant control) factors that affect these mechanisms. While our knowledge of mechanisms resulting in tolerance or compensation is increasing rapidly, our ability to predict the levels of compensation which will occur in any given system is still relatively poor. In most plant systems, interactions between available nutrients, timing and intensity of defoliation, water stress, plant competition etc. are highly significant, in other systems such interactions appear minimal. Thus, until a much more substantial data base is developed, few generalizations regarding the ecological or agricultural importance of compensatory responses will be forthcoming. Indeed, development of general theories on plant compensation will rely on the recognition that a broad range of responses are probable in differing ecosystems.

## CONSERVING NATURAL ENEMIES TO CONTROL LYGUS IN ALFALFA SEED PRODUCTION FIELDS IN WASHINGTON STATE

Ann E. Jorgensen and William E. Snyder

Department of Entomology, Washington State University, Pullman, Washington 99164

Alfalfa seed production is an integral part of agriculture in Washington State, grossing over 12 million dollars per year. Lygus are a particularly damaging pest that currently must be controlled using broad-spectrum insecticides. However, growers must balance lygus control and the conservation of beneficial pollinators. Through the 2003 summer frequent sampling was performed in alfalfa seed and hay fields. Seed fields had high pesticide input while hay fields had

little or no input. Growers achieved low lygus densities in seed fields compared to the untreated hay fields. However, seed growers experienced severe late-season outbreaks of pea aphid, apparently induced by the disruptive effects of insecticides on aphid natural enemies.

## RED IMPORTED FIRE ANT (*SOLENOPSIS INVICTA)* ERADICATION (FACT OR FICTION) IN THE URBAN AND NURSERY SETTINGS

John Kabashima

UC Cooperative Extension, 7601 Irvine Blvd., Irvine, CA 92618

The initial California infestation in Orange County that triggered the current Red Imported Fire Ant (RIFA) quarantine in California was discovered in 1998. A survey of Southern California following the initial discovery found RIFA in five counties: Los Angeles, Orange, Riverside, San Bernardino, Sacramento and San Diego, isolated agricultural areas of Kern, Fresno, Madera and Stanislaus counties. In Southern California, state and federal officials have placed Orange County and portions of Los Angeles County and Riverside County under a RIFA quarantine. The quarantine limits the movement of items such as baled hay and baled straw stored on the ground, bee hives from RIFA infested states, soil, and requires commercial nursery growers shipping from quarantine areas to treat all potting soil following USDA treatment protocols, to ensure their products are free of RIFA. It is believed that the infestations in Southern California may have come from infested nursery stock from the southeastern states. Almond orchard infestations in the agricultural regions of California's San Joaquin Valley have been traced back to colonies that hitchhiked on beehives shipped to California from Texas.

Infestations in the San Joaquin Valley orchards and in southern California nurseries have been successfully eradicated, however, urban infestations have proven more difficult to eradicate. The California Department of Food and Agriculture convened a panel of nationally recognized experts in December of 1998. This Science Advisory Panel expressed reservations about the possibility of eradicating RIFA from California. In subsequent meetings, in May of 2000 and March of 2003, the panel expressed the belief that considerable progress had been made and emphasized the need for emphasis on detection to document the efficacy of the eradication efforts as the density of ants decreased.

The Orange County program has been recognized for their effective use of GPS technology and approach of treating an entire area if six or more colonies are discovered in a small area, rather than treating only individual yards when there are multiple colonies. Extensive experience with RIFA in southern California indicates that the dry desert climate has limited RIFA to irrigated landscape areas. The low humidity has also severely impacted their ability to fly long distances and mate in the air over large areas. These factors combined with the effectiveness of the IGR and hydramethlnon baits indicate a strong probability that RIFA populations can be reduced below economically important levels or eradicated.

## INTERACTIONS BETWEEN INDIGENOUS AND INTRODUCED LADYBIRDS IN JAPAN

Yukie Kajita

Department of Agriculture, Yamagata University, Tsuruoka, Yamagata, Japan
Department of Biology, Utah State University, Logan, UT

We examined the effects of the native Japanese ladybird species, *H. axyridis* (Ha), *C. septempunctata* (Cs) and *P. japonica* (Pj), on the development and survival of the exotic species, *A. bipunctata* (Ab) larvae in relation to food availability. In addition, we investigated the effects of Ha and Cs on the oviposition behavior of Ab. The number of aphids was dramatically decreased in the presence of Ha or Cs, but many more aphids remained when only Ab or Pj were present. The survivorship of Ab from second instar to adulthood was significantly reduced in the presence of Ha, but not in the presence of Cs or Pj. Most deaths were the result of IGP, especially when Ha was present. Ha and Cs suffered very high mortality in this experiment, but survived better when reared with Ab than when reared only with conspecifics. Pj survived better when kept with conspecifics than with Ab. In particular, Pj was much more likely to die of apparent starvation when it was kept with Ab than when it was kept alone. The number of eggs laid by Ab females over a 30-day period differed significantly when placed with females of Ha and/or Cs. Our results may bear on the questions of why Ab has not established more successfully in Japan and why Ha and Cs are so successful in establishing themselves in North America.

## ENHANCING THE SUSTAINABILITY OF BIOLOGICAL CONTROL IN GERBERA

Roy Kaspi and Michael P. Parrella

Department of Entomology, University of California, One Shields Avenue, Davis, CA 95616

The serpentine leafminer, *Liriomyza trifolii* (Burgess) is a cosmopolitan pest of ornamental and vegetable crops in the field and glasshouse. Damage is caused mainly by larvae feeding on the leaf tissue which form serpentine mines that widen as the larvae grow. The most promising non-chemical control tactic used in greenhouses is the regular release of the parasitoid *Diglyphus isaea.* However, the use of parasitoids for biological control of leafminers may be more practical and efficient when supplemented with additional control strategies, such as the Sterile Insect Technique (SIT). In the SIT, a large number of mass-reared insects are sterilized and released into an area populated by the pest. The wild population has to be overwhelmed with high quality compatible sterile males, which allow the sterile males to compete with the wild males for copulation with wild females. The objectives of our study were to determine the feasibility of using the SIT method to control *Liriomyza* leafminers. In addition, the hypothesis that an Integrated Pest Management (IPM) approach that combines the augmentative release of *D. isaea* together with sterile *L. trifolii* males are compatible and more efficient than the use of either alone, was examined.

## EVALUATION OF SURROUND KAOLIN CLAY FILM AS A MANAGEMENT TOOL FOR ROOT WEEVILS IN STRAWBERRIES

Diane Kaufman [1], Wei Yang [1], Judy Kowalski [1], and Glenn Fisher [2]

[1] Oregon State University, North Willamette Research and Extension Center (NWREC), 15210 NE Miley Rd, Aurora, OR
[2] Oregon State University, Department of Crop and Soil Science, Corvallis, OR

Surround kaolin clay particle film, in two formulations, was applied to strawberry plants at NWREC every week from bloom (4/15/03) to the first week of September to determine if the white clay residue would affect adult root weevil movement, feeding behavior and/or reproduction. The experiment was conducted in a third year planting of 'Totem' strawberry that was infested with strawberry root weevils (*Otiorhynchus ovatus*). Adult root weevil movement was monitored from early June to mid-August with the use of pitfall traps (12 per plot) examined twice per week. Numbers of adult weevils, carabids and spiders were recorded. Because adult root weevils produce marginal leaf notching when feeding, the number of notched leaves counted in two minutes per plot was recorded in June and July. Finally, in March 2004, three plants per plot were shoveled out of the beds with roots and surrounding soil left intact. Plants and soil were carefully screened and numbers of root weevil larvae recorded by treatment to determine if there was a treatment effect on reproductive activity.

There were no statistically significant differences in numbers of adult root weevils caught in pitfall traps, numbers of notched leaves, or in numbers of live larvae among treatments.

There were also no differences among treatments in number of carabid ground beetles or spiders recovered from pitfall traps. Mean weekly numbers of carabid ground beetles recorded from pitfall traps remained fairly consistent, ranging from a low of 60 to a high of 97. The predominant carabid ground beetle was *Pterostichus melanarius*. Spider counts peaked during the first week of June (mean of 88), and then declined steadily each week to a low of 6.5 in August. Hunting spiders dominated trap catches early in summer, giving way to web weavers through the summer.

## VISUAL STIMULUS, AND POTENTIAL EFFECTS ON MATING DISRUPTION OF THE WESTERN POPLAR CLEARWING MOTH

Neal T. Kittelson, Eugene R. Hannon and John. J. Brown

Washington State University, Department of Entomology, Pullman, WA

The Western Poplar Clearwing Moth (WPCM) [*Paranthrene robiniae* (Hy. Edwards)] is a brightly colored, diurnal moth. Larvae of the WPCM can severely damage stands of hybrid poplar trees used for high quality paper pulp and non-structural saw timber. Conventional pesticides have had little effect in controlling WPCM. We have implemented a mating

disruption strategy for WPCM control. A question we have when considering the disruption of WPCM with a pheromone-based strategy is: Do the male WPCM use any visual cues to find mates? If male WPCM use visual cues to find mates, this may lead to lower success of mating disruption. In 2002 we performed preliminary experiments using various colored traps to explore the idea of visual attraction. These initial experiments lead us to believe male WPCM may use visual stimulus along with pheromone cues to find mates. We followed up with a more extensive series of experiments in 2003. We used traps painted similar to the moth's coloration and 'normal' traps with various combinations of the pheromone lure to determine the effect visual stimulus has on the male WPCM. The series of traps was also repeated with acetate sheets with life size pictures of the female WPCM.

## PHARAOH'S ANT AND ODOROUS HOUSE ANT BEHAVIOR AND CONTROL MEASURES

John H. Klotz

Department of Entomology
University of California, Riverside

The Pharaoh's ant, *Monomorium pharaonis* (Linnaeus), and odorous house ant, *Tapinoma sessile* (Say), share certain characteristics that contribute to their importance as structural pests and the difficulty in controlling them. For example, both species are polygynous and undergo fission during colony multiplication. Their high reproductive rates and colony budding can lead to infestations that are distributed throughout a building complex. Laboratory and field experiments have demonstrated the effectiveness of slow-acting toxicants and residuals as control measures. A summary will be given of these two species nesting and foraging behavior as well as several recent laboratory and field studies on controlling them.

## TRACKING NON-RESIDENTIAL PESTICIDE USE IN URBAN AREAS OF CALIFORNIA

Nila I. Kreidich[1], Cheryl Wilen[2], Mary Lou Flint[3], and Minghua Zhang[4]

[1]University of California, Department of Land, Air, and Water Resources,
One Shields Avenue, Davis, CA 95616
[2]IPM Advisor, UCCE, San Diego County, 5555 Overland Ave, San Diego, CA 92123
[3]IPM Education and Publications, Department of Entomology, One Shields Avenue, Davis, CA
[4]Department of Land, Air, and Water Resources, One Shields Avenue, Davis, CA 95616

The amount of pesticides used in urban non-residential areas of California is unknown. The objective of this study is to expand our understanding into non-residential urban insecticide and herbicide user groups. This information will be used to develop an education/ outreach strategy

to reduce pesticide use in urban areas. A portion of urban pesticide use is reported to the California Department of Pesticide Regulation (CDPR), but an unknown percentage remains not reported. The major groups that do not report pesticide use are the following: residential use, industrial use, institutional use, non-reporting professional landscapers, maintenance staff at any non-farm private establishment, and pet groomers/ kennels. The Pesticide Use Report (PUR) database from CDPR was used to identify the primary urban pesticide user groups who reported use in Sacramento, San Diego, and Orange counties from 1993 until 2002. A PUR-GIS application was used to manipulate data from the PUR database. The major pesticide groups that report use include: structural pest control operators, professional landscape gardeners, public agencies or local districts conducting public health or regulatory pest control, and rights-of-way pest control operators. Of these categories, structural pest control accounts for the greatest percentage of pesticide use and is the most accurate estimate of use because most pesticide applications are reported. Pesticide use for structural pest control has been declining since 1993 and pyrethroids are replacing the use of organophosphates in Sacramento, San Diego, and Orange counties. Dry wood termites are a major pest in the southern coastal counties; as a result, fumigant use is much greater in San Diego and Orange County than in Sacramento County. In the landscape maintenance category, herbicides and fungicides predominated over insecticides. According to 2002 PUR data, among the top twelve pesticides used for landscape maintenance, 47% are herbicides, followed by fungicides (33%), insecticides (11%), molluscicides (6%), and fumigants (3%). Glyphosate accounts for over 60% of the herbicides reported under landscape maintenance. Over the past ten years the use of diazinon and chlorpyrifos has gradually declined in all areas; there is no clear trend among replacement insecticides. For rights of way, virtually all of the reported pesticide use was herbicides. Vector and mosquito control districts are the primary users under public health pest control. Regulatory pest control includes the control of invasive species. Future surveys will document the use and disposal practices of user groups that do not report pesticide use.

## EVALUATION OF IPM PRACTICES FOR CONTROLLING THE SPREAD OF TOMATO SPOTTED WILT VIRUS IN TOMATOES

Gregory Kund, William Carson, and John Trumble

Department of Entomology, University of California, Riverside CA 92521

Until recently, sustainable, low input IPM strategies for tomato production in California's $350 million industry have been widely adopted. Pesticide use on tomatoes declined by nearly 50% from the late 1980s to the late 1990s. In addition, a greater proportion of the remaining materials in use are environmentally-friendly products. However, these recent gains are at immediate risk because of the development of large populations of Western flower thrips (*Frankliniella occidentalis* Pergande) and the losses associated with tomato spotted wilt virus (TSWV). Growers in California have suffered major economic losses. As a result of the thrips and TSWV problems, growers are dramatically increasing pesticide use. The loss of biological control agents usually results, causing outbreaks of secondary pests such as *Liriomyza* leafminers and spider mites. The situation is further complicated by only being able to apply pesticides with

short harvest intervals during the picking season. This cycle is threatening to eliminate the practice of sustainable IPM programs, and promoting rapid development of resistance. We report here on results of IPM practices designed to minimize these problems.

## MOTHS TRAPPED WITH THE FEEDING ATTRACTANT ACETIC ACID AND 3-METHYL-1-BUTANOL

P. J. Landolt

USDA-ARS, 5230 Konnowac Pass Road, Wapato, WA 98951

With the testing of volatile odorants from fermented molasses headspace, the combination of acetic acid and 3-methyl-butanol was found to be attractive to several pest species of moths. Several tests have been conducted to determine what types of moths can be trapped with this lure. These include season-long studies to determine the phenology of response, and studies in different habitats and in different geographic areas. Generally, many more individual moths are caught in traps baited with this lure in late summer. Most species are Noctuidae, although several species of Thyatiridae and Pyralidae also have been captured. Many species of noctuine, hadenine, and amphipyrine noctuids have been trapped. Pest species responding to this lure include species of Agrotis, Xestia, and Euxoa, as well as *Mamestra configurata*, *Lacanobia subjuncta*, and *Pseudaletia unipuncta*.

## REDUCED RISK, REDUCED TOXICITY AND BIORATIONAL PESTICIDES: THEIR ROLES IN GREENHOUSE IPM SYSTEMS

Richard Lindquist

Senior Technical Manager, Olympic Horticultural Products, 1594 Sunset LN, Wooster, OH

Insect and mite management on most greenhouse ornamental crops cannot easily be accomplished using biological controls alone. Pesticides must be used at some point to either obtain or maintain pests at non-damaging levels, whether this “damage” is actual plant injury or mere visible presence of the pests. On the other hand, relying only on conventional chemical pesticides to do the job has not been a total success either, as the major pest groups attacking greenhouse crops are notorious for their ability to become pesticide resistant.

Because of the above, it would seem obvious that one way to accomplish more stable and sustainable insect and mite pest management programs for greenhouse crops would be to integrate the use of introduced (or conserved) beneficial organisms and certain pesticides that were not unduly harmful to them. Most of the participants in this symposium are working toward this goal. Integration has become easier to accomplish – in theory at least – because of the registration of more reduced risk, reduced toxicity and biorational pesticides to replace

carbamate and organophosphate products. Of course there still are numerous pyrethroid products available, but it is possible now to produce a greenhouse ornamental crop without using any of these last three product classes, which generally are quite harmful to beneficial insects and mites.

Some of the questions that will be addressed include the following:

1. Are these reduced risk, reduced toxicity and biorational products as effective as conventional pesticides?
2. Will using these products make pesticide resistance less likely?
3. Are these products less harmful to beneficial organisms used for biological control? Can they be integrated without any restrictions?
4. What are some examples of how these products can be, and are being, used in commercial greenhouses?

## HOST SPECIFICITY TESTING OF *ACERIA DRABAE* (ERIOPHYIDAE) FOR THE BIOLOGICAL CONTROL OF *LEPIDIUM DRABA* (BRASSICACEAE)

J. L. Littlefield[1] and J. Kashefi[2]

[1]Montana State University, Department of Entomology, P.O. Box 173020, Bozeman, MT 59717
[2]USDA-ARS European Biological Control Laboratory, Greece Field Station, Thessaloniki, Greece

*Lepidium draba* L. (Brassicaceae), commonly known as whitetop, is a perennial weed introduced from Eurasia. This plant reproduces from seeds and a spreading root system, forming dense monocultures in rangeland, pastures and croplands. To date, no biological control agent has been introduced into North America, although one promising agent is the gall mite *Aceria drabae* (Nal.) (Eriophyidae). *Aceria drabae* has been found in Eastern Europe and Eurasia. Mites induce leafy galls on the stems or in inflorescences, which either stunts the plant or reduces seed formation. Although the mite has been reported on a number of mustard species, field observations indicate that the mite has a narrow host range. Host specificity testing of 53 species/varieties of economic and weedy mustards thus far confirms these field findings. Additional testing of native mustards, especially those closely related to whitetop or of threatened and endangered species, still needs to be conducted before the mite can be petitioned for field release.

## THE ROLE OF SOURCE-SINK MANIPULATION BY RUSSIAN WHEAT APHID IN END-PRODUCT INHIBITION OF PHOTOSYNTHESIS IN WHEAT

Tulio Macedo[1] and Leon G. Higley[2]

[1]Montana State University, Department of Entomology, 333 Leon Johnson Hall, Bozeman, MT

[2]University of Nebraska-Lincoln, Department of Entomology, 202 Plant Industry Building, NE

The mechanism underlying the leaf-feeding aphids' reductions in photosynthesis is still unclear. Although much research has focused on how injury affects chlorophyll and other features of light reactions, recent studies suggest other physiological processes may be more immediately associated with injury. We examined the influence of Russian wheat aphid, *Diuraphis noxia* Mordvilko, on photosynthetic processes of wheat seedlings under different light regimes. Gas exchange, A-$C_i$ response curves, total chlorophyll content, chlorophyll *a* kinetic, and nonstructural carbohydrate concentrations in injured leaves were determined at 3, 5, 7, and 9 d after aphids were introduced on plants maintained at 24:0, 16:8 , and 0:24 light:dark. In 24:0 and 16:8 treatments at 3 days post infestation, greater accumulation of non-structural carbohydrates were observed than in controls. This measured increase in end products of photosynthesis was coincident with decreased photosynthesis and increased quenching, but without changes in chlorophyll content or integrity of light reactions as measured by fluorometery. These results are consistent with end product inhibition of photosynthesis associated with altered source-sink relations arising from aphid injury.

## SEX ATTRACTION IN *POLISTES DOMINULUS* (HYMENOPTERA: VESPIDAE) DEMONSTRATED USING Y-TUBE AND PARALLEL TUBE OLFACTOMETERS

John K. MacKenzie[1], Peter J. Landolt[2], and Richard S. Zack[1]

[1]Washington State University, Department of Entomology, Pullman, WA
[2]USDA-ARS, 5230 Konnowac Pass Rd., Wapato, WA

Y-tube and parallel tube bioassays were performed using male and virgin reproductive female *Polistes dominulus* Christ during late summer and early autumn 2003 in Pullman, Washington. The wasps were reared from nests collected in the middle of August and housed in separate rooms to prevent possible exposure to sex pheromones. The wasps were kept at 22$^{o}$C under natural light and provided a 10% molasses solution in water, as well as distilled water. In the Y-tube bioassay, males did not respond to other males; however, they were significantly repelled by virgin females. Conversely, virgin females showed a strong attraction to males and did not respond to other virgin females. Pheromonal responses demonstrated with the Y-tube olfactometer were evaluated also in a parallel tube olfactometer. In the parallel tube bioassay, the forward movement of wasps was measured under timed conditions. Movement of males upwind towards females was not different than to controls. Similarly, movement of females upwind towards males was not different than to controls. However, the percentage of females that reached the end of the olfactometer tube while moving towards males was significantly greater than the percentage of females moving toward the control.

## SUPPRESSION OF MELON FLY IS AS SIMPLE AS 1, 2, AND 3

R.F.L. Mau, R. Pandey, and M.Y. Chou

Department of Plant and Environmental Protection Sciences, University of Hawaii at Manoa, 3050 Maile Way, Honolulu, Hawaii 96822, maur@ctahr.hawaii.edu

The melon fly, *Bactrocera cucurbitae*, is the most harmful pest of cucurbit and melon crops in Hawaii. It is one of four tephritid fruit fly pests found in Hawaii. Melon fly is the first species targeted by the multi-agency areawide suppression program. At the onset, growers reported losses 40-60% of harvested yields. This loss did not include the infested fruit that did not reach maturity. The technology transfer program was implemented in demonstration zones on the Hawaiian islands of Maui and Oahu. The program is now being implemented to interested growers and home gardeners. In addition to establishing a monitoring program, step-wise implementation of the following technologies was performed. Only three suppression tactics were needed. They were 1) field sanitation; 2) environmentally safe GF-120 spinosad bait sprays; 3) male annihilation with the male parapheromone cue-lure. Geographical positioning systems (GPS) and geographical information systems (GIS) were used to follow and manage the suppression program. As a result of the program, melon fly populations are at an all-time low. Peak male populations at the start of the program in 2000 were 100, and 135 flies/trap/day, respectively at Kula, Maui and Ewa, Oahu. Adult population densities were reduced to less than 20 flies/trap/day, and total (immature and mature) fruit infestations were usually less than 5%.

## IMPACT OF *BEAUVERIA BASSIANA* ON LYGUS POPULATIONS

Michael R. McGuire[1] and Jarrod Leland[2]

[1]USDA-ARS, 17053 North Shafter Ave., Shafter, CA
[2]USDA-ARS, Stoneville, MS

*Beauveria bassiana* is an entomopathogenic fungus that has been widely studied. Commercial products based on the fungus are used for control of glasshouse pests and, at times, rangeland pests in the US. Previous studies with *B. bassiana* against Lygus spp. have yielded pretty good laboratory results, but activity in the field was less than satisfactory. Several authors have postulated that strains of entomopathogenic fungi isolated from the target pest from their environment should be more suitable for use as microbial pesticides than other strains of the same fungus.

In an attempt to find natural enemies of *Lygus hesperus* (CA) and *Lygus lineolaris* (MS), collections of adult bugs were made and held in the laboratory. In California, collections were made throughout the San Joaquin Valley and at several spots in the Delta region of Mississippi at various times of the year. In California, at least a few adults from all collections were infected

with *B. bassiana* and infection levels were as high as 65% in some fields. In Mississippi, adults were not as widely infected, but *B. bassiana* was found.

Isolates from these collections were cultured and screened for a variety of factors including: insecticidal activity ($LC_{50}$ and $LT_{50}$) against both *L. hesperus* and *L. lineolaris*, ability to grow *in vitro* at high temperatures, presence of beauvericin (with R. Plattner, ARS-Peoria, IL), activity against natural enemies, survival of spores in simulated sunlight, and potential for mass production (with S. Jaronski, ARS-Sidney, MT). In addition, seven SSR markers were used to analyze the genetic relatedness of the isolates (with M. Ulloa and Y.H. Park, ARS-Shafter, CA). All tests were done in parallel with the commercial isolate (GHA).

Currently, we are focusing on two new isolates, one from California and one from Mississippi. The isolates have approximately 10 fold higher activity and a 1 day faster activity than the commercial isolate, GHA; grow at 35° C, unlike GHA; beauvericin production is not different among the three strains; activity against natural enemies is similar; and spores survive in simulated sunlight the same or better than GHA. Preliminary information indicated that the two new strains produce fewer spores than GHA under semi commercial production conditions. The SSR markers suggest that isolates from the SE US are genetically distinct from most of the California isolates. The GHA isolate was intermediate between the two groups.

Both new isolates and GHA will be field tested in July 2004. Hay alfalfa will be treated because *L. hesperus* is not considered a pest and populations can reach high densities, which may then migrate into cotton. *L. lineolaris* builds up on field side weeds such as pigweed before moving to cotton. Therefore, populations of *L. lineolaris* will be treated on pigweed. Genetic markers will be used to determine which isolate caused infection in post treatment samples.

## INCREASED GROWTH VIGOR OF THE MUSTARD *LEPIDIUM DRABA* L. PROVIDES SUPPORT FOR THE ENEMY RELEASE HYPOTHESIS

Jessica L. McKenney[1], Michael G. Cripps[1], Hariet L. Hinz[2], and Mark Schwarzlaender[1]

[1]Department of Plant, Soil, and Entomological Sciences,
University of Idaho, Moscow, ID 83844-2339
[2]CABI Bioscience Switzerland Centre, 1 Rue des Grillons, 2800 Delémont, Switzerland

Heart-podded hoary cress (*Lepidium draba* L.) is an invasive perennial mustard that was introduced to North America in the late 1800s from Eurasia. One mechanism proposed to explain plant invasions is the enemy release hypothesis. The hypothesis states that plant species introduced to an exotic region will experience an increase in distribution and abundance as a result of decreased regulation by host-specific insect herbivores. In 2002 and 2003, we collected data on plant vigor and insect herbivory at 72 heart-podded hoary cress populations in the northwestern U.S. and seven European countries. We compared *L. draba* biomass and shoot density per unit area, *L. draba* cover, and specialist insect herbivore diversity and attack rates among populations in the native and exotic range. *L. draba* biomass was approximately three

times greater in the exotic compared to the native range. Similarly, shoot density per unit area was three times higher in the U.S. Thus, the higher biomass values in the exotic range can be explained through the higher shoot density. Additionally, there were significant differences in specialist insect herbivore attack rates between the exotic and the native range with greater rates in the native range. Our results indicate increased growth vigor and decreased regulation by specialist insect herbivores of *L. draba* in the exotic range, thus providing support for ERH.

## IMPACT OF HARVEST PRACTICES ON WHEAT STEM SAWFLY PARASITOIDS

Scott Meers

Pest Risk Management Specialist, Entomology, Crop Diversification Centre South,
Alberta Agriculture, Food and Rural Development,
SS #4, Brooks, Alberta, T1R 1E6, Canada

*Bracon cephi* and *Bracon lissogaster* are the only significant parasites of *Cephus cinctus* in wheat production systems. *Bracon cephi* is found throughout almost all of the *C. cinctus* range in the northern Great Plains. *Bracon lissogaster* on the other hand has only been documented in Montana wheat systems. Both species parasitize the larvae of the wheat stem sawfly inside the wheat stem and their larvae over-winter at the point of parasitism. This in-stem over-wintering means that the larval parasitoids are at risk of being damaged by fall threshing operations. This study illustrates the location of the over-wintering both within the stem and within the field. It also investigates the impact of harvesting operations on the survival of the parasitoid larvae and subsequent impact on the parasitoid population the following year.

## RELATIVE CAPTURE OF MALE AND FEMALE ADULT WHEAT STEM SAWFLIES BY PHEROMONE AND HOST PLANT ATTRACTANT LURES IN FIELD TRAPS

William G. Meikle[1], David K. Weaver[2], Christian Nansen[2], Justin B. Runyon[2,3], Gavin E. Peck[2], and Wendell L. Morrill[2]

[1]European Biological Control Laboratory, Entomopathology, USDA-ARS,
Campus International de Baillarguet, CS 90013 Montferrier sur Lez,
34988 St. Gely du Fesc,CEDEX, France
[2]Montana State University, Department of Entomology, 333 Leon Johnson Hall, Bozeman, MT
[3]Penn State University, Department of Entomology, 501 ASI Building,
University Park, PA

Trials of pheromone lure components were conducted in two locations in Montana in June 2003. Four replicate traps of each of eight lure types containing pheromone and host plant components, plus one blank lure (hexane-treated septa and unbaited acetone-treated filter papers in microcentrifuge tubes) as a control were placed near the border of a wheat field and a fallow

field. At site 1, Willow Creek, the traps were arranged linearly from north to south, with traps randomly assigned to positions within 4 blocks, for a total of 15 trapping days. At site 2, Conrad, blocks were arranged along both the east and west perimeters of the fallow field for a total of 12 trapping days. The lure components consisted of various combinations and dilutions of nonanal, tetradecanal, hexadecanal, 9-acetyloxynonanal, phenylacetic acid, and cis-3-hexenyl acetate.

The average numbers of sawflies caught per trap per day were not significantly different (alpha = 0.05) between the two sites. At Willow Creek, lure type had a significant effect on the number of males caught but not on the number of females caught. Lures containing 1) 500 µg of nonanal, tetradecanal, hexadecanal, 9-acetyloxynonanal, and phenylacetic acid; 2) the same as 1) with hexadecanal diluted tenfold; 3) 500 µg of 9-acetyloxynonanal alone; and 4) same as 3) with the addition of 1 mg of cis-3-hexenyl acetate were all significantly different from the control lure. Of those lures, the last one, 500 µg of 9-acetyloxynonanal with 1 mg of cis-3-hexenyl acetate, was by far the most effective in attracting males. At Conrad, lure type had a significant effect on both males and females, and the same four lure types attracted significantly more males and females than the control lure. Two additional lure types were also significantly more attractive than control to males and one other lure type was more attractive to females. Comparisons were also made between trap catches the fallow vs. the wheat sides of the trap, and between the western and eastern blocks at Conrad.

## REDUCING PESTICIDES AND RUNOFF THROUGH UCCE'S AG WATER QUALITY RESEARCH AND EDUCATION PROGRAM

Valerie J. Mellano, Karen L. Robb, David A. Shaw, and Diane C. DeJong

University of California Cooperative Extension, San Diego County
5555 Overland Ave., Suite 4101, San Diego, CA 92123

U.C. Cooperative Extension Farm Advisors in San Diego County have designed and implemented an Ag Water Quality Research and Education Program to help growers and regulatory agencies achieve water quality goals. The program is funded through a coordination of grants, contracts, and foundation monies. The program utilizes an integrated approach to this issue by utilizing workshops and tours, site visits, and the development of resources to enable growers to assess and document water quality management.

With the overall goal to eliminate runoff from all types of agricultural operations, the objectives of the program are to provide information on practical Best Management Practices (BMPs) and available technologies for minimizing agricultural runoff and nonpoint source pollution that can be tailored to the needs of individual situations. U.C. Cooperative Extension has the capabilities to transfer the latest research findings in cultural practices and water quality management into real impact through educational programs such as this.

The success and effectiveness of the Ag Water Quality Research and Education Program are being evaluated through detailed surveys, records of grower contacts, self-assessment questionnaires and follow-up consultations. To ensure grower participation in this program, all names, locations, and operation details are kept confidential.

## THE DREADED COLORADO POTATO BEETLE (*LEPTINOTARSA DECEMLINEATA* SAY, COLEOPTERA: CHRYSOMELIDAE)…OR IS IT? A NOVEL APPROACH TO IPM OF SOLANACEOUS WEEDS

Chase Metzger[1], Richard Boydston[2], Timothy Waters[1], Holly Ferguson[1], Martin Williams[3], and Douglas Walsh[1]

[1]Washington State University, Irrigated Agriculture Research and Extension Center, Prosser, WA
[2]USDA-ARS, Irrigated Agriculture Research and Extension Center, Prosser, WA
[3]USDA-ARS, Department of Crop Sciences, University of Illinois, Urbana, Illinois

Volunteer potato is very difficult to control in potato crop rotations. We are exploring the ability of Colorado potato beetle (CPB) to suppress this weed and other Solanaceous weeds in carrots, corn and mint. The purpose of this study is to quantify the interactions of herbicide dose and herbivore load on weed fitness. The results would identify the extent to which herbicide use could be reduced for a range of beetle densities, while maintaining weed suppression. Corn, mint, and carrots commonly rotated with potatoes were surveyed bi-weekly in 2003 for the presence and number of CPB as well as the density of Solanaceous weeds. The crop survey will be repeated in 2004. The abundance of CPB in these crops will later be used to establish the implementation of our model (to be designed in 2004). Statistically significant differences in beetle abundance were found between crops. In 2003, field work was also conducted in carrot/potato test plots comparing how the carrots were affected by the presence of CPB, two applications of a 1 lb a.i. rate of Caparol (prometryn), and absence of CPB. No statistical difference was found among treatments. This study will also be repeated in 2004.

## INOCULATIVE RELEASES OF *BRACON* SPP. FOR CONTROL OF WHEAT STEM SAWFLIES (HYMENOPTERA: CEPHIDAE)

Wendell L. Morrill, David K. Weaver, and S. Meers

Department of Entomology, Montana State University, Bozeman, MT 59717

The wheat stem sawfly, *Cephus cinctus* Norton (Hymenoptera: Cephidae) was first collected in native grasses where population densities were suppressed by several species of parasitoids. Sawflies adapted to wheat when the prairies were cultivated, and two species of parasitoids have followed their host into wheat fields. Sawfly damage is extensive in Montana. However, in some locations, parasitoids have reduced sawflies to a low level. The effectiveness of parasitoids

varies greatly between locations. Therefore, we distributed "effective strains" into new areas. Results indicate that inoculative releases of parasitoids were successful in several locations.

## INCIDENCE OF POTATO LEAFROLL VIRUS: WITHIN-FIELD INOCULUM AND VECTOR CONTROL USING DEGREE-DAY TRIGGERS

Thomas M. Mowry and Noemi M. Fernandez

University of Idaho, Department of Plant, Soil and Entomological Sciences,
Parma Research and Extension Center, 29603 U of I Lane, Parma, ID 83660-6699

Two years of field testing were conducted to measure *potato leafroll virus* (PLRV) incidence after suppressing green peach aphid densities by applying insecticides based on aphid degree-days. Four foliar insecticide applications were made based on green peach aphid phenology and these regimes were compared to the current Pacific Northwest PLRV Management Plan that calls for a systemic insecticide at planting followed by foliar applications at aphid detection in leaf samples. In 2002, one PLRV-infected potato plant was inserted into the center of each treatment plot resulting in an initial inoculum density of 0.3%. No additional inoculum was supplied in 2003. In 2002, under relatively low green peach aphid densities, there were no significant differences between any insecticide treatment with PLRV incidence ranging from 35% to 55%. In 2003, green peach aphid densities were approximately 50-100 times higher than in 2002, but the incidence of PLRV was less than half that in 2002. Our results indicate that applying insecticides based on green peach aphid phenology can provide reasonably effective aphid control, but not as effective as the Management Plan. However, neither method of aphid suppression reduces the incidence of PLRV if sufficient inoculum is present in the field. It is clear that inoculum load has a far greater effect on the incidence of PLRV than does management of the vector population.

## A GIS-BASED RISK WARNING SYSTEM OF RUSTY GRAIN BEETLE FLIGHT NEAR GRAIN ELEVATORS

Christian Nansen[1,2], Thomas W Phillips[2], and Albert Sutherland[3]

[1]Montana State University, Dept Entomol.
[2]Oklahoma State University, Dept Entomol. & Plant Path.
[3]Oklahoma State University Mesonet Asst. Ext. Spec.

The rusty grain beetle, *Cryptolestes ferrugineus*, is the most common grain insect found in Oklahoma stored wheat, and its presence triggers price discounts at sale due to the special category "infested" applied during grading of the grain. Here we present a weather-driven flight activity model of *C. ferrugineus* flight activity from 1993, 1994, and 2002, and we describe how the model was used to develop weekly maps of *C. ferrugineus* flight activity for this important

stored-grain pest. Unbaited sticky traps were placed on ropes in the four cardinal directions and at different heights on the outside of commercial steel bins containing stored wheat. Significant yearly and between-steel bin variation was found, and these effects were removed before using a response surface regression analysis to determine how well two time variables (day length and day number) and three weather variables (minimum and maximum temperature and precipitation) could explain the seasonal variation in *C. ferrugineus* flight activity. The full model of the two time variables and three weather variables explained 48% of the variance in this subset of trap catches, while a model based on weekly means of day length and minimum and maximum air temperatures explained 40% of the total variance in *C. ferrugineus* trap catches. Subsequently, weather data from Mesonet weather stations in Oklahoma were used to develop weekly maps of *C. ferrugineus* flight activity, and these were validated with trap catches collected in 2003.

## USE OF HYPERSPECTRAL TECHNOLOGY FOR GROUND-BASED REMOTE SENSING OF WHEAT STEM SAWFLY INFESTATIONS

Christian Nansen[1], Rand Swanson[2], Casey Smith[2], Rick Lawrence[3], and David K. Weaver[1]

[1]Montana State University, Department of Entomology, 333 Leon Johnson Hall, Bozeman, MT.
[2]Resonon Inc., 611 North Wallace #7, Bozeman, MT.
[3]Montana State University, Department of Land Resources and Environmental Sciences, 334 Leon Johnson Hall, Bozeman, MT.

The wheat stem sawfly, *Cephus cinctus*, is a major pest on wheat in Montana, and there are currently no reliable tools for rapid and reliable early detection of infestation by this insect. Consequently, wheat growers have very few means to respond to heavy infestations of this insect. The results reported here represent the initial research phase of an on-going effort to development of a mobile hyperspectral monitoring unit for early detection of *C. cinctus* infestation. Hyperspectral images were collected from experimentally infested and non-infested spring wheat plants. Hyperspectral profiles consisted of 213 bands within the range from 443-895 nm, and individual wheat plants were photographed on separate images in weekly intervals. A stepwise discriminant analysis of each weekly training data set was used to select the most important bands and to develop a discriminant function for separation of hyperspectral profiles from non-infested and infested plants. The main objective was to demonstrate the sensitivity of this technology to low levels of insect-induced stress in cereal crops and provide the baseline for field-based experiments with naturally infested wheat plants.

# POTENTIAL IMPACT OF THE CANCELLATION OF ORGANOPHOSPHATE INSECTICIDES ON LETTUCE PRODUCTION IN CALIFORNIA

Eric T. Natwick

University of California Cooperative Extension, UC Desert Research and Extension Center, 1050 East Holton Road, Holtville, CA

Three parameters were used to summarize the production-related consequences of the cancellation of organophosphate (OP) insecticides on lettuce production in California: per-acre yield changes, per-acre cost changes and total acres that use OP insecticides. Without OP insecticides, a pest management program in head lettuce will rely on pyrethroid insecticides (Ammo 2.5EC, Asana XL, Pounce 3.2EC, Capture 2EC, Warrior T and others) and carbamates (Lannate SP and Larvin 3.2F) for lepidopterous and seedling pests (cutworms, e.g. variegated cutworm, *Peridroma saucia*, black cutworm, *Agrotis ipsilon*, granulate cutworm, *Agrotis subterranea*, crickets, *Gryllinae* spp., flea beetles, *Epitrix hirtipennis*, Garden symphylan, *Scutigerella immaculata* and darkling beetles, *Blaspstinus* spp.), Success 2SC, Lannate SP and Warrior T for thrips, *Frankliniella occidentalis*, Thiodan 3EC or 50WP for seedling pests and aphids, *Bacillus thuringienesis* (Dipel 2X or others), Success 2SC, Avaunt 30 DG, and Proclaim 5 WDG for lepidopterous pests and Provado 1.6F or Admire 2F for aphids and whiteflies. A leaf lettuce pest management program will rely on the same insecticides as head lettuce with the exceptions of Agri-mek 0.15 EC, Ammo 2.5EC, and Asana XL that are not registered for use on leaf lettuce. However, the lack of these product registrations on leaf lettuce should not be a major obstacle in developing an OP free IPM program because there are insecticides registered on leaf lettuce that can be readily substituted for the insecticides that are not registered. Multiple insecticide applications are required to maintain marketable lettuce, free of insect contamination. Lettuce consumers demand an insect free commodity, with high cosmetic standards, severely limiting integrated pest management options in both leaf and head lettuce. Lettuce growers use precision planting practices to reduce hand-thinning costs, particularly in the lower desert region and southern San Joaquin Valley. To establish uniform plant stands, growers must use multiple insecticide applications of broad-spectrum pyrethroid and carbamate insecticides to suppress seedling pests. Thrips have become an important pest of both head and leaf lettuce in the low desert production region. Loss of OP insecticides would not only make thrips control difficult and expensive, but would place an increased amount of selective pressure on Success and pyrethroid insecticides, potentially leading to resistance problems. Yield estimates for California head and leaf lettuce are not projected to change with the loss of OP insecticides. However, insect control costs in California are estimated to increase between $64 to $107 per acre for head lettuce if OP insecticide registration is canceled and insect control costs for leaf lettuce in California are estimated to increase from between $87 to $129 per acre if OP insecticides are lost.

## PHYTOSANITATION OF PEARS AND APPLES USING ORGANOSILICONES AND HIGH PRESSURE WASHING

Lisa G. Neven and James D. Hansen

USDA-ARS Yakima Agricultural Research Laboratory,
5230 Konnowac Pass Road, Wapato, WA 98951

The presence of arthropods and arthropod eggs on the surface of pome fruits often causes a disruption in the international trade of these fruits. In the Pacific Northwest fruits are either rejected or fumigated when more than 5% have European red mite eggs. Spider mites, specifically McDaniel and Pacific spider mites, are considered pests of quarantine concern to many U.S. trading partners. Previous research on postharvest control in Israel has shown that high temperature, high pressure washing of fruits and vegetables removes a considerable number of arthropods and decay organisms from the surface. Other research from New Zealand and the U.S. demonstrated the miticidal qualities of the organosilicone SilWet L-77. In our study, we collaborated with the pathologists and postharvest physiologists at Oregon State University in Hood River, Oregon to investigate the potential of combination high temperature, high pressure washing and organosilicone dips in removal of surface arthropods and eggs. We found that the high temperature provided no additional benefit to the high pressure washing in egg removal or mortality. However, high pressure washing is very effective in removing both European mite and codling moth eggs. We also found that organosilicone emulsifiers and surfactants are very effective in adding to the mortality of grape mealybug and spider mites. The results of this study, in combination with the results from pathology and fruit quality indicate that high pressure washing anole or in combination with organisilicone dips, are very effective in removal of surface arthropods while providing control of decay and excellent fruit market quality.

## SEASONAL MORTALITY FACTORS IN THE ALFALFA LEAFCUTTING BEE, *MEGACHILE ROTUNDATA*

R. P. O'Neill and S. Blodgett

Department of Entomology, Montana State University, Bozeman MT 59717

Nests from five seed alfalfa sites of the alfalfa leafcutting bee *Megachile rotundata* were monitored over the duration of the nesting season in 2000 and 2001, from early July through late August. Cells containing progeny of known age and known position within the nest were subsequently analyzed for five commonly encountered sources of pre-diapause mortality in this species. Parasitism by the chalcid wasp *Pteromalus venustus* affected a high number of cells in the earliest-provisioned positions of nests, as did infection by a chalkbrood fungus *Ascosphaera* spp. Chalkbrood was also more prevalent in cells provisioned early in the nesting season. Unexplained early larval death, or pollen ball, was higher in cells from late-season nests. In older larvae and prepupae, unexplained mortality was higher in the most recently provisioned cells (i.e., from the outer portions of nests); however, seasonal trends were more variable.

## MORE THAN PRETTY MAPS: GEOSTATISTICS IN INSECT ECOLOGY AND PEST MANAGEMENT

Yong-Lak Park

Department of Entomology, University of California, Riverside, CA 92521

Studies on spatial dynamics of insect populations have been a very challenging part of insect ecology and pest management mainly because there have been no suitable technologies to generate distribution maps of insects until recently. During the last 15 years, technological advances in the positioning system (e.g., GPS) and the information system (e.g., GIS) have facilitated generating the geo-referenced data and mapping the insect populations. Although distribution maps can simply present where insects are, more information about structures and patterns of insect distributions can be obtained with advanced statistical methods. One way to characterize and analyze the spatial structure and pattern of distribution is using geostatistics. Geostatistics considers the spatial dependence of each datum, which means samples spatially close to each other are more similar than they are more distant samples. Geostatistics is a set of procedures that analyzes spatial relationships of a phenomenon by using the spatial variation in direction and distance between samples (i.e., variogram modeling) and predicts spatial phenomena at unsampled locations (i.e., kriging). In this paper, two main topics will be discussed: geostatistical analyses to characterize and map insect distributions and applications of geostatistics to the ecological research and management of insect pests.

## ECOLOGICAL STOICHIOMETRY OF *CULEX* MOSQUITOES AND THEIR LARVAL FOODS

George W. Peck and William E. Walton

Department of Entomology, University of California, Riverside, CA 92521.

Biological stoichiometry is the study of how disparities in optimal elemental composition (molar ratios of carbon, nitrogen, and phosphorus; C:N:P) between consumers and their foods can affect individual consumer growth, consumer population stability, and community structure. Previous studies suggest that mosquitoes are choosy about their larval habitats. For example, *Culex quinquefasciatus* is usually found in relatively nutrient-rich water, whereas *Culex tarsalis* is usually found in relatively nutrient-poor water. These differences in habitat nutrient concentrations affect the quality (C:N:P) and quantity (gDW/L) of larval foods. Previous studies also suggest that aquatic bacteria are an important component of larval diets in all types of habitats. In this study we were interested in how variation in the density and cellular C:N:P of a common aquatic bacterium, *Pseudomonas aeruginosa*, would affect the growth and whole body C:N:P of larval *Cx. quinquefasciatus* and *Cx. tarsalis*. We used three densities of *P. aeruginosa* with two different cellular C:N:P levels as food for larval mosquitoes. We measured differences in larval growth rate and whole body C:N:P, and relate it to natural conditions for these two mosquitoes.

## DETECTION OF STORED-GRAIN INSECT INFESTATION IN WHEAT TRANSPORTED IN RAILROAD HOPPER-CARS

Joel Perez-Mendoza[1], Paul W. Flinn[2], James F. Campbell[2], David W. Hagstrum[2], and James E. Throne[2]

[1]Department of Entomology, University of Montana, Bozeman, MT 59717

[2]USDA ARS Grain Marketing & Production Research Center, 1515 College Ave. Manhattan, KS 66502

Levels of insect infestation, insect spatial distribution, and the relationship between the number of insect-damaged kernels (IDK) and the number of insects present in grain samples in three-hopper railcars transporting wheat from country elevators to a mill were studied. Six of eight sampled railcars were infested with more than two species of insects. The most abundant species collected were the lesser grain borer, *Rhyzopertha dominica* (F.), and rusty grain beetle, *Cryptolestes ferrugineus* (Stephens), with the larval stage of the two species being the most prevalent (> 90%). The spatial distributions of these two species within the grain mass were typically clumped in railcar compartments containing more than 0.4 insects/2.75-kg sample of wheat, and these foci of high infestation levels varied in compartments within the railcars and among the sampled railcars. There were no significant correlations between IDK and insect density for any of the different stage-specific insect populations that were collected in the grain samples. Mean numbers of immatures and IDK differed among railcars and compartments within railcars, but not among grain depths. Number of insects in the first discharge sample was not correlated with mean numbers of insects in the entire compartment. This indicates that each compartment of a railcar should be sampled to determine level of insect infestation, but that sampling at different depths within a compartment is less important.

## A GIS-BASED APPROACH TO PIERCE'S DISEASE VECTOR (GWSS) REDUCTION

Thomas M. Perring[1], Carmen Gispert[2], and Charles A. Farrar[1]

[1]Department of Entomology, University of California, Riverside, CA
[2]UC Cooperative Extension Riverside County, Indio, California

Pierce's disease (PD) has been known in California for over 100 years, but with the recent introduction of the glassy-winged sharpshooter (GWSS), *Homalodisca coagulata,* into the state, the epidemiology of this devastating disease has radically changed. Since 1994, at least 1,500 acres of vineyards have been lost to the disease in California, and in the Temecula Valley alone, losses have been estimated at $13 million. The California grape industry is estimated to contribute $33 billion to the state economy, and GWSS transmission of PD threatens to destroy one of the state's most important commodities.

Early in our research program, we established a geographic information system (GIS) in which we have managed data from 156 yellow sticky traps. This provides a powerful tool for data manipulation and allows us to link GWSS densities to spatial information, and use these relationships to identify sites that should be targeted for vector reduction. For example, the GIS allows us to display the traps that have caught more than 0 GWSS per week (or conversely identify traps that have never caught a GWSS) through the course of the study. Similarly, the GIS can be used to display traps with other densities of GWSS. If we specify a certain distance around each of the traps, we can identify citrus blocks near traps with those various GWSS densities. From this exercise, we identified the groves within certain distances of traps that have caught various densities of GWSS/week during any week from May 2001 – October 2003. This analysis allowed us to identify fields that needed treatment, based on a determined vector density. Depending on resources available for vector reduction, these types of analyses can be extremely useful to prioritize citrus groves for application.

## PLANT-INSECT ECOPHYSIOLOGY: WHERE HAVE WE BEEN AND WHERE ARE WE NOW?

Robert K. D. Peterson

Montana State University, Department of Entomology,
333 Leon Johnson Hall, Bozeman, MT

Our understanding of how plants respond physiologically to insect-induced injury has changed dramatically since the early 1970s. The concept of injury has evolved from simply placing insects into taxonomic categories to describing physical appearance to understanding physiological impact. Despite this, we still haven't moved much beyond quantitative descriptions of pest numbers and resulting yield loss. The plant largely remains a black box, in which little is understood of how it responds physiologically and biochemically to insect injury. The numerous reasons for this will be outlined in the presentation. Advances in plant physiological understandings and instrumentation have allowed us to make great strides in illuminating the black box. I argue that physiology provides the common language for integrating understandings of plant stress and review how this common language can improve IPM decisions.

## PRIMARY AND SECONDARY METABOLIC RESPONSES OF DALMATIAN TOADFLAX AFTER INJURY BY INSECT BIOLOGICAL CONTROL AGENTS

Robert K. D. Peterson, Sharlene E. Sing, and David K. Weaver

Montana State University, Department of Entomology, 333 Leon Johnson Hall, Bozeman, MT

Experiments were conducted in Montana during 2003 to characterize the primary and secondary metabolic responses of Dalmatian toadflax to injury by *Mecinus janthinus*, a stem boring weevil,

and *Calophasia lunula*, a defoliating noctuid. Field research at two sites where *M. janthinus* was released revealed that Dalmatian toadflax primary metabolism was significantly impacted by the biological control agent. In particular, gas exchange processes such as photosynthesis and transpiration for plant stems infested by *M. janthinus* larvae were significantly lower compared to uninfested plants in the same location. These results suggest that primary metabolic processes of Dalmatian toadflax are impacted by this control agent. The data also show that there are a number of secondary metabolic compounds specifically associated with both plant growth stage and infestation state for both *M. janthinus* and *C. lunula*. To our knowledge, these studies are the first to demonstrate primary and secondary metabolic impacts by an insect biological control agent on a weed. Further, our results indicate that two biological control agents differentially impact toadflax physiology. This information is valuable because it suggests that weed primary physiology can be used as an indicator of biological control impact both before and after agent introduction.

## WHEAT PRIMARY METABOLIC RESPONSES TO WHEAT STEM SAWFLY INJURY: FROM BASIC UNDERSTANDINGS TO MANAGEMENT

Robert K. D. Peterson, Tulio B. Macedo, and David K. Weaver

Montana State University, Department of Entomology,
333 Leon Johnson Hall, Bozeman, MT

Other than general descriptions of yield loss, virtually nothing is known about how the wheat stem sawfly impacts wheat physiology. This research focuses on understanding how wheat responds physiologically to wheat stem sawfly injury. By understanding this aspect of the wheat-wheat stem sawfly interaction, we may be able to identify novel approaches to effectively manage this important pest. Progress to date on the wheat-wheat stem sawfly system has revealed that wheat stem sawfly injury significantly reduces wheat photosynthetic rates. The physiological mechanisms underlying the reductions in photosynthesis are unclear at this time, but results suggest that the reductions are not due to disruption of water transport, closure of stomata, reduced efficiency of rubisco, or reduced efficiency of light harvesting and electron transport. The reductions may be due to end-product inhibition of photosynthesis as a result of disruptions of phloem loading and unloading or to a metabolic cost associated with a shift from primary to secondary defensive compound production.

## CALIFORNIA'S AVOCADO THRIPS, *SCIRTOTHRIPS PERSEAE* NAKAHARA : WHY IS IT A NON-PEST IN ITS NATIVE HOME OF MEXICO AND GUATEMALA?

Phil A. Phillips

University of California, Cooperative Extension, 669 County Square Drive # 100, Ventura, CA 93003 USA, paphillips@ucdavis.edu

The avocado thrips is just one of several recent invasive species that have challenged California's existing IPM programs. *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 its 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 6 years in southern California.

Additionally, the Mexican and Guatemalan avocado thrips populations were confined to the new growth, never moving to the tender new fruit to cause feeding scars as they do in southern California. Although there were some temporal differences between the thrips populations in Mexico and in Guatemala, they remained confined to the flush growth, their preferred feeding substrate, which continued through the fruit set and early development periods. In the native subtropical home of the avocado, fruit set occurs during the growth flush period, while in the cooler, temperate climate of southern California avocado fruit set is delayed by 2 months until temperatures warm sufficiently. This results in the major growth flush period ending just as avocado thrips populations have peaked and young avocado fruitlets are developing. Under these southern California conditions the thrips move from the hardening and maturing foliage to the newly developing succulent fruitlets where they continue to feed and breed, causing significant fruit rind scarring.

## SEMIOCHEMICAL-BASED APPROACHES TO MANAGING STORED-PRODUCT MOTHS (PYRALIDAE)

Thomas W. Phillips[1], Christian Nansen[2], Charles Konemann[1] and Manuel Campos[1]

[1]Oklahoma State University, Department of Entomology and Plant Pathology, 127 Noble Research Center, Stillwater, OK 74078
[2]Montana State University, Dept of Entomology, 333 Leon Johnson Hall, PO Box 173020, Bozeman, MT 59717

Studies were conducted with the Indianmeal moth, *Plodia interpunctella*, aimed at suppressing populations with various strategies that utilized the major component of its sex pheromone, (*Z, E*)-9,12-tetradecadienyl acetate, referred to as "ZETA". Potential for developing an attracticide

for *P. interpunctella*, in which ZETA was combined with permethrin in a matrix to achieve mass-killing of males. Two concentrations of ZETA (0.16% and 0.32% w/w) and five concentrations of permethrin (0, 3, 6, 12, and 18% w/w) were incorporated into Last Call™ gel from IPM Technologies (Portland, OR). Attracticide gels were evaluated in a toxicity test, in which either the tip of a leg or an antenna of a virgin *P. interpunctella* male was touched into a dot of attracticide gel. These males were subsequently transferred to jars with virgin females. The toxicity test showed that even subtle contact of *P. interpunctella* males with attracticidal gel containing 3-18% permethrin caused a significant reduction in mating and killed male moths within 24 hours. A wind tunnel test was conducted to evaluate the flight responses of *P. interpunctella* males to the 10 attracticide gels. Male moths displayed significantly higher levels of anemotactic flight and contact with the attracticide gel when the ZETA concentration was 0.16% compared to 0.32%. *P. interpunctella* males showed no signs of repellency to permethrin concentration within a range of 0-18% in the gel. When *P. interpunctella* mating pairs were released into small warehouse rooms, we found that the attracticide gel suppressed oviposition when the moth density was at a low level, but it was ineffective when the moth density exceeded one male-female pair per 10 $m^3$. Other experiments investigated attracticide bait stations as alternatives to gels. A 900 sq. cm panel coated with an oil-based formulation of permethrin and baited with a single standard pheromone lure was very effective at attracting and killing male moths before they could reproduce. Other three-dimensional stations such as cylinders and spheroids were investigated. The relatively large treated surface area of a killing station allows for adequate contact of responding males with the insecticide, and serves as a potentially more attractive landing site than a gel dot.

Mating disruption (MD) of the Indianmeal moth was suggested and proven on a small scale in the laboratory more than 30 years ago, but no commercial scale treatments have been demonstrated. We studied mating disruption of *P. interpunctella* in a controlled field situation in which ZETA was loaded into high release-rate bags that were distributed throughout the test site to disrupt male orientation and mating. A "switching" experiment was done using two similar chicken houses in which adult moths were released weekly and monitored by trapping with virgin females. Reproduction was monitored with oviposition dishes placed in both chicken houses. Mating disruption was implemented in one house while the other remained as an untreated check during the 4-week treatment period. Bags were removed and placed in the other chicken house following one week of recovery. The protocol was repeated three times throughout the summer. Male responses to females and reproduction were significantly suppressed by MD. Mean male trap catch during MD was 1.6 (± 7.2 SE) vs. 44.6 (± 5.3 SE) in non MD checks. The mean larval count in oviposition dishes during the four week period before the MD was 181.8 (± 26.3 SE), whereas the mean larval count during MD was 82.5 (± 35.4 SE). This controlled experiment indicates that mating disruption can be used to suppress Indianmeal moth populations. Subsequent experiments to test efficacy in commercial food facilities were conducted in warehouses located in four states: Oklahoma, Texas, Washington and Indiana. Each location had pairs of non-mating disruption (control) and mating disruption (treatment) buildings. Monitoring of male and female behavioral responses was similar to the previous set of experiments, with the exception that synthetic pheromone lures were used in place of live females. All locations resulted in near total male trap shut down, much like in the chicken house experiment. Only at the Othello, WA sites did MD show larval means significance between MD and non-MD controls. At other locations larval production was either very low in both control

sites and treatment sites, or sometimes was higher at MD locations. Low larval counts at some locations may be attributed to competing food sources. Migration of IMM into treatment facilities from other areas may account for abundance of larvae in some treatment areas. Testing will continue, but recommendations so far are to thoroughly treat all areas in a facility, perhaps even outdoors, so that mated females from untreated areas do not invade areas targeted for control.

## THE IMPACT OF LOSS OF ORGANOPHOSPHATE INSECTICIDES ON ALMONDS

C. Pickel

University of California Statewide IPM Project, UCCE,
142-A Garden Hwy, Yuba City, CA 95991

California is the only state in the United States to commercially produce almonds and they produce 75% of the world's production. California's almond acreage is estimated by California Agricultural Statistics Service at 595,000 acres in 2000. Approximately 50 varieties of almonds are grown commercially, with Nonpareil a soft shell variety that is more prone to insect damage, as the primary variety. The most significant pests include navel orangeworm (*Amyelois transitella)*, peach twig borer *(Anarsia lineatella)*, San Jose scale (*Quadraspidiotus perniciosus)*, ants (*Tetramerium caespitum* and *Solenopsis xyloni*) and webspinning mites (*Tetranychus spp.)*. These pests are present in all almond growing areas of the state. New pests are now emerging such as the oblique-banded leafroller *(Choristoneura rosaceana)*, european fruit lecanium (*Parthenolecanium corni)*, and oriental fruit moth (*Grapholita molesta)* due to the reduction of broad spectrum insecticides. According to Pesticide Use Reports published by California Department of Pesticide Regulation, pesticide use in California almonds continues to decline since 1997, the highest reported use. From 1999-2003, the California almond industry has reduced its annual use of all pesticides by almost 3 million pounds, a 20% reduction in pounds applied per acre. Almond growers have done this by relying more on winter sanitation, monitoring for pests, and softer insecticides. Almonds can be grown without organophosphates and increased crop loss but the soft chemical alternatives can increase costs from $72.00 to $206.00 per acre in a high pest pressure situation and more monitoring will be required to avoid loss from secondary pests.

# IMPORTATION AND ESTABLISHMENT OF LYGUS PARASITOIDS IN CALIFORNIA

C. H. Pickett[1], R. Rodriguez[1], D. Coutinot[2], L. Ertle[3], K. A.Hoelmer[2], and K. Casanave[1]

[1]California Department of Food & Agriculture, Biological Control Program, Sacramento
[2]European Biological Control Laboratory, USDA ARS, Montferrier, France
[3]USDA ARS Beneficial Insects Research Laboratory, Newark, Delaware

*Lygus hesperus* Knight (Hemiptera: Miridae) is native to western United States and is a pest to numerous seed crops including alfalfa. In California, it is a key pest of cotton and strawberries, both highly valued crops. Currently Lygus is managed on most crops through applications of broad spectrum insecticides. Cultural and biological alternatives are not considered useful. Extensive surveys for natural enemies in western United States have found one egg and two nymphal parasitoids attacking *Lygus* species, primarily *L. hesperus*. However in central California surveys in alfalfa by ourselves and others have failed to find any nymphal parasitoids. Recent, limited collections along the central coast of California, a strawberry growing region, suggest *Lygus* spp. are either attacked at very low levels by nymphal parasitoids, or not at all. Beginning in the early 1970s the USDA ARS initiated importation of parasitoids associated with *Lygus rugulipennis* infesting alfalfa in central Europe. Van Steenwyk and Stern attempted but failed to establish *Peristenus stygicus* (Hymenoptera: Braconidae) during the mid '70s in the southern region of the San Joaquin Valley in central California. Importation of nymphal parasitoids into eastern United States during the 1980s, however, successfully reduced *Lygus lineolaris* infesting alfalfa, a close relative of *L. hesperus*.

Beginning in 1998 we renewed the effort to establish new parasitoids of *Lygus* originating from Europe. Several populations of *Peristenus stygicus* and *P. digoneutis* were cleared through quarantine (USDA ARS, Delaware) and reared in Sacramento and released initially at a nearby study site of alfalfa. Populations of parasitoids were collected from southern France, central Italy and Spain. In 2000 and 2001 parasitoids were released into additional sites in the central region of California, a region of high cotton acreage. And in 2002 and 2003, releases were initiated at two central coast sites near strawberry production. Several thousand parasitoids have been released at each site either as adults or as developing larvae inside *Lygus* nymphs. Releases of parasitoids ceased at Sacramento, our initial release site, in 2001.

Parasitism has increased each year at our original release site of alfalfa in Sacramento. Two and a half years following our last releases there, we continue to find abundant numbers of both *P. stygicus* and *P. digoneutis*. Maximum summer parasitism has increased each year since releases were made, reaching 75% summer 2003. The former parasitoid emerged from a collection of *Closterotomus* (=*Calocoris*) *norvegicus* and *L. hesperus* made from a vacant field filled with black mustard (*Brassica nigra*) 0.20 m away in 2003 and we just recovered live adults from the same field March 2004. These results indicate that these parasitoids are permanently established in the Sacramento region. Over the same period of time, maximum *Lygus* counts have varied from 3 to 14 per sweep, and have yet to show a decline. Most likely until parasitoids have expanded throughout the region, migration of Lygus into our isolated 0.5 ha plot of alfalfa will affect results. Impact on Lygus during a similar effort on the east coast of the U.S. was not

realized for 7 years following release of parasitoids. In contrast to results at the first release site in Sacramento, parasitism at our other central California release sites, including one at UC Davis has yet to increase, despite additional releases in 2002 and 2003. However at one of our new central coast sites we picked up parasitoids (as larvae) at a control site 300 m from where they were first released 6 weeks earlier. Only the introduced parasitoids *Peristenus stygicus* and *P. digoneutis* were recovered, i.e. no native braconids (identification by H. Goulet, Agriculture and Agri-Food Canada).

To date, *P. stygicus* has been the dominant species of parasitoid recovered from the Sacramento release site. However, the relative proportion of *Peristenus digoneutis* among recovered parasitoids increased to 50% by October 2002. Due to problems with emerging adult wasps, we were unable to replicate the same degree of sampling in 2003.

The ease with which parasitoids have established in Sacramento compared to other sites has been perplexing. Reasons vary from climate to differences in soil quality. The UC Davis site is only 24 km from the Sacramento site, yet colonization to date has been poor. We are now modifying our release sites to mimic that in Sacramento. Changes include the elimination of baling hay (allows for buildup of thatch), switching from surface to overhead irrigation, and addition of insectary flowers. Difficulty in parasitoid establishment may simply have to do with low numbers of Lygus. The population at UC Davis is less than half that at the Sacramento site.

## GREEN PEACH APHID OVERWINTERING IN WASHINGTON

K. S. Pike, D. Allison, and G. Graf

Washington State University, Irrigated Agriculture Research and Extension Center,
24106 N Bunn Rd, Prosser, WA 99350

Multi-year field research on green peach aphid, *Myzus persicae*, in Washington was undertaken to elucidate the extent of its survival over winter 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 the aphid will be discussed in the poster.

## MOLECULAR PHYLOGENY OF SYMPETRINAE – EXPOSING THE PERILS OF USING SOLELY WING VENATION FOR SYSTEMATICS

Erik M. Pilgrim and Carol D. von Dohlen

Utah State University, Department of Biology, Logan, UT

Libellulidae is by far the largest family of Odonata with over 1000 species and 10-12 subfamilies. Most odonatologists follow the taxonomic work of Fraser (1957) for recognizing the different subfamilies of Libellulidae. Under this classification scheme, the Sympetrinae is the largest subfamily with over 20 genera and nearly 200 species. The subfamily designations of Fraser are problematic for two reasons: 1) Fraser's work occurred before phylogenetic systematics came about in the 1960s, so these subfamilies have not undergone any phylogenetic analysis, and 2) Fraser's work is based on (often few) wing-venation characters only. For Sympetrinae, Fraser admitted that the subfamily would likely need revision, yet to date Fraser's designations are still in use as no revisions of the libellulid subfamilies have taken place. In this study, we use DNA sequences from one nuclear gene (Elongation Factor 1-$\alpha$) and two mitochondrial genes (12S and 16S ribosomal genes) to test the monophyly of Sympetrinae. Preliminary analyses suggest that Sympetrinae is not monophyletic and other subfamilies within Libellulidae may not be monophyletic as well. A revision of the subfamilies of Libellulidae is likely necessary and should address morphological characters in addition to wing venation.

## CLADISTIC ANALYSIS AND CLASSIFICATION OF THE SPIDER WASPS (HYMENOPTERA: POMPILIDAE)

James P. Pitts

Utah State University, Department of Biology, 5305 Old Main Hill, Logan, UT

Spider wasps (Pompilidae) are a common and readily recognizable group of wasps. These wasps serve as important models for ecological and evolutionary studies. Although pompilids are quite uniform in their biology, considerable diversity in ethological types does exist. In order to determine if there are any evolutionary trends in ethological types, a solid phylogenetic foundation is needed. For this study, phylogenetic relationships of the genera of Pompilidae were investigated using cladistic methods. The cladistic analysis was performed using more than 75 morphological characters. Successive approximations character weighting yielded results contrary to the recently proposed classification of the group by Shimizu (1994) (Ceropalinae + (Notocyphinae + (Pepsinae, Epipompilinae, Ctenocerinae, Pompilinae)), which suggests that classification changes are in order. The preferred phylogeny revealed that pompilid ethology tends towards more complicated behavioral sequences. However, some morphologically derived genera have secondarily reduced behavioral sequences.

## EFFECTS OF TEMPERATURE AND RELATIVE HUMIDITY ON ALFALFA LEAFCUTTING BEE IMMATURE SURVIVAL

Theresa L. Pitts-Singer and Rosalind James

USDA-ARS Bee Biology & Systematics Laboratory, Utah State University, Logan, UT

Samples of alfalfa leafcutting bees, *Megachile rotundata*, were collected at the end of the nesting season from commercial alfalfa fields in five northwestern states for a total of eight samples. Using x-radiographs, up to 100 cells with solid masses appearing to lack viable larvae were selected and dissected. The content of each dissected cell was determined (provision only, egg or first instar larva, pre- or post-defecating larva, moldy, or with pest), and the condition of any pollen-nectar provision was categorized as very dry, very wet, or moist. Cell content and condition as well as duration of nesting season was correlated with temperature and relative humidity collected using Hobo dataloggers placed with bee boards in nesting shelters. The results will afford a better understanding of why many alfalfa leafcutting bee cells fail to produce larvae, or why bees fail to lay eggs on provisions.

## INFLUENCES OF CHLORPYRIFOS AND SULFUR ON WINE GRAPE MITES (TETRANYCHIDAE, PHYTOSEIIDAE)

D. A. Prischmann[1], W. E. Snyder[1], and D. G. James[2]

[1]WSU Entomology Dept., FSHN 166, PO Box 646382, Pullman, WA 99164-6382
[2]IAREC, WSU, 24106 N. Bunn Rd., Prosser, WA 99350

Spider mites are important phytophagous pests of Washington State wine grape vineyards, and are often controlled by predatory phytoseiid mites. Previous surveys have shown that mite densities in Washington vineyards were not significantly higher in sites receiving insecticides and acaricides versus those only receiving fungicides and herbicides, a finding contrary to the literature. We hypothesized that both indirect and direct effects of sulfur applications were masking the effects of insecticides on mite community structure. Thus, we conducted a field experiment, replicated in two separate plots within an abandoned vineyard with naturally high densities of phytoseiid mites. We followed the impacts of the broad-spectrum insecticide chlorpyrifos and sulfur, alone and in combination, on the population dynamics of spider mites and specialist and generalist phytoseiid mites from May-September. Plot designation influenced effects of pesticides on spider mite densities, which we suspected was due to differences in plant architecture, with one replicate having a less vigorous canopy and wider vine spacing. Sulfur suppressed both pest and predatory phytoseiid mite densities. Effects of chlorpyrifos on spider mite densities varied, and it was initially toxic and/or repellent to both generalist and specialist phytoseiid mites. However, the latter reinvaded plants sprayed only with chlorpyrifos, presumably in response to high spider mite densities. Impacts on spider mite biocontrol in vineyards will be discussed.

## HOST SPECIFICITY TESTING FOR CLASSICAL BIOLOGICAL CONTROL OF WEEDS USING THE ENVIRONMENTAL RISK ASSESSMENT PARADIGM

**Kenneth P. Puliafico and Robert K. D. Peterson**

Department of Entomology, 333 Leon Johnson Hall, Montana State University, Bozeman, MT 59717

Host specificity screening of insects for the biological control of weeds is the first step taken to ensure environmental and agricultural safety. However, concerns about injury to economically, environmentally, and socially important plants have resulted in a confusing array of host specificity test strategies. Modern host tests would be improved through the application of a systematic testing framework based on the environmental risk assessment paradigm. We propose a tiered risk assessment strategy adapted from traditional biological control host screening protocols. Our framework increases predictability of a putative agent's host range through prioritization of host testing procedures. The host range of a candidate agent is determined through a series of tiers that elucidate the physiological and ecological constraints faced by the insect. Each host test tier determines the potential effects of the agent while quantifying the probability of environmental exposure. Higher tiers increase in complexity as they include more environmental factors to simulate the weed-infested ecosystem. Use of the risk framework increases system transparency by fully describing the assumptions and uncertainties correlated with the host test results. This framework allows biological control researchers to communicate risks with a broader group of stakeholders, while increasing screening efficiency.

## CEREAL LEAF BEETLE: HOST RANGE AND FIELD EVALUATION OF AGGREGATION PHEROMONE

Sujaya Rao

Department of Crop & Soil Science, Oregon State University, Corvallis, OR 97331

The cereal leaf beetle (CLB) is a new pest in the PNW. It is known as a grain pest, and is reported feeding on diverse grasses but its impacts on cultivated grasses remain unknown. We studied CLB impact on grasses raised for seed in the PNW, and evaluated a pheromone trap for monitoring adults. We evaluated six grasses and two cereals for presence of adults, eggs, larvae and damage. In the presence of spring planted cereals, spring planted grasses did not attract overwintering CLB adults. However, in summer, adults were attracted to majority of grasses tested. Damage to grasses ranged from low to medium. In contrast, overwintering adults were observed to feed and lay eggs on fall planted grasses but damage was not significant.

In 2002 a range (50 to 500 μg per septum) in CLB aggregation pheromone doses was tested. The study indicated that the synthetic pheromone is effective in trapping CLB adults, but for large-scale field implementation, higher captures are required. In 2003 higher doses and a modified

trap for retention of captured adults were tested. We obtained three times the adults on the 0.5 mg trap compared to the trap with the same dose tested in 2002.

## FIELD EVALUATION AND CONTROL OF ARGENTINE ANTS IN AGRICULTURAL ENVIRONMENTS: A CONTRAST TO URBAN SETTINGS

Donald A. Reierson[1], M. K. Rust[1], and J. Klotz[1]

[1]University of California, Department of Entomology, Riverside, CA 92521

The Argentine ant, *Linepithema humile* (Mayr), is extremely abundant and troublesome in many agricultural settings. Besides directly reducing the efficacy of a wide variety of important natural parasites and predators against important honeydew-producing insects, *L. humile* causes abandonment of beehives it discovers and invades, chews through nozzles and drip irrigation tubes, and readily invades potted plants, thereby being spread commercially. Having enormous populations, *L. humile* also affects semi-agricultural natural environments by displacing and out-competing other arthropods.

Large-scale monoculture environments typify many present-day agricultural settings. Orchard crops, grapes and nurseries extending over tens or hundreds of hectares are representative of such an environment. Compared to urban, such environments lack significant diversity of refugia, food or predators. Most insecticidal sprays, granules or combinations used in urban environments may not be used where food is being grown. Skirting, banding with repellents, and directed sprays provide minimal temporary suppression of limited value.

Because baits have advantages over sprays, we concentrated our efforts on controlling *L. humile* with honeydew-mimic sugar baits composed of 25% sugar water. Control was directly related to the amount of bait foraged. Concentration of AI was critical. As in urban settings, effective rates were about $1 \times 10^{-3}$ to $1 \times 10^{-4}$% fipronil, imidacloprid, or thiamethoxam. Much higher rates were repellent or killed too quickly, whereas lower rates were foraged but were ineffective. Techniques to enhance take enhanced control. For instance, adding preservative to prolong field life was unnecessary and deleterious; using more stations improved take; and using sufficiently large stations was critical.

## EVALUATION OF HOT PINK STICKY TRAPS TO MONITOR PESTS OF ORNAMENTAL CROPS

Karen L. Robb[1], Julie P. Newman[2], Heather Costa[3], and Diane DeJong[1]

[1]University of California, Cooperative Extension, San Diego County,
5555 Overland Ave., Suite 4101, San Diego, CA 92123
[2]University of California, Cooperative Extension, Ventura County,
666 County Sq. Dr., Ste 100, Ventura, CA
[3]University of California, Department of Entomology, Riverside, CA

Tsuchiya et al. 1995 demonstrated a preference by western flower thrips for hot pink in mandarin oranges. Industry standards for ornamental crops are blue or yellow for thrips and yellow for other pests of ornamentals. Trials were conducted to evaluate the effectiveness of hot pink traps for monitoring pests on ornamental crops in California.

Blue, yellow and hot pink traps were made. Each trap was placed directly above the crop canopy of test crops in a randomised design, at least 10 meters away from other traps. In the San Diego County trial, 10 traps of each color were evaluated on a blooming crop of field-grown chrysanthemums over 5 weeks. In the Ventura County trial, 24 traps of each color were placed in a 558 square meter greenhouse over a crop of impatiens bedding plants that were just beginning to show color. In both trials, the traps remained in the field for 24 hours and were then collected for counting the trapped insects in the laboratory. Data were analyzed using ANOVA.

There was no advantage to using hot pink sticky traps for thrips, leafminers, whiteflies, aphids or fungus gnats. Thus, no modification to existing monitoring traps is recommended.

## MEETING THE CHALLENGE OF DIVERSITY: IMPLEMENTING IPM IN THE OREGON GREENHOUSE/NURSERY INDUSTRY

Robin L. Rosetta[1]

[1]Oregon State University, NWREC, 15210 NE Miley Rd., Aurora, OR 97002-9543

One of the greatest challenges facing implementation of Integrated Pest Management (IPM) in Oregon's Greenhouse and Nursery industry is its size and diversity. Oregon's nursery and greenhouse industry ranked number one in the State's agriculture for the last ten years. For nurseries exclusive of greenhouse and floriculture production and according to the Nursery Crops Summary by USDA/NASS, Oregon ranked second (15% of total nursery sales) to California (28%) and was closely followed by Florida at 14%. The 2000 survey stated that Oregon leads the nation in value of sales in the areas of deciduous shade tree production, conifer sales, and was in the top three states in terms of sales of deciduous shrubs, broadleaf evergreens, propagation material (tied with Washington), fruit and nut trees, deciduous flowering trees,

Christmas trees, and plant starts for truck crops. In 2002, the total gross value of sales in Oregon for nursery and greenhouse crops came in at $727 million which was a 7% increase from 2001. It was the twelfth straight year that record sales were reported. Container nurseries dominate sales with bare root and ball and burlap roughly equivalent. Additionally there are greenhouse and specialty crops such as bulbs which add to the diverse range of ornamental plant material grown in Oregon. The Oregon Association of Nurseries' *Directory and Buyers Guide* lists over 4,500 varieties grown by 500 of its association members. The USDA survey stated that the number of operations increased in 2002, to 2,183, up from 2,139, the number in 2001. The top five counties in terms of gross sales were located in areas of expanding population centers. Conducting pest management activities near urban/suburban residential areas surrounded with sensitive riparian and stream habitat presents increasing challenges for nursery producers.

IPM implementation is a multi-faceted effort reaching across a number of disciplines. Within IPM implementation one might focus on exclusion or prevention, pest identification, monitoring, increasing the understanding of the pest biology, and management options including cultural, biological, and chemical tactics. With such a wide array of plants grown in Oregon, the potential pest complex in nursery production and the knowledge base required to have successful IPM programs is large and extensive. Research, Extension, and management efforts have focused on key pests and generalized IPM practices. Nurseries which actively introduce IPM into their practices realize significant economic and plant quality benefits while generally reducing non-target impacts.

Exclusion and prevention efforts have been extremely helpful to reduce the flow of exotic pests into Oregon production and to manage existing pests. Sudden Oak Death, citrus longhorned beetle, fire ants, gypsy moth, and kudzu vine are just a few of the invaders looming over the industry. Within disciplines we see a much greater emphasis on sanitation and exclusion of key pests. In the area of weed management, a large number of nurseries are using sawdust and other products such as geotextile disks for mulch. Many container nurseries are concentrating on sanitation in areas surrounding production. This has led to reduced weed pressure in the containers and ensuing reduced herbicide usage. Many greenhouses and nurseries are using hydrogen peroxide and similar reduced risk materials to manage liverwort and disease organisms in propagation in lieu of more toxic fungicides. Basic sanitation tactics such as cleaning up leaf debris occur on a regular basis.

Diagnostics play an extremely important role in correct identification of our pest problems and potential reduction in unnecessary or ineffective intervention. Approximately 30-40% of the samples received at the Plant Clinic at Oregon State University are abiotic in nature. Many of the samples coming into the OSU Insect ID Clinic from concerned employees in the green industry are comprised of beneficial insects such as ladybeetle larvae, and aphid mummy cases mistaken for harmful insects. Pest identification efforts help the nurseries focus their efforts and explain difficult production problems such as the cause of tree losses due to cankers by *Phytophthora syringae* and terminal losses in red maple due to lygus bugs.

Monitoring has increased in prominence as nurseries more precisely manage their pest complex. More nurseries are incorporating monitoring traps for pests such as shothole borers, leafrollers, clearwing moths, fungus gnats, or lygus bugs. Visual plant monitoring also occurs, particularly

for key pests such as root weevils, spider mites, or honeylocust pod gall midge. Timing improvements for management practices have increased management effectiveness, plant quality and value, decreased labor needs and costs, decreased plant losses, in many cases reduced pesticide frequency and toxicity, and often increased environmental and employee safety. Examples of this include sampling and monitoring for verticillium which has enabled nurseries to map problem locations to avoid losses; honeylocust pod gall midge oil applications to smother eggs, and applications to reduce terminal losses of red maples to lygus injury.

A better understanding of life cycles of pests is also represented by similar examples of enhanced management including: drenches to control honeylocust pod gall midge prior to emergence; and better timing of *Phytophthora syringae* applications based on epidemiology trials. This better understanding of the pest species has also been important when preparing various management programs using diverse tactics. By switching to drip irrigation many field growers have dramatically reduced tillage and herbicide uses (water is applied through buried drip tape so the soil surface is rarely wet and less prone to germinating weeds. Nursery growers have a better understanding of the need for good drainage in their media for *Phytophthora* root rot prevention and thus incorporate bark pieces. Understanding movement of that same organism has led to more sloped gravel beds in container yards. Getting better air movement has been a goal in much of the recent greenhouse design and attraction to structures such as retractable roof greenhouses.

In all, IPM has had noticeable impacts contributing to sustainable production in the Oregon nursery and greenhouse industry and will likely do so in the future.

## ARGENTINE ANTS – BIOLOGY, BEHAVIOR AND CONTROL IN THE URBAN SETTING

Michael K. Rust, Donald A. Reierson, John H. Klotz, and Andrew Soeprono

University of California, Department of Entomology, Riverside, CA 92521

The Argentine ant, *Linepithema humile*, is the most important pest species in urban areas throughout much of California. Multiple queen colonies, numerous satellite colonies, and a lack of intraspecific aggression contribute to tremendous populations of ants that displace native species. Control efforts have historically relied on the use of chemical sprays and granules for control. Factors such as irrigation, excessive ground cover, concrete and stucco surfaces, and warm summer temperatures contribute to the short residual activity of such treatments. Targeted applications around structures and ant routes significantly increase their performance.

Bifenthrin, cyfluthrin, and fipronil applied as barriers were not repellent to foragers. The bifenthrin and cyfluthrin produced 90% mortality within 10 min after a 1-min exposure and prevented ants from recruiting workers across the barrier. Other workers did not avoid the treated surfaces. Fipronil produced 90% kill within about 114 min and allowed workers to recruit nest mates over treated surfaces. There was horizontal transfer of fipronil from exposed

ants to naïve workers. Confinement of ants with workers exposed to bifenthrin and cyfluthrin did not result in any increased mortality.

Aqueous sugar baits incorporating slow-acting toxicants such as imidacloprid, thiamethoxam, and fipronil look extremely promising. Bait preparations that produce 50% kill of workers in 1-4 days and that are readily accepted by workers provide the greatest colony kill. Concentrations of $1 \times 10^{-3}$ to $1 \times 10^{-4}$% provide slow enough kill to permit recruitment and trophallaxis.

## INDIRECT EFFECTS OF AN ANT-APHID MUTUALISM ON THE TRITROPHIC INTERACTIONS OF *RHABDOPHAGA STROBILOIDES*

Amy M. Savage and Merrill A. Peterson

Department of Biology, Western Washington University
MS 9160, Bellingham, WA USA

*Rhabdophaga strobiloides* (Diptera: Cecidomyiidae) induces rosette galls on the developing shoots of *Salix exigua* trees. Populations of *R. strobiloides* can reach outbreak densities (<100 galls/stem) along the Columbia River, in Washington State. Many other insects feed on *S. exigua* stems as well, including ant-tended aphids, which often feed on gall tissue. *Rhabdophaga strobiloides* is a host for a suite of parasitoids including the specialist *Torymus strobiloides* (Hymenoptera: Torymidae). Preliminary observations suggested that the ant-aphid mutualism might protect *R. strobiloides* larvae from parasitoid attack. The purpose of this study was to determine the indirect effects of ant tending on the parasitism rates of *R. strobiloides* in the field. We conducted two exclusion experiments. The first tested the survival rate of aphids in the absence of ants and/or *R. strobiloides* galls. The second tested the effect of ant and/or aphid removal on *R. strobiloides* parasitism rates. Aphids enjoyed higher survival rates in the presence of both ants and galls. Although gall formation was not influenced by ants or aphids, survival of gallers through the growing season was higher on stems with aphids present. The presence of ants alone or ants and aphids did not result in lower parasitism rates for *R. strobiloides* larvae. These results will be discussed in the context of understanding the role of mutualisms in community structure.

## BENEFITS OF POLYANDRY IN THE BLUE MILKWEED BEETLE, *CHRYSOCHUS COBALTINUS* (COLEOPTERA: CHRYSOMELIDAE)

Steven K. Schwartz and Merrill A. Peterson

Biology Department, Western Washington University, Bellingham, WA 98225, USA

There is growing evidence that females of many species mate with multiple males, a strategy termed polyandry. The benefits of such a strategy are many, and include enhanced reproductive

success due to having more genetically diverse offspring, and also due to greater overall fecundity. Females of the leaf beetle, *Chrysochus cobaltinus*, are extremely polyandrous in nature. To assess the benefits of this behavior to females, we compared the reproductive success of females mated once with a single male (single), females mated multiple times with the same male (repetitive), and females mated multiple times with multiple males (multiple). We found that the females in the repetitive and multiple treatments enjoyed fecundity benefits from the multiple matings. Specifically, compared to singly-mated females, polyandrous females exhibited a significant increase in daily egg production and in the number of eggs produced per egg mass. There were no significant differences between the repetitive and multiple-mating treatments. These findings indicate that although there are fecundity benefits for females that mate multiple times there is no evidence that the identity of their mates influences those benefits.

## BIOLOGICAL CONTROL OF RED GUM LERP PSYLLID IN SAN DIEGO COUNTY

David A. Shaw[1], Karen L. Robb[1], Diane De Jong[1], and David L. Rowney[2]

[1]University of California Cooperative Extension, San Diego County
5555 Overland Avenue, Suite 4101, San Diego, CA

[2]University of California, Center for Biological Control, Berkeley, CA

The red gum lerp psyllid, *Glycaspis brimblecombei*, arrived from Australia and rapidly spread throughout California in 1998. Red gum (*Eucalyptus camaldulensis*) is heavily attacked by this pest, resulting in considerable leaf drop, tree stress, and in many cases, tree mortality. A team of U.C. researchers, led by the late Dr. Donald L. Dahlsten, monitored the spread and population levels of the psyllid, and made releases of *Psyllaephagus bliteus* to establish biological control of the red gum lerp psyllid. In San Diego County, *P. bliteus* was released at three monitored sites near Rancho Santa Fe, Mission Bay and Scripps Ranch beginning in September of 2000. A total of 470 parasitoids were initially released at these sites and an additional 2411 parasitoids were released in 2001 and 2002. Establishment of the biological control was monitored weekly using yellow sticky traps placed in the foliage of *E. camaldulensis*. Parasitoids were recovered within five and six months at the Scripps Ranch and Rancho Santa Fe sites, respectively. Extensive county-wide surveys were conducted in June 2002 and April 2004 to evaluate the establishment and distribution of *P. bliteus*. Presence of psyllid mummies and immature parasitoids demonstrated establishment of the biological control agent throughout San Diego County.

## INSECTOR, THE UTILITY OF AN AUTOMATED INFESTATION MONITORING TOOL

Dennis Shuman[1], Ron Larson[2], and David Crompton[2]

[1]USDA-ARS, 1700 SW 23 Drive, Gainesville, FL
[2]OPIsystems Inc., Calgary, Alberta, Canada

Development of a computer-based insect monitoring system was completed and is now commercially available. Each system probe employs two orthogonal infrared beams to count and identify the species of insects that enter and fall through its body. Real-time infestation data from probes deployed throughout a grain storage facility are transmitted and displayed at a remote computer terminal. Intelligent probe circuitry and a complex data analysis algorithm residing in the remote computer terminal are able to elicit accurate system performance despite the unpredictable insect behavior and harsh conditions encountered in grain bins. This is demonstrated by tests results obtained at several commercial grain storage sites.

## CHARACTERIZATION OF SAWFLY SPATIAL DISTRIBUTION IN WILD OAT-INFESTED, SOLID-STEM SPRING WHEAT

[1]Sharlene E. Sing, [2]Bruce D. Maxwell, [3]Greg Johnson, and [3]Wendell L. Morrill

[1]USFS Rocky Mountain Research Station – Forestry Sciences Lab – Bozeman, MT
Departments of [2]Land Resources and Environmental Sciences and [3]Entomology –
Montana State University – Bozeman, MT

A national initiative to implement ecologically-based pest management (EBPM) was introduced in 1996. EBPM strives to manage pests over the long term using methods that minimize adverse environmental, economic and safety consequences while maximizing safety, profitability and sustainability. Key to the success of EBPM is the dissemination of relevant information to growers and other pest managers, the 'end users' who actually implement pest management. Management of coexisting weed and insect herbivores has been conventionally isolated and non-integrated. Increasing available information about biotic interactions is the first essential step in implementing effective EBPM. The impetus for this study arose from the need to more clearly understand the biological and ecological interactions between two economically significant pests of Montana dryland spring wheat, the wheat stem sawfly, *Cephus cinctus* Norton, and wild oat, *Avena fatua* L.

An accurate characterization of the spatial pattern and distribution of adult and larval stages of sawfly in sawfly-resistant spring wheat was developed to enhance existing management tools. Contrary to the conventionally held perception that sawfly is an edge-effect pest, sawfly infestation was not found to be predominantly focused at field margins. The influence of wild oat on sawfly spatial distribution was also examined. Although sawfly larval mortality was 100% in all infested wild oat stems examined, sawfly acceptance of this plant species as a host

was not rare. However, sawfly preference was significantly higher for spring wheat than for wild oat hosts based on the relative abundance of each species. Sawfly attack on the small number of spring wheat stems within wild oat patches at a higher rate than on spring wheat in weed-free areas further indicates sawfly host preference for spring wheat.

Management strategies including planting antibiotic or antixenotic trap strips and destroying the outer edges of cropped wheat fields had been proposed by early sawfly researchers and was subsequently widely implemented by farmers, based on the perception that sawfly is an edge-effect pest. The results of this study indicate that while adult sawflies were frequently observed at high densities on field margins, oviposition and resulting larval infestation were in fact dispersed evenly throughout the fields included in this evaluation.

## DEVELOPING AND APPLYING A PROTOCOL FOR WEED BIOLOGICAL CONTROL RISK ASSESSMENT FOR INVASIVE *LINARIA*

Sharlene E. Sing[1], Robert K.D. Peterson[2], and David K. Weaver[2]

[1]USFS Rocky Mountain Research Station – Forestry Sciences Lab – Bozeman, MT
[2]Department of Entomology, Montana State University – Bozeman, MT

Risk assessments have conventionally evaluated the potential for harm to human or environmental health from exposure to chemical toxins. In this scenario, risk is assessed as a function of the interaction of hazard and exposure, and expressed in terms of a dose response. Risk assessments associated with invasive species have typically focused on the probability of successful invasion by an exotic, undesirable organism. Success/risk in this case is expressed in terms of the cumulative potential for introduction, establishment, and radiation of the exotic species. Strategies for instituting risk assessments for either of these scenarios is well documented and standardized. Although published weed biological control risk assessments are numerous, because each prioritizes and evaluates non-target impacts (=hazards) quite differently, standardized approaches and methodologies in this area of investigation remain in incipient stages. Perhaps more significantly, parameterization of exposure is seldom addressed in conventional biocontrol research.

We propose that a comprehensive approach to weed biocontrol risk assessment would involve a three-tiered, ecologically-informed evaluation of: primary risk due to the invasive weed; secondary risk due to direct or indirect impacts of the biological control agent on other organisms; and tertiary risks due to other organisms negatively impacting the agent. Economic constraint restricts how comprehensive pre-release testing will be. As a result, gaps in ecological information about the target weed, the candidate agent, their interaction with each other and the abiotic and biotic environment are unfortunately generally addressed after the agent is approved and released in North America. Our research on the biological control of yellow and Dalmatian toadflax, *Linaria vulgaris* and *L. dalmatica*, identifies potential methods for pre-release agent evaluation in terms of agent impact on target host primary and secondary metabolic function.

## INTRAGUILD PREDATION AND SUCCESSFUL INVASION BY EXOTIC LADYBIRD BEETLES

William E. Snyder[1], Garrett M. Clevenger[1], and Sanford D. Eigenbrode[2]

[1]Washington State University, Department of Entomology, 166 FSHN Building, Pullman, WA
[2]Division of Entomology, Department of Plant, Soil and Entomological Sciences, University of Idaho, Moscow, ID

Introductions of two ladybird beetle (Coleoptera: Coccinellidae) species, *Coccinella septempunctata* and *Harmonia axyridis*, into North America for aphid biocontrol have been followed by declines in native species. We examined intraguild predation ("IGP") between larvae of these two exotic species and larvae of the two most abundant native coccinellids in eastern Washington state, *Coccinella transversoguttata* and *Hippodamia convergens*. In pairings between the two native species in laboratory microcosms containing pea (*Pisum sativum*) plants, neither native had a clear advantage over the other in IGP. When the natives were paired with either *H. axyridis* or *C. septempunctata*, the natives were more frequently the victims than perpetrators of IGP. In contrast, in pairings between the exotic species, neither had an IGP advantage, although overall rates of IGP between these two species were very high. Adding alternative prey (aphids) to microcosms did not alter the frequency and patterns of relative IGP among the coccinellid species. In observations of encounters between larvae, the introduced *H. axyridis* frequently survived multiple encounters with the native *C. transversoguttata*, whereas the native rarely survived a single encounter with *H. axyridis*. Our results suggest that larvae of the native species face increased intraguild predation following invasion by *C. septempunctata* and *H. axyridis*, which may be contributing to the speed with which these exotic ladybird beetles displace the natives following invasion.

## ROLE OF HAIRY NIGHTSHADE *SOLANUM SARRACHOIDES* ON POTATO LEAFROLL VIRUS VECTOR DYNAMICS AND DISEASE EPIDEMIOLOGY

Rajagopalbabu Srinivasan[1], Juan Manuel Alvarez[2], Nilsa A. Bosque-Pérez[1], and Sanford D. Eigenbrode[1]

[1]University of Idaho, Dept. of Plant, Soil & Entomological Sciences, P.O. Box 442339, Moscow, ID 83844-2339
[2]Aberdeen R & E Center, 1693 S. 2700 W., Aberdeen, ID 83210

Hairy nightshade, *Solanum sarrachoides* (Sendtner) is a solanaceous weed abundantly distributed in potato ecosystems of Southeastern Idaho. *S. sarrachoides* is a reported host for potato leafroll virus (Polerovirus: Luteoviridae) and for its main vector, the green peach aphid *Myzus persicae* (Sulzer) (Homoptera: Aphididae). Our previous laboratory experiments and field sampling data showed that *S. sarrachoides* attracted and arrested more aphids than potato plants, *Solanum tuberosum* (L.). Two field trials were conducted at Kimberly, Idaho to study the role of *S. sarrachoides* on vector distribution and leafroll disease epidemiology. Different treatments of *S. sarrachoides* were established on potato plots in a randomized complete block design. Aphid

counts and disease progression were monitored at weekly intervals. Results indicate that plots with *S. sarrachoides* had an increased number of aphids and a higher number of potato leafroll virus infected plants. A field trial was conducted at Aberdeen, Idaho to monitor the host preference of dispersing aphids. Aphid counts taken at weekly intervals revealed increased preference of *M. persicae* for *S. sarrachoides*. These findings suggest that *S. sarrachoides* might play a major role in the epidemiology of potato leafroll virus in the potato ecosystem.

## SPINOSAD AND STORED-PRODUCT INSECTS: RESEARCH ACCOMPLISHMENTS AND DATA GAPS

Bhadriraju Subramanyam

Department of Grain Science and Industry, Kansas State University,
Manhattan, KS 66506

Spinosad, a reduced-risk commercial bacterial insecticide, was evaluated under laboratory and field conditions against several stored-product insects. In the laboratory, spinosad was found to be effective at 1 mg/kg rate on five classes of wheat against 12 insect species. Spinosad is extremely effective against the lesser grain borer, *Rhyzopertha dominica*. At 1 mg/kg spinosad is stable for at least 6 months to a year on stored hard red winter wheat. Although there is a slight decrease in spinosad residues on wheat over time, the activity against insects is unaffected. Spinosad also has contact activity against eight insect species. Parasitoids are highly susceptible to spinosad, but not the predator, *Xylocoris flavipes*. Spinosad was also found to be effective against eight insect species on stored shelled corn in the laboratory, and the 1 mg/kg rate provided complete control of the Indian meal moth, *Plodia interpunctella* and almond moth, *Cadra cautella* over a period of one year. The US-EPA may approve spinosad as a grain protectant at the 1 mg/kg rate before September/October of this year. The efficacy of spinosad in protecting bird seed and pelleted feed still remain to be established. Spinosad efficacy on grain beyond one year also needs to be verified. The development of dust and liquid formulations for both organic and non-organic uses are currently underway. These new formulations need to be tested for their effectiveness against insects. International tolerances and product stewardship program will be critical for widespread adoption of spinosad as a grain protectant on wheat and other grains.

## CHANGING GREENHOUSE CUT ROSE PRODUCTION SYSTEMS ALTERED THE COURSE OF IPM PRACTICES AND SUSTAINABILITY

Steven A. Tjosvold

University of California Cooperative Extension, 1432 Freedom Blvd., Watsonville CA 95076

California greenhouse cut-rose growers have traditionally grown crops trained in "hedgerows" and in field soil. In the past 15 years, all rose growers have changed to a production system where roses are trained with cane-bending techniques ("arching") and grown in soil-less media in containers ("hydroponics"). These changes have been made primarily to increase rose productivity and average quality. In addition, the new production system eliminates the annual summer cutback required in hedgerow systems, and roses are trained at a practical working-height level.

With the changes in production systems, there have been significant associated changes in the occurrence and management of pests and diseases. The new production system created opportunity to enhance management of the most difficult pests. For example, success with biological control of spider mites (*Tetranychus urticae*) can be attributed in part to the new production system. The success of targeted chemical sprays for western flower thrips (*Frankliniella occidentalis*) can be attributed in part to the new system. There have been significant drawbacks in the management of diseases and pests associated with the new production system too. Increased leaf density and bending into the walkway has enhanced environmental conditions favorable to infection and transmission of the pathogens that cause downy mildew (*Peronospora sparsa*) and rust (*Phragmidium* spp.). A dramatic increase in mealybug (*Planoccocus citri*) has been associated with the new management practices.

In this presentation, the old and new production systems and the associated changes in management practices for diseases and pests will be illustrated and described.

## MONITORING RED FLOUR BEETLE IN INSECTICIDE TREATED PILOT SCALE WAREHOUSES

Michael Toews, James Campbell, and Frank Arthur

USDA-ARS Grain Marketing & Production Research Center,
1515 College Ave, Manhattan, KS

The red flour beetle, *Tribolium castaneum*, is a serious insect pest of the milling, grain processing, and retail food industries. We conducted laboratory studies in pilot scale warehouses to investigate the effects of water (control), cyfluthrin, or (S)-hydroprene treatment and two insecticide application strategies on red flour beetle populations. Insect populations were quantified with absolute sampling of food patches and insect captures in pheromone baited pitfall traps over a six wk period. Sealed warehouses (2.8 m by 5.9 m) were first provisioned with

protected food patches and then infested with 200 eggs, small larvae, large larvae, pupae, and adults each. Twenty-four h later, warehouses were treated with insecticides using one of two application strategies, along the floor wall junction (perimeter treatment) or targeted applications around the food patches (shelf treatment). Treatment with cyfluthrin, regardless of application strategy, resulted in more dead adults and fewer immatures than the control or (S)-hydroprene treatments. Quantity of immature insects in the food patches was not different between (S)-hydroprene and the control treatment. Finally, there were substantially fewer insects captured in traps positioned along walls and in corners of warehouses where the perimeter application of cyfluthrin was utilized, indicating that trap position is an important consideration when monitoring red flour beetle populations in facilities treated with this compound.

## MECHANISMS OF TOLERANCE TO ARTHROPOD HERBIVORY

John T. Trumble and Peter D. Jensen

Entomology, University of California, Riverside CA 92521, USA

Plant compensation for arthropod damage is a general occurrence and of considerable importance in both natural and agricultural systems. Plant species that can tolerate or compensate (e.g. recover equivalent yield or fitness) for herbivore feeding have obvious selective advantages leading to genotype maintenance and productivity. This presentation covers some of the historical problems that have impeded our understanding of compensation mechanisms, as well as both the endogenous (within plant control) and exogenous (outside of plant control) factors that affect these mechanisms. While our knowledge of mechanisms resulting in tolerance or compensation is increasing rapidly, our ability to predict the levels of compensation which will occur in any given system is still relatively poor. In most plant systems, interactions between available nutrients, timing and intensity of defoliation, water stress, plant competition etc. are highly significant, in other systems such interactions appear minimal. Thus, until a much more substantial data base is developed, few generalizations regarding the ecological or agricultural importance of compensatory responses will be forthcoming. Indeed, development of general theories on plant compensation will rely on the recognition that a broad range of responses are probable in differing ecosystems.

## PHYLOGENY AND CLASSFICATION OF ICERYINE SCALE INSECTS (HEMIPTERA: MARGARODIDAE)

Cory M. Unruh and Penny J. Gullan

University of California, Department of Entomology, One Shields Ave., Davis, CA

This study examines the taxonomy and evolutionary relationships of selected members of the tribe Iceryini within the scale insect family Margarodidae. This tribe is monophyletic and

belongs to the subfamily Monophlebinae. Relationships among iceryine genera and species are largely unknown. The only phylogenetic studies of margarodids are a cladistic analysis of morphology including three genera of Iceryini and an unpublished preliminary molecular phylogeny. The subfamily Monophlebinae consists of five tribes, of which the Iceryini is the largest and best known because many species are important pests of commercial agriculture across the world. The six genera in this tribe are *Auloicerya* Morrison (2 species), *Crypticerya* Cockerell (15 species), *Echinicerya* Morrison (1 species), *Gueriniella* Fernald (2 species), *Icerya* Signoret (40 species) and *Steatococcus* Ferris (14 species). This is a preliminary molecular analysis of the iceryine tribe and its outgroups with species from the Americas, Australia, New Caledonia, Hong Kong and Thailand. These molecular data are from the mitochondrial gene cytochrome oxidase subunit I (COI) and a nuclear gene from the D2 expansion region of the large subunit ribosomal DNA gene (28S).

## INTRODUCTION TO THE IMPACT OF THE LOSS OF ORGANOPHOSPHATE INSECTICIDES ON CALIFORNIA AGRICULTURE

Robert A. Van Steenwyk

University of California, Department of Environmental Science, Policy and Management, 201 Wellman Hall, Berkeley, CA

The Food Quality Protection Act (FQPA) was unanimously passed by both houses of the Congress and signed into law by President Clinton on August 3, 1996. This piece of legislation has had and will continue to have a major impact on agricultural pesticide use. The law significantly amends two previous laws: the Federal Insecticide, Fungicide and Rodenticide Act and the Federal Food, Drug and Cosmetic Act. The FQPA establishes a new human health based standard of "reasonable certainty of no harm will result from aggregate exposure to the pesticide chemical residue…." An important feature of FQPA is its special consideration of health effects on children and other vulnerable individuals.

The FQPA requires EPA to reassess all tolerances. The tolerance reassessments must consider the accumulative effects of the aggregate exposure from all sources (dietary, drinking water and residential) of pesticides with a common mechanism of toxicity. In addition, the tolerance may be reduced 10-fold as a safety factor to further protect infants and children. This 10-fold safety factor need not be imposed when reliable information indicates that no harm will result to infants and children. The law calls for the reassessments of tolerances to be completed within 10 years in three-year increments (last increment to be four years) with priority given to pesticides that may pose the greatest risk to public health.

In addition to establishing a new health based standard of no harm, the act also provides for expedited registration review for reduced risk pesticides. The act also offers economic incentives to registrants who register minor use pesticides. The incentives may include one additional year of exclusive data use, waivers of certain data requirements and expeditious review which could bring the product to market sooner. California's diverse crop production

includes many minor uses, and this has often resulted in fewer available pesticide options for fruit, nut and vegetable growers relative to those producing larger acreage field crops such as corn, cotton and soybean. Additional provisions of FQPA are somewhat less likely to impact California agriculture. The entire law can be found at www.epa.gov/oppfead1/fqpa.

Reassessment of all pesticide tolerances by EPA presents a daunting task for that agency since there were over 9,700 pesticide tolerances to reassess in 1996 when the law was enacted. Therefore, priority is being given to pesticides that may pose the greatest risk to public health. The EPA has first focused on reassessment of organophosphate (OP) and methyl carbamate insecticides. The OP insecticides accounted for an estimated 34% of worldwide insecticide sales in 1995. The mechanism of toxicity of the OP insecticides is to bind to the enzyme acetylcholinesterase in the central and peripheral nervous systems. This deactivates the acetylcholinesterase, resulting in repeated uncontrolled stimulation (firing) at the nerve junctions. The EPA has tentatively considered the OP insecticides to act through a common mechanism of toxicity. While dietary exposure to a particular OP may be low, the simultaneous exposure to multiple OP insecticides may result in exceeding the maximum daily allowance in some segments of the population. The implementation and ramification of OP insecticides having a common mode of toxicity has not been clarified at this point.

When FQPA was passed in 1996, 49 OP pesticides were registered for use in pest control in the United States. When EPA released the *Revised OP Cumulative Risk Assessment* in 2002, 14 pesticides had been cancelled or proposed for cancellation and 28 others had partial use bans. Voluntary and mandated cancellation or restriction on a number of uses for OP insecticides, such as azinphosmethyl, chlorpyrifos, ethion, ethyl parathion and methyl parathion, has had particular significance for California growers. It is anticipated that further restrictions on OP insecticides including product cancellations will be imposed in the future.

The regulatory focus for the FQPA is the reduction of human health effects of pesticides, however it is understood that economic and environmental consequences will also result from its implementation. The quantitative and qualitative impact of the FQPA as the act relates to the modification of use or cancellation of OP insecticides depends on the availability and adoption of effective alternative control measures. A study of 13 major California crops having a total market value of about $10 billion estimated that a total ban of OP insecticides on these crops would result in a loss of over $203 million for growers and consumers. The study can be found at www.cdfa.ca.gov/publications.htm. Individual presentations in this symposium will focus on the impact of current and future IPM systems following the elimination of OP insecticides.

## THE IMPACT OF THE LOSS OF ORGANOPHOSPHATES ON GRAPE PRODUCTION

Lucia G. Varela

University of California Cooperative Extension & Statewide IPM Program, Santa Rosa, CA

California ranks first in grape production in the United States and grapes are ranked second in value of all California agricultural commodities. Production is divided into fresh market/table, raisin and wine grapes. A total of 847,000 acres of grapes were harvested in 2002, of which 273,000 acres (32.2%) were planted with raisin grape varieties, 486,000 acres (57.4 %) were wine grapes and about 88,000 acres (10.4%) were table grapes.

There are four major areas of production in the state: the southern San Joaquin Valley (498,567 acres), northern San Joaquin and Sacramento Valley (107,354), coastal (213,419 acres) and desert (16,773 acres). The southern San Joaquin Valley produces 99% of California's raisins, 85% of table grape production and 60% of the wine grape crop. Coastal areas, northern San Joaquin and Sacramento Valley produce primarily wine grapes and the desert area produces table grapes.

Some of the more common pests include leafhoppers, spider mites, mealybugs, leafrollers, western grape sceletonizer, thrips, sharpshooters and phylloxera. The relative importance of these pests depends on the type of grape crop being produced and the region.

Eliminating organophosphate insecticides from grape production would have minor impact with the exception of vine mealybug control in some areas, ant control in vineyards with high populations of mealybugs, and root knot nematode in the southern San Joaquin Valley and the desert.

## INVESTIGATING APHIDOPHAGY IN MONTANAN CARABIDS USING PCR

S.K. Wallace and S. Blodgett

Montana State University, Department of Entomology
333 Leon-Johnson Hall, Bozeman, MT 59715

We use carabid observation results from the literature, laboratory, and field to discern aphidophagous carabids, and subsequently focus on aphidophagy in carabid beetles of Montana dryland cropping systems. *Pterostichus* spp*., Bembidion* spp. and other frequently trapped carabid species are included in the predation studies. Amplifying prey DNA from predator gut contents can elucidate predator-prey relationships. To determine time limits of prey nucleic acid detection after laboratory feeding, we used aphid-specific PCR primers (Chen *et al.,* 2000) to amplify aphid DNA from carabid beetles. Beetles were observed until one aphid was eaten, allowed to digest according to treatment, and then frozen at –80$^{o}$C. As expected, PCR detection

of aphidophagy lowers over longer digestion times. Field captured beetles were then tested, and differences amongst species were found.

## *LYGUS HESPERUS* – STUDIES IN WASHINGTON STATE APPLE ORCHARDS

Doug Walsh[1], Mike Bush[2], Tim Waters[1], Holly Ferguson[1], and Ron Wight[1]

[1]Washington State University, Dept. of Entomology, IAREC, Prosser, WA
[2]Washington State University, County Extension, Yakima, WA

The Lygus bug, *Lygus hesperus* Knight (Hemiptera: Miridae), is an occasional pest of apples in several distinct geographic growing regions of south-central Washington State. The industry identified Lygus as an insect in need of some study in 2000. In this symposium we plan to present the significant findings from three years of efforts investigating Lygus bug thresholds, and cultural and biological control efforts in Washington State apple orchards.

*Lygus* Economic Thresholds. Branch cage studies in 2001 and 2002 helped quantify proportional *Lygus* abundance to fruit damage. *Lygus* feeding in April resulted in greater proportional amount of fruit injury than *Lygus* feeding in May 2002 or July 2001. Additional branch cage studies were conducted for three years (2001, 2002, & 2003) to determine the period of time at which Lygus feeding resulted in the greatest amount of fruit injury. From these studies, we determined that Lygus feeding can result in sub-surface superficial feeding injury at any point between fruit set and harvest. However, we have determined that early to mid-spring feeding is cosmetically more damaging than summer feeding.

Biological Control/Orchard Surveys for Lygus Parasitoids. A parasite, *Peristenus* spp., attacks the nymph stages of Lygus and keeps individuals from reaching sexual maturity by emerging in the late instar nymph or early adult stage. Extensive surveys conducted in 2002 and 2003 determined the presence of Lygus parasitism by *Persitenus* spp. in several important fruit production regions in Washington State. However, the results of the survey were disappointing in that levels of parasitism were low or not detected in several locations.

Phenology Model. A phenology model currently used in California proved effective at predicting the first generation hatch of *Lygus* in late-May in Eastern Washington and the subsequent peak hatch event in mid-July. However, the model lost predictive accuracy as the season progressed and would provide little predictive value for when adult migration into orchards might occur in April or May.

Cover Crops/Indigenous Plants. Replicated plots of 14 cover crop blends were established on the Roza unit at WSU IAREC in May 2003. We have documented significant differences among cover crop blends in their potential to support and build populations of Lygus bugs. We also established replicated stands of indigenous native and exotic plants, and we are evaluating these plants for their ability to serve as complete hosts for Lygus.

## PLANT COMMUNITY IMPACT ON ARTHROPOD POPULATIONS IN DISTURBED AND REHABILITATED RIPARIAN BUFFERS

Timothy D. Waters[1], Douglas B. Walsh[1], and Richard S. Zack[2]

[1]Washington State University, Entomology, 24106 N. Bunn Rd. Prosser, WA
[2]Washington State University, Entomology, PO Box 646382, Pullman, WA

Stream health and water quality are major concerns in the Pacific Northwest. An integral component of all stewardship plans conducted in disturbed watersheds includes the establishment of preferred vegetation in riparian buffers. Arthropod and vegetation surveys have been conducted over three years (2001, 2002, & 2003) in representative riparian buffers directly adjacent to apple orchards and grape vineyards in the Lower Yakima Valley near Prosser, Benton County, WA. Our results document that haphazard establishment and poor maintenance of vegetation in riparian buffers results in increased populations of pest arthropods including *Lygus* spp. and *Frankliniella occidentalis.* These pests are more abundant in the presence of exotic flowering plant species that typically persist in degraded riparian buffers. Conversely, the aforementioned pest arthropods occur in lower abundance in pristine or properly rehabilitated and maintained riparian buffers that consist of woody perennials and native bunch grasses. Concurrently, our data indicate that populations of beneficial arthropods including spiders and carabid beetles increase by the greater food resources available in degraded buffers that consist primarily of exotic flowering plant species.

## INSECT-INDUCED EXPRESSION OF PLANT SECONDARY METABOLITES: VOLATILES AND THEIR IMPORTANCE TO ECOPHYSIOLOGY

David K. Weaver[1], Wendell L. Morrill[1], Robert K. D. Peterson[1], Sharlene E. Sing[2], and Christian Nansen[1]

[1]Montana State University, Department of Entomology, 333 Leon Johnson Hall, Bozeman, MT
[2]USDA Forest Service, Rocky Mountain Research Station, Forestry Sciences Laboratory, 1648 S. 7th Ave., Bozeman, MT

Field and laboratory experiments were conducted to evaluate potential correlations between plant physiological responses and volatile secondary metabolite production using several systems of insect herbivory. The relationship between insect-induced changes in photosynthetic rates and secondary metabolite emissions will be presented for *Calaphasia lunula* caterpillars feeding on Dalmation toadflax foliage; for immature *Mecinus janthinus* weevils feeding within Dalmation toadflax stems; and for larval wheat stem sawflies, *Cephus cinctus*, feeding within wheat stems. Major factors impacting the dynamic relationship between primary and secondary metabolism include the type of feeding injury and the physiological state of the host plant. In general, the production of secondary metabolites following insect injury is more consistent than changes in photosynthetic patterns, which are readily attenuated by other sources of plant stress such as high temperature and drought. The ecological implications of these relationships will be discussed.

## FAUNA OF NEWLY-STORED WHEAT IN MONTANA AND THE IMPACT OF AUTOMATED AERATION ON COMMUNITY STRUCTURE

David K. Weaver[1], Megan L. Johnson[1], Tracy L. Campbell[1],
and Matthew J. D. Grieshop [1,2]

[1]Montana State University, Department of Entomology, 333 Leon Johnson Hall, Bozeman, MT
[2]Kansas State University, Department of Entomology, 123 Waters Hall,
Manhattan, KS

Pitfall traps were used to monitor stored-product insect populations in newly-stored wheat at three sites in Montana from 1999 – 2002. Newly-stored wheat was colonized rapidly by a number of beetle species, but overall numbers were low in comparison with those reported for more southerly locations with newly-stored wheat. The dominant insect species were secondary pests, with the rusty grain beetle, *Cryptolestes ferrugineus*, being the most commonly encountered pest species. There were only a few individuals of the lesser grain borer captured, and in no cases was there any evidence of reproduction by this species in the stored commodity. Automated aeration helped to reduce the numbers of overwintering rusty grain beetles on a number of occasions, but for several site/year combinations there was no appreciable infestation of commodity at all. The dominant natural enemy species was *Xylocoris galactinus*, with the highest captures occurring shortly after storage. Populations of this species failed to overwinter in either aerated or unaerated bins.

## ROLE OF HOST PLANT VOLATILES IN THE SPATIAL ORIENTATION OF WHEAT STEM SAWFLY ADULTS

David K. Weaver[1], Justin B. Runyon[1,2], Wendell L. Morrill[1],
Dariusz Piesik1[1,3], and Micaela L. Buteler[1]

[1]Montana State University, Department of Entomology, 333 Leon Johnson Hall, Bozeman, MT
[2]Penn State University, Department of Entomology, 501 ASI Building,
University Park, PA
[3]University of Technology and Agriculture, Department of Applied Entomology,
20B Kordeckiego Street, Bydgoszcz, Poland

Volatile collections from several varieties of spring wheat commonly grown in Montana indicated that there were seven compounds consistently produced by wheat plants. Variety, soil type, and growth stage influenced the overall amount of volatiles produced by these wheat plants. Of the seven compounds, four of these were behaviorally active, with three attractants and one repellent. One compound, *cis*-3-hexenyl acetate, is highly attractive to females at the amount it is released by plants. The other attractants and repellents are behaviorally active at concentrations higher than collected. Behavioral activity for these volatile compounds was seen for females only. A field experiment conducted in the summer of 2003 clearly showed that females chose to oviposit in a spring wheat variety that produced large amounts of *cis*-3-hexenyl

acetate, when it was planted in rows or patches alternated with a spring wheat variety that produced comparatively small amounts of *cis*-3-hexenyl acetate. Commonly grown winter wheat varieties show similar variation in attractiveness.

## FACTORS THAT INFLUENCE PHEROMONE MONITORING PROGRAMS AND WHAT WORKS IN FIELD SITUATIONS

Jeffrey A. Weier

Sprague Pest Solutions, P.O. Box 2222, Tacoma, WA 98401

Developing and implementing a pheromone monitoring program requires a balance of efficacy and economy. Laboratory studies and field research provide guidance but recommendations may not stand up to the needs of commercial programs. Trap density, trap location and trap type will be discussed in the context of a commercially viable program. The uses and limitations of different types of commercially available pheromone lures will be considered. Finally, different methods of evaluating trap capture data will also be discussed. Data from monitoring programs will be presented to support the discussion.

## GREEN PEACH APHID RESPONSES TO POTATO LEAFROLL VIRUS-INDUCED VOLATILES PRODUCED DURING DISEASE PROGRESSION IN POTATO

Brent J. Werner[1], Thomas M. Mowry[2], Sanford D. Eigenbrode[1], Nilsa A. Bosque-Pérez[1], Hongjing Ding[1], and Karla J. Medina Ortega[1]

[1]University of Idaho, Department of Plant, Soil & Entomological Sciences, PO Box 442339, Moscow, ID 83844-2339
[2]Parma Research & Extension Center, Parma, ID 83660-9627

Emigration rates were measured by observing apterous green peach aphids presented with leaves from potato, *Solanum tuberosum,* infected with Potato leafroll virus (PLRV). Treatments included PLRV-inoculated potato, sham-inoculated potato, and a paper leaf model. Responses to volatiles were recorded from potatoes 2, 4, 6, 8, and 10 weeks following inoculation with PLRV. Uninfected plants sham-inoculated with non-viruliferous aphids served as controls and were "inoculated" during the same two-week intervals. Plants of all infection stages were available simultaneously during the experiment. Tests were conducted in darkness with 30 aphids being placed on a screened floor suspended over the surface of treatment leaves. Observations were recorded every 10 minutes for 1 hour documenting the number of aphids that emigrated from the treatment leaf. Aphids were considered to have emigrated if they were no longer over the leaf surface and were subsequently removed from the test arena. Following the bioassay, headspace volatiles were collected and plant tissues frozen for use in determining virus titer. When using treatment leaves from the lower part of the plant, emigration rates from PLRV-infected or sham-

inoculated leaves did not differ. However, when using upper leaves, green peach aphid emigration from PLRV-infected leaves differed from sham-inoculated leaves or paper leaf models.

## CLONING AND CHARACTERIZATION OF THE *COPIDOSOMA FLORIDANUM* HEDGEHOG GENE

Michael A. White and Laura S. Corley

Washington State University, Department of Entomology, PO BOX 646382, Pullman, WA

*Copidosoma floridanum* (Hymenoptera: Encyrtidae) represents a developmental extreme among the polyembryonic wasps of Hymenoptera. Within Encyrtidae, a single egg proliferates to several thousand adult wasps while forming two distinct larval castes: reproductive and precocious. The regulatory systems that control proliferation, though, remain unknown. To explore potential mechanisms, I employed the candidate gene approach, focusing on the Hedgehog (Hh) signal transduction pathway as a prime candidate. Among metazoan taxa, one function of Hh is to regulate cellular proliferation during development. Within Drosophila, for instance, Hh has been shown to control the proliferation and differentiation of somatic stem cells within the ovary. Using PCR, a 149 bp fragment of *Cf-hh* was cloned with degenerate primers. Temporal expression patterns were characterized using RT-PCR. *Cf-hh* mRNA is expressed throughout polyembryonic proliferation of *C. floridanum*, as well as during embryonic segmentation of the reproductive embryos. Expression of *Cf-hh* is not detectable when proliferation ceases at the onset of the host fourth instar and expression begins again at the onset of segmentation. In this manner, the Hh pathway may be regulating proliferation, as hypothesized. Future characterization through *in situ* hybridizations will be conducted to clarify the function of Hh during the proliferative phase of development.

## PYRETHROID SPRAY BARRIERS FOR CUTWORMS IN VINEYARDS

Ronald Wight, Douglas Walsh, Holly Ferguson, & Tim Waters

Washington State University – IAREC, 24106 North Bunn Road, Prosser WA 99350

Delayed-dormant barrier applications of synthetic pyrethroid insecticides to the soil/vine/trellis interface in wine grape vineyards repels or kills cutworms and prevents them from subsequently climbing vines and feeding on swelling buds in spring. The pyrethroid barrier reduces cutworm damage significantly ($p<0.01$) when compared with the chlorpyrifos standard. This information has been extended to the wine grape industry via newsletters and presentations. We estimate that chlorpyrifos use will be reduced by over 10,000 pounds per year in Washington State vineyards as a result of our research and extension efforts. Anecdotal evidence has been provided to us that

yields were increased by approximately ½ ton per acre in pyrethroid barrier treated vineyards versus organophosphate treated vineyards.

## NECTAR AND HONEYDEW SUGARS INFLUENCE GUSTATORY ACCEPTANCE AND LONGEVITY OF *ANAPHES IOLE*, AN EGG PARASITOID OF *LYGUS*

Livy Williams, III and J. Peirce Beach

United States Department of Agriculture, Agricultural Research Service, Southern Insect Management Research Unit, P.O. Box 346, Stoneville, MS 38776-0346

Habitat management is a component of conservation biological control that aims to improve the availability of resources required by natural enemies. Access to non-host foods is a critical requirement for many natural enemies, and one that can be manipulated via habitat management. Food sources, usually in the form of nectar (floral or extrafloral), pollen, and honeydew supply natural enemies with energy for maintenance and reproduction. These food sources have different chemical compositions, and studies on parasitoid acceptance, survival, and longevity have helped identify the compounds most important to parasitoids, and therefore, habitat management. While pests may also exploit food sources intended for natural enemies, recent studies have shown that careful selection of food sources can reduce this possibility. Therefore, detailed knowledge of the biology of the pests and natural enemies present in the agroecosystem in question is crucial for selection of appropriate habitat management strategies.

*Anaphes iole* is an egg parasitoid that attacks *Lygus* species and other mirids in North America. However, nothing is known about the suitability of individual sugars for *A. iole*. A better understanding of nutritional ecology of *A. iole* may facilitate the development of natural or artificial food sources that confer greater benefit to this parasitoid than to *Lygus*. We studied the gustatory response and longevity of *A. iole* provisioned with naturally occurring carbohydrates and a commercial food source. Wasps responded to all 14 of the sugars at the highest concentration tested (2 M). At this concentration, sucrose, glucose, maltose, melezitose, fructose, and erlose all elicited >90% acceptance. The lowest concentration that evoked a response (=acceptance threshold) for these sugars was <1/256 M, with the exception of glucose, which was 1/16 M. Raffinose, trehalose, mannose, galactose, melibiose, rhamnose, stachyose, and lactose led to <50% gustatory response by the wasps at 2 M, and were categorized as 'moderately stimulatory sugars'. The acceptance threshold for these sugars was >1/4 M, with the exception of raffinose, which was 1/256 M. In trials with moderately stimulatory sugars combined with either sucrose or maltose, only the rhamnose+maltose mixture significantly inhibited the gustatory response of *A. iole*. Food and water deprived parasitoids readily accepted the moderately stimulatory sugars. Eliminade™, a commercial food supplement, was readily accepted (92%) by *A. iole*. Longevity of *A. iole* was relatively consistent with gustatory discrimination. Wasps provisioned with sucrose, trehalulose, maltose, and Eliminade™ had the greatest longevity. Temperature was also an important factor; longevity of wasps was significantly greater at 20°C than at 27°C.

With respect to gustatory response to nectar and honeydew sugars, *A. iole* differed markedly from other hymenopterans that have been studied in that this parasitoid accepted all the naturally occurring sugars with which it was tested. Moreover, this parasitoid exhibited lower acceptance thresholds than other hymenopterans for many of the sugars. This broad and sensitive range of gustatory perception, coupled with enhanced longevity afforded by some sugars, might be helpful in the development of a food source for *A. iole* that is not exploited by *Lygus*.

## ASSESSING THE INCIDENCE OF PARASITOIDS OF THE EGYPTIAN ALFALFA WEEVIL (*HYPERA BRUNNEIPENNIS*) IN CALIFORNIA ALFALFA

Karey C. Windbiel, Larry D. Godfrey, and Richard R. Lewis

Department of Entomology, University of California, One Shields Avenue, Davis, CA

The major arthropod pest of alfalfa in California is the alfalfa weevil complex, comprised of the Egyptian alfalfa weevil (EAW), *Hypera brunneipennis* and alfalfa weevil, *Hypera postica*. Weevil larvae cause the majority of damage on alfalfa, greatly reducing yield and nutrient quality. Insecticides such as organophosphates, carbamates and pyrethroids are effective against the weevil, but environmental concerns related to these materials warrant the use of more ecologically sound control alternatives. Ten species of parasitic wasps were released in California for control of EAW from 1957-1988 and three were reported as established, but incidence of these organisms has not been studied in the last 15 years. Parasitoids have proven successful against the alfalfa weevil (*H. postica*) in many other states, but the same success has not been observed against *H. brunneipennis* in California. Our study focused on eight sites throughout California in the following counties: Kern, Tulare, Merced, San Joaquin, Yolo, Colusa, Siskiyou, and Shasta. Eggs, larvae, pupae and adults were collected from each site and analyzed to determine percentage parasitized per sample and species of parasitoid present. Weevil larvae were collected from each site and reared on greenhouse-grown alfalfa plants in the lab. To date, parasitoids have been recovered from larvae from four counties, but percentage parasitized per sample is low.

## ASYMMETRIC LARVAL INTERACTIONS BETWEEN INTRODUCED AND INDIGENOUS LADYBIRDS IN NORTH AMERICA

Hironori Yasuda[1], Edward W. Evans[2], Yukie Kajita[2], Keiko Urakawa[1], Takizawa Takizawa[1]

[1]Faculty of Agriculture, Yamagata University, Tsuruoka, Yamagata 997-8555, Japan
[2]Department of Biology, Utah State University, Logan, UT

Understanding the mechanisms that result in the success of introduced species will contribute to predicting future invasions and managing invaded systems. We examined interactions between larvae of two predatory ladybird species recently introduced to North America, *Coccinella*

*septempunctata* and *Harmonia axyridis*, and two indigenous ladybirds, *C. transversoguttata* and *Hippodamia convergens.* By pairing young and old larvae in the laboratory at low and high levels of aphid availability, we assessed the degree of asymmetry in intraguild predation, the strength of competitive effects on growth and development of larvae escaping predation, and the nature of attack and escape behavior among the species. Interactions were generally asymmetric, with larvae of introduced species acting most frequently as intraguild predators and larvae of indigenous species serving most frequently as intraguild prey (the two *Coccinella* spp., however, preyed on each other at similar rates). Because they were especially aggressive and because other larvae were least successful in escaping their attacks, larvae of *H. axyridis* had stronger negative effects on larvae of the two indigenous species than did larvae of *C. septempunctata.* Such negative effects, expressed most strongly when aphid availability was low, were especially adverse for the smaller of the two indigenous species, *H. convergens*. In general, older larvae interacted with each other more strongly than young larvae did, and older larvae had especially strong negative effects on young larvae when interactions occurred between age classes. Our results suggest that *H. axyridis* more than *C. septempunctata* may represent a threat to indigenous ladybirds as an intraguild predator, and that intraguild predation in turn may play a stronger role for *H. axyridis* than for *C. septempunctata* in promoting successful invasion of North America.

## EXOTIC PESTS IN THE WEST AND THEIR TKOs FOR EXPORTS

Victoria Y. Yokoyama

USDA-ARS, San Joaquin Valley Agricultural Sciences Center
9611 S. Riverbend Ave., Parlier, CA

Pests of regulatory concern found in commodities produced in the western U.S. may limit intrastate shipments or foreign exports. Methods must be developed to prevent the accidental introduction of such pests into regions where they are not found through these shipments. A multiple quarantine treatment was developed that combined bale compression and hydrogen phosphide fumigation to control Hessian fly in hay exported to Japan, and to control cereal leaf beetle in intrastate shipments of Oregon rye straw. A pest-free period from the beginning of harvest through July 1, and data supporting the poor host status of stone fruits was used to substantiate a negligible risk for accidental introductions of walnut husk fly through California stone fruits exported into foreign countries. A methyl bromide fumigation of nectarines in cartons was developed to control codling moth in fruit exported to Japan. Low temperature storage and brine solutions were developed as methods to control and contain olive fruit fly in olives shipped from infested areas to processing plants to prevent dispersal of the pest. A low temperature treatment alone and in combination with slow release sulfur dioxide pads was developed to control pests of regulatory concern in exported table grapes.

# THE EFFECTS OF COMPETITIVE INTERACTIONS BETWEEN TWO *CHAETORILLIA* SPECIES AND THEIR IMPACT ON YELLOW STARTHISTLE

F. Brent Young and Mark Schwarzlaender

Department of Plant Soil and Entomological Sciences,
University of Idaho, Moscow, ID 83844-2339

Yellow starthistle (*Centaurea solstitialis* L.) is an invasive annual weed of rangelands in the western U.S. Observational reports of increasing abundances of the accidentally introduced *Chaetorellia succinea* over *C. australis* led us to test the hypothesis that *C. succinea* is successfully out competing the approved agent. The consequences of this interaction are unknown. Both flies were surveyed at eight field sites in Idaho during 2003 to determine their relative abundance. In a greenhouse experiment, flies were released onto individually caged yellow starthistle plants for ten days, using the following five treatments: 1) *C. succinea* alone, 2) *C. australis* alone, 3) both simultaneously, 4) *C. succinea* for five days with *C. australis* for the subsequent five days, and 5) *C. australis* for five days with *C. succinea* for the subsequent five days. The attack rates and relative impact on yellow starthistle achene production were assessed after each treatment. Results of the field surveys indicated that *C. succinea* and *C. australis* were equally abundant at field sites. Results of the greenhouse experiment indicated a competitive advantage for the fly species that was later released in the sequential treatments. There was no advantage for either fly species when released simultaneously. The percentage of yellow starthistle seed heads attacked per plant (21%) and the percentage of achenes reduced per attacked seed head (78%) were equal for all treatments. Our data suggest that the interactions between these two flies are neutral and that the combined impact of both fly species on yellow starthistle seed production is additive.

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**Key to Presentation Types:**

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| PAPER | Submitted 10 minute Paper |
| SC-MS | Student Comp. Paper (M.S.) |
| SC-PHD | Student Comp. Paper (Ph.D.) |
| POSTER | Submitted Poster Display |
| DSC-MS | Student Comp. Poster Display (M.S.) |
| DSC-PHD | Student Comp. Poster Display (Ph.D.) |
| SYMP | Symposium Presentation |
| AWARD | Woodworth or Comstock Award Winner |